Energy Innovation Needs Assessment

Sub-theme report: Building fabric

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Contents

The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
BEIS	Department for Business, Energy and Industrial Strategy
BIM	Building Information Modelling
CCC	Committee on Climate Change
DfMA	Design for Manufacture and Assembly
EINA	Energy Innovation Needs Assessment
ESME	Energy System Modelling Environment
EU	European Union
GHG	Greenhouse Gas
GVA	Gross Value Added
IEA	International Energy Agency
IP	Intellectual Property
KfW	Kreditanstalt für Wiederaufbau
kWh	Kilowatt-Hour
PCM	Phase Change Materials
POE	Post-Occupancy Evaluation
RCA	Revealed Comparative Advantage
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RoW	Rest of World
SAP	Standard Assessment Procedure
TINA	Technology Innovation Needs Assessment
TRV	Thermostatic Radiator Valve
TWh	Terawatt hour
UK	United Kingdom

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development, and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (R&D) (rather than from ‘learning by doing’).
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides[1]. This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME™) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

The building fabric sub-theme report focusses on all UK buildings, both domestic and non-domestic. The report focusses on building fabric exclusively as: 1) current building fabric inefficiencies are significantly increasing the indirect contribution of the building stock to UK emissions and targeting them is essential for the UK to achieve environmental targets, and 2) they provide opportunity for wider system benefits and export opportunities to be unlocked by the UK.

Building fabric innovations that are applicable across the design, construction, operation, and decommissioning phases of UK building lifecycles will all be important for reducing the emissions produced by the UK building stock. The most important innovations across all life cycle stages will be those that reduce the cost, improve the performance, and/or enable the circular economy of building fabric. Deployment of such innovations will be dependent on overcoming sector barriers, such as the contractor skills-gap, and the development of tighter building regulations.

The report has four sections:

- **Building fabric and the energy system:** Describes the role of building fabric in the energy system.
- **Innovation opportunities:** Provides lists of the key innovations available within building fabric, and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities of building fabric, the GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunities.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

Key findings

Innovation areas in building fabric

The main innovations for building fabric are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Table 6 sets out the full list of innovations and their scores.

Guaranteed Performance: Innovations that can address the performance gap between building design and real-life results. Examples include:

- Advances in the modelling and testing of low-carbon innovations across the building lifecycle including: In-construction testing, post-construction testing, in-use monitoring (e.g. use of smart systems and data) and Building Information Modelling (BIM).
- Unlocking the potential of design for manufacture and assembly (DfMA).
- Prefabricated envelopes for retrofit, which can contribute to minimising human construction errors.

Low embodied carbon materials: Innovations to reduce the embodied emissions of building fabric across the whole lifecycle of that material, from resource extraction to disposal. Examples include:

- Assessing actual life cycle costs of building fabric to inform what the biggest energy uses and costs are: manufacturing, construction/ installation, in-use, or end-of-life stage?
- Achieving cost reductions in low embodied carbon materials.
- Taking a circular economy (whole-life) approach to the specification of building fabric materials in tenders during procurement processes.
- Using prefabricated envelopes for retrofit to reduce material waste.

Energy generation and storage: Innovations that incorporate these into the building fabric and reduce cost and deployment barriers will be critical to ensure a future clean and flexible energy system.

Skills and Knowledge Sharing: Innovations in training, knowledge sharing platforms, and process improvements are an essential enabler to the effective use of other innovations discussed in this report[2].

Business opportunities to the UK

Business opportunities associated with building fabric exports are expected to peak in the 2030s, contributing around £720 million GVA per annum and 9,100 jobs. As the building stock modernises, and the retrofit market shrinks towards the 2050s, export opportunities for the UK are expected to decline to around £390 million GVA per annum and 4,000 jobs. In the business opportunities section below, GVA and jobs results are set out by component (Table 7).

- **Services for pre-construction and design** represent the greatest UK export opportunity. This is driven by the UK achieving a high market share for these services, building on existing expertise such as BIM, and the expected growth of the domestic market to meet emissions reduction targets. Pre-construction and design contribute over £450 million to GVA per annum and 5,700 jobs by 2030.

- **Within goods exports, opportunities are concentrated in building operation and the build process.** This assumes the UK can export offsite construction components globally following high innovation in efficient offsite construction techniques. Exports within building operation are primarily around the export of smart systems and home hubs, using the UK's expertise in IT systems and early smart meter deployment.

- **Building fabric materials other than offsite construction are not expected to present a major export opportunity,** given the low value-to-weight ratio and hence likely low trade levels.

- **The timing of the market peak is highly dependent on the level of global climate action.** Given the large market for retrofitting and the long lifetimes of retrofit measures, the market for energy efficiency building fabric is expected to peak by 2050. In the International Energy Agency's (IEA's) 2-degree scenario this peak happens around 2030. However, this assumption relies on strong policy action around buildings' decarbonisation, a sector which to date has been slow to decarbonise.

- **Domestic business opportunities are significantly larger than export opportunities, peaking at £5.7 billion GVA per annum and 82,000 jobs by the mid-2030s.** This is because retrofit and other services are a large market and unlikely to be traded extensively.

[2] Committee on Climate Change (2019) UK Housing: Fit for the Future? https://www.theccc.org.uk/wp content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant and they cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 8). The main market barriers identified by industry relate to:

- **Building standards are designed for minimum compliance, rather than for maximum performance in use.** This leads to a focus on meeting the minimal criteria at lowest cost. While they can help to accelerate deployment of existing innovations, they are less effective in providing incentives for new innovations and upskilling that push performance beyond the standards, especially beyond currently best available technologies.

- **Refurbishing domestic buildings incurs a high 'hassle cost'**. Such costs often relate to underlying behavioural norms and building-specific idiosyncrasies. For example, retrofits are often triggered by external factors, such as remodelling the bathroom, and are difficult for industry to predict. Therefore it is important to understand how to influence homeowners behaviours and decisions in order to stimulate demand and make them more likely to carry out retrofits.

- **The industry lacks the skills in modern methods of construction that are needed to implement novel technologies.** Training in new innovations is an underlying barrier across industries, because the trained employees can take their skills elsewhere making it hard to capture the full benefits of training. Industry reported that this is made considerably worse in the construction sector due to high turnover, limited requirements to demonstrate experience and accreditation, limited of on-going training, and low levels of formal skills dissemination across the sector. Recruiting and retaining skilled staff is a challenge, in part due to the construction industry not providing attractive career options for young talent.

- **Limited demand for improved building energy efficiency given high upfront costs involved**. Despite the potential energy cost benefits, high capital costs can be a significant barrier, and difficulties accessing (or being willing to access) finance can be hard to overcome. For non-domestic buildings, this is compounded by the fact that energy efficiency is normally not a material business concern relative to other investment decisions.

Key findings by component

Government support is justified when system benefits and business opportunities are high, and government is needed to overcome barriers.

Table 3. **Cost and performance in Building Fabric (see key to colouring below)**

Overall statistics for building fabric: System value* = £10.9 billion (range: £5.4-20.3 billion), 2050 export opportunity (GVA) = £390 million, 2050 potential direct jobs supported by exports = 4,000				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Pre-Construction and Design	Design to achieve guaranteed in-use performance	Medium-Low	Critical	In order to close the performance gap that is currently significant across the UK building sector, innovations that allow designed building performance to match in situ performance need to be improved and commercialised. Use and development of innovations in this field will not spread through the industry if there is no enforcement of regulations to ensure in situ building performance matches building designs. Government investment will be important for the development of these innovations, which could help the UK capture a significant market share of associated services in Europe. Without government intervention, innovation in pre-construction and design will not occur in the UK.
Materials and Components	Low embodied carbon materials; Energy Storage Integrated energy generation	Low	Severe	Innovations in low embodied carbon building fabric aim to improve the circular economy of the sector by incorporating non-operational material footprints into building designs. Energy storage and integrated energy generation focus on improving building material performance and functionality during operation. Without government support, material innovations are likely to occur at a low scale and speed. The considered materials are unlikely to represent a major export opportunity as transport costs mean that most are produced locally.
Build Process	In-construction testing Post-construction testing	Low	Critical	Innovation will support a decrease in the UK building performance gap at low cost to contractors. It will also reduce the operational energy use, and costs of buildings, by improving their productivity. There are already some drivers for off-site production, but Government intervention in build process innovations is critical and innovation is unlikely to occur without it. With innovation, the UK could capture an appreciable market share of traded prefabricated components as well as gain knowledge, especially around retrofit.

Overall statistics for building fabric: System value* = £10.9 billion (range: £5.4-20.3 billion), 2050 export opportunity (GVA) = £390 million, 2050 potential direct jobs supported by exports = 4,000				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Building Operation	In-use monitoring and feedback	Low / Medium	Moderate	The active management of buildings during their operational phase, in order to optimise their energy use, will promote large energy and cost savings. Innovations in building management and operations, including smarter systems with improved data analysis and automation, will occur at a lower scale and speed without government intervention.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below.*

** Estimates of change in total system cost (measured in £ GBP) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets.*

Table 4. **Key to colouring in the key findings by component**

Business opportunities	**Market barriers**
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 19th February 2019 with delegates from the building fabric industry. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. The views of the industry experts, and the evidence that they provided, has been included throughout this report.

In addition, several contextual issues were raised at the workshop:

- Innovations that add costs to contractors, for example in-construction testing, are less likely to reach commercialisation without being mandated by building regulations. This is because the benefits they offer are to the UK environment and not directly to contractors.
- The tightening of regulations, as well as harsher implications for contractors who do not abide by them, were deemed by industry experts as key drivers for the uptake of building fabric innovations.

These overarching messages, while not fitting within the limited scope of the EINA framework, are important for consideration in setting innovation policy.

Building fabric and the whole energy system

Current situation

The operational emissions of the UK building sector account for ~19% of UK greenhouse gas (GHG) emissions[3]. Of these direct emissions, 77% are from the domestic build stock, 14% from commercial buildings, and 10% from public sector properties[3]. Space heating is one of the most emission-intensive processes attributed to the building sector and currently accounts for ~25% of the UK's total energy demand[4]. Further building sector emissions stem from the use of grid electricity to power homes. In 2017, the UK building sector accounted for 66% of national electricity consumption[3].

Future deployment scenarios

The Committee on Climate Change (CCC) has stated that without adaptation of the housing stock, through the deployment of decarbonising innovations, the UK will be unable to reach its legally binding 2050 emission reduction targets[4]. This is specifically related to innovations to help reduce the performance-gap, introduce low-carbon heating systems into homes, and address the skills and knowledge deficit within the industry. For example, it recommends that in order to guarantee that a building's performance matches its design, innovations to aid accurate performance testing and reporting on building fabrics must be developed by 2020-2025. The report also recommends that in order to reach targets, new homes should be built to deliver energy efficiency levels consistent with a space heat demand of 15-20 kWh/m^2/yr by 2025. This is a high efficiency level that approaches current Passivhaus standards and will require a firm trajectory to be set out before 2020[5]. The UK Clean Growth Strategy has begun to do this in the UK by setting targets to improve the energy performance of homes and non-domestic buildings[6]. A key theme of CCC's targets is the phasing out of fossil fuel-based heating sources

[3] Committee on Climate Change (2018), Reducing UK emissions: 2018 Progress Report to Parliament, https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf
[4] Committee on Climate Change (2019), UK Housing: Fit for the Future? https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf
[5] International Passivhaus Association Guidelines, https://www.passivehouse-international.org
[6] HM Government (2018), The Clean Growth Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

throughout the 2020s. Achieving this will require building fabric, energy storage and generation technology innovations to be at a deployable stage before 2020.

Reaching deployment targets will be helped significantly by market and regulatory changes that enable building fabric innovations to overcome barriers. A key change will be the tightening of regulations, such as the minimum energy efficiency standards for landlords[7], and the implementation of new building efficiency standards. This would force the uptake of innovations for the future-proofing of buildings, low-carbon heat sources, and low embodied carbon materials. Increasing the uptake of innovations will provide the energy efficiency market with certainty of demand, a factor which will increase spending on innovation and learning by decreasing investment risks. The regulation of compliance, and enforcement frameworks that address differences between actual performance levels and those specified in designs, will play an important role in creating demand for the large-scale deployment of building fabric innovations that address these gaps.

Sub-theme system integration: Benefits, challenges and enablers

Building fabric innovations should aim to support the deployment of low-carbon solutions in a way that is most cost-effective to consumers. Benefits flowing from such innovations would include reductions in the demand that UK buildings place on the national grid, the amount of construction waste going to landfill, and the direct emissions attributed to the building sector. These benefits will be essential in aiding the UK to reach national greenhouse gas emission reduction targets whilst also delivering lower energy bills to consumers.

One of the main challenges surrounding the deployment of sustainable building fabric innovations is a lack of knowledge and skills across sector employees. This is in part, due to the industry's current business model which utilises self-employed and sub-contractor employee structures. The lack of skills prevents low emission building fabric innovations from being appropriately prescribed in designs, correctly installed, and efficiently utilised.

There are several enabling technologies and regulation changes that could facilitate the large-scale deployment and integration of building fabric innovations into the UK industry. Enabling technologies include improved testing facilities and data sharing platforms. These would both reduce the costs associated with proving the benefit of novel innovations and enable innovators to connect and

[7] HM Government (2018), The Private Rented Property Minimum Standard- Landlord Guidance Documents. https://www.gov.uk/government/publications/the-private-rented-property-minimum-standard-landlord-guidance-documents

share knowledge. Attendees at the expert workshop help to support this report highlighted that regulatory changes which could facilitate deployment benefits relate to holding contractors accountable for performance gaps between building designs and real-time performance. Further changes could be applied to building regulations to increase the ambition of requirements surrounding energy efficiency and waste. The need to implement such changes in the building and retrofit sector was recognised in a 2016 independent review commissioned by HMG to inform future actions[8]. Enforcement of such requirements is another important aspect that must also be considered.

[8] Dr Peter Bonfield (2016), Each Home Counts: an independent review of consumer advice, protection, standards and enforcement for energy efficiency and renewable energy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/578749/Each_Home_Counts__December_2016_.pdf

Box 3. **System modelling: Building fabric in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model (covering the electricity, heat and transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050 meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction.[9]. The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over a period of over 10 years and is published.[10]. ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world, but it is able to provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset. Estimates for new build properties are as follows:

- The modelled high innovation case implies building performance improvements in new build properties of about 60% by 2050.
- The modelled costs estimated for new builds in 2050 shows cost of build reaching £48-52,000 for high-density properties, £65-71,000 for medium-density, and £70-76,000 for low-density buildings. The cost range gives allowance for varying levels of thermal performance.

Two retrofit options were considered in terms of estimating cost reductions through technology innovation. The RetroFIX renovations included floor edge, wall and loft insulation, draught stripping, single room heat recovery, A-rated gas boilers, and thermostatic radiator valves (TRVs) and zone controls. The

RetroPLUS model includes all the RetroFIX renovations in addition to window and door replacements, modular boiler installation, and floor insulation. The cost reductions of these retrofit scenarios between 2020 and 2050 are as follows:

- RetroFIX- From £15-10,000 for low density properties, from £17.5-14,000 for medium density and from £14-10,000 for high density buildings
- RetroPLUS- From £24-16,000 for low density properties, from £11-7,000 for medium density and from £7-4,000 for high density buildings.

Whole system analysis using the BEIS EINA Methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in building fabric. The value to the energy system of innovation in building fabric technologies is £10.9 billion cumulative to 2050 (discounted at 3.5%).

Further work is required to estimate the value of particular innovations in building fabric, or how these estimates may change in the case of different energy system scenarios.

[9] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[10] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance, for example optimising interactions between energy efficiency building fabrics and low-carbon heat sources. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that HMG can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies it contributes around one-third.[11].

To reach a quantitative estimate of the system value attributable to RD&D, these ratios are applied to the system value. This implies a £3.6 billion (of the total £10.9 billion) system value could follow from building fabric RD&D efforts. Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[11] Jamasb, Tooraj (2007) Technical Change Theory and Learning Curves, The Energy Journal 28(3).

Innovation opportunities within building fabric

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within sustainable building fabric and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within sustainable building fabric across key components and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.

There are three objectives that innovations in building fabric should aim to achieve in order to increase the energy performance and sustainability of UK buildings. These objectives are to improve performance, promote a circular economy, and reduce costs.

Improve performance: The EU Energy Performance of Buildings Directive requires the establishment of a cost-effective roadmap to transition all existing building stock to nearly zero-energy buildings by 2050.[12]. It also requires that all new buildings be constructed as nearly zero-energy buildings by 2020.[13]. These aims are echoed in the UK Clean Growth Strategy, which highlights the phasing out of high-carbon heat sources in buildings in the 2020s as a key target.[14]. Furthermore, Government has now legislated for a Net Zero target by 2050. In order to achieve these targets, innovations will be needed that increase the cost-effectiveness of:

- Integrating energy efficiency into new build properties and allowing for existing properties to be retrofitted to high energy efficiency standards.

[12] European Union Law (2018), Directive (EU) 2018/844 of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AL%3A2018%3A156%3ATOC&uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG

[13] European Commission, Nearly Zero-Energy Buildings, https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

[14] HM Government (2018), Clean Growth Strategy: executive summary. https://www.gov.uk/government/publications/clean-growth-strategy/clean-growth-strategy-executive-summary

- Supporting renewable energy generation innovations to be integrated into new build and existing properties.
- Enabling energy storage materials to be designed into new build properties and integrated into modules/materials specified in the retrofit of existing properties.

Promote a circular economy: The 2019 UK Statistics on Waste Report states that in 2016 construction, demolition, and excavation activities were responsible for 61% of UK waste.[15]. Building materials going to landfill is a barrier to meeting building sector emissions targets because their manufacturing processes are extremely emissions-intensive, and their non-recovery means that manufacturing demand is higher than necessary. Innovations that promote low embodied carbon materials, the reuse of demolition materials, and material efficiency improvements will be influential in increasing the circular economy of the buildings sector.

Reduce cost: The deployment of innovations in the construction sector is highly cost-sensitive, and innovations that increase the capital cost of building/retrofitting are unlikely to be utilised widely by builders under the current regulatory climate. Innovations that reduce costs, especially in relation to reducing the cost of retrofit, will be essential to increasing the performance of existing buildings and supporting the wider roll-out of highly efficient new buildings.

The building industry currently focusses on delivering low-cost building solutions. The UK building regulations set out the minimum standards that a building must have in order to comply with UK law. Work is being done to update and tighten these regulations, include the Future Homes Standard, but further actions may be needed to meet 2050 targets.

Cost breakdown

The following key cost components are significant to the cost of building fabric:

- Design
- Materials and Build Process

[15]Department for Environment Food and Rural Affairs (2019), UK Statistics on Waste, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/778594/UK_Statistics_on_Waste_statistical_notice_Feb_2019.pdf

- Operations and Maintenance
- Deconstruction
- Retrofits

Table 5. **Example life cycle cost breakdown of a domestic semi-detached house and a non-domestic office building**

Cost Element	Non-Domestic	Domestic
Design	8%	5%
Materials and Build Process	46%	30%
Operations and Maintenance	33%	39%
Deconstruction	-	14%
Retrofits	13%	12%

Note: *Non-domestic breakdown is based on an office building with a total life cycle cost of £8,252,286. Domestic breakdown is based on a 90m² semi-detached house with total life cycle cost of £192,000. The table assumes that design costs are 15% of the materials and build process costs.*

Source: *Non-Domestic: BREEAM Man 02: Life Cycle Costing. Domestic: Life Cycle Cost Analysis of the UK Housing Market (2013), The International Journal of Life Cycle Assessment.*

Inventory of innovation opportunities

Guaranteed and Improved Performance

Delivering guaranteed in-use performance of new and retrofitted buildings is essential in meeting the decarbonisation targets for the UK building stock. Evidence shows that new UK domestic buildings currently produce 2 to 3 times more emissions than predicted at the design stage[16] and non-domestic buildings up to 10 times more[17]. This difference between a building's designed and actual attributed emissions is known as the performance gap. The following innovations in modelling and testing will enable the UK to tackle the performance gap and increase the efficiency of the building stock:

Advancements in modelling and testing

[16] Innovate UK (2016), Low-Carbon Homes: Best Strategies and Pitfalls, https://www.gov.uk/government/publications/low-carbon-homes-best-strategies-and-pitfalls

[17] Innovate UK (2016), Non-Domestic Buildings: Best Practice and What to Avoid, https://www.gov.uk/government/publications/low-carbon-buildings-best-practices-and-what-to-avoid

Innovations that unlock data collection, analysis, and sharing across all stages of building construction are needed for contractors and regulators to gain a greater understanding of building material performance. This knowledge will show them how materials behave and therefore increase the accuracy of building design performance estimates. Proving the performance of novel building fabrics will also help to dispel perceived utilisation risks and uncertainties, which centre on the new and different integration considerations that are often required. Examples of modelling and testing innovations across the building fabric lifecycle follow.

BIM: Innovations that advance the precision of BIM will be key to improving the accuracy of building performance estimates. Leveraging sets of real-world, detailed metadata from existing buildings will provide accurate case studies that can be used to model performance estimates for new build or retrofit projects. The greater the quantity and quality of data that is fed into BIM models, the more accurate the predictions of building stock performance will be. Improved BIM data collection and archiving will also reduce the cost of designing buildings, which in turn will improve the uptake of such innovations by industry.

In-construction testing: Monitoring performance during construction would enable contractors to spot performance gaps throughout the early stages of construction or as soon as they appear. This would reduce the time and costs compared to if they had to close the performance gap upon completing the project. In-construction testing innovations will also make it cheaper for contractors to avoid regulation infringements. Computer technology and data storage developments will be key to innovations in both during- and post-construction performance monitoring.

Post-construction testing: Monitoring post-construction performance will highlight materials, designs, and areas of buildings that are most poorly delivering on performance estimates. This will focus the work of material engineers by identifying the materials and designs most in need of development. The data could also be used by officials to monitor the actual performance of buildings and better enforce performance gap regulations.

In-use monitoring: Innovations that ensure that building fabric is always at the optimum temperature according to the external and internal climate as well as overall environmental conditions. This is in order to promote healthy conditions for occupants while protecting the building fabric. Protecting the building fabric through correct temperature control will minimise degradation and increase a building's longevity, reducing the need for retrofit. Innovations that inform occupants of the real-time performance of their building have also been shown to reduce energy consumption.[18]. Examples of such innovations could include remote operation of

[18] Ea Energy Analyse (2015), Impact of Feedback about Energy Consumption. http://www.ea-energianalyse.dk/reports/1517_impact_of_feedback_about_energy_consumption.pdf

heating technologies, occupancy sensors, and trigger alarms for temperature fluctuations.

Design for Manufacture and Assembly

New build and retrofit building fabric constructed offsite is precision manufactured, more accurately constructed, and can achieve higher standards than traditional buildings. Offsite construction is also less affected by delays resulting from on-site conditions (e.g. weather), meaning that build programmes are more dependable and often lower cost. The factory business model utilises full-time employees and is structured to allow for staff retention. This means that employees receive high quality, and more frequent, training and can practise skills more often. These factors can result in factory staff retaining skills, knowledge, and experience better than self-employed or sub-contracted builders. There are also circular economy benefits of pre-assembly innovations; buildings constructed offsite can be designed for relocation, repurposing, and expansion which adds to the longevity and reusability of a building and ultimately reduces lifetime energy consumption. The factory business model does, however, face a key model barrier. Traditional on-site construction companies can scale their staff according to the boom/bust nature of the construction market. The factory business model, with greater fixed and capital costs, is less resilient to this type of cyclical market.

Low embodied carbon materials

Meeting emission reduction targets within the buildings sector will require consideration of more than just the operational emissions produced by buildings. It is important to also consider the large quantity of emissions that are produced across the pre- and post- operational life cycle stages of buildings. Embodied carbon relates to the emissions associated with the whole life cycle of a material, from resource extraction to disposal. Depending on the construction type and heating system installed, embodied energy and carbon account for 30-50% of the net 80-year lifecycle CO_2 emissions from a Passivhaus standardised dwelling.[19].

Innovations that reduce the embodied carbon in building materials will be important in reducing the emissions attributed to the UK building sector. They can also contribute to increasing the recycling rate of building materials. The UK is a world leader in material science research and has substantial knowledge of life cycle

[19] McLeod, R. S., Hopfe, C. J. and Rezgui, Y. (2012), An investigation into recent proposals for a revised definition of zero carbon homes in the UK, Energy Policy, 46, pp. 25–35.

assessment modelling[20]. It is therefore well placed to innovate and create an export market in this field[21]. The main innovations will be in:

- Actual life-cycle costs of building fabrics: understanding ways of measuring the costs and emissions associated with each material lifecycle stage to understand the embodied carbon of a material.
- Linking low embodied materials with costs: methods to model a material's lifecycle emissions against the cost savings during its operational life.
- Understanding energy use: opportunities to minimise additional consumption through optimised programming during building. Taking a circular economy approach to the specification of building materials through innovations that allow for the embodied life-cycle emissions of materials to be included in the performance specifications of building designs.
- Developing real-world testing facilities to improve the reliability of results and quickly identify the most performance-enhancing innovations for deployment focus.

Integrated Energy Generation and Storage solutions

Innovations that incorporate these into the building fabric and that reduce cost and deployment barriers will be critical to the future clean and flexible energy system. Thermal generation and storage solutions, in particular, will be critical to tackle the challenges of peak heat demands in an electrified future.

Integrated generation: Building fabrics with energy generation properties, for example solar facades, can reduce the fluctuating demand that buildings currently have on the UK mains grid systems. They will also produce cost benefits to building owners as they present an opportunity to offset the capital cost of the innovation by saving money on energy bills. Building fabric innovations that provide system integrated energy generation to buildings will be important in enabling the UK building sector to adhere to the soon-to-be introduced Future Homes Standard. This standard was announced in the 2019 Spring Statement and mandates that no new build houses will have fossil fuel-based heating systems installed by 2025[22]. This was highlighted by workshop industry experts as an essential move for reducing the operational emissions associated with the UK building sector. Example innovations that, when deployed in combination with other heating and building fabric

[20] EPSRC (undated), Materially Better: Ensuring the UK is at the Forefront of Materials Science, https://epsrc.ukri.org/files/funding/calls/2013/materially-better-ensuring-the-uk-is-at-the-forefront-of-materials-science/
[21] EPSRC (undated), Materially Better: Ensuring the UK is at the Forefront of Materials Science, https://epsrc.ukri.org/files/funding/calls/2013/materially-better-ensuring-the-uk-is-at-the-forefront-of-materials-science/
[22] HM Treasury (2019), Spring Statement 2019: Philip Hammond's Speech. https://www.gov.uk/government/speeches/spring-statement-2019-philip-hammonds-speech

innovations, will act to support this mandate include building integrated PV, solar thermal collectors, and solar facades.

Integrated energy storage: Building fabrics with integrated thermal energy storage can store internal and external thermal energy when it is in excess and then release it internally when there is an environmental deficit. This reduces the additional space and water heating that is currently used by buildings to compromise for fluctuating environmental temperatures. Their integration into the UK building stock will therefore flatten out peak building heat demand from the national grid. Important innovations in energy storage should focus on identifying building fabrics with high thermal masses and understanding how they can be integrated into new build and retrofit building designs. A fabric's thermal mass refers to its ability to absorb and store heat energy; materials with higher values represent those that provide a greater inertia against external temperature fluctuations. Phase Change Materials (PCM) are examples of building fabrics with high thermal masses and their use in buildings is increasing. Innovations in PCM could be a good focus for the UK as it already houses several of the key companies in the field[23]. Electricity storage technologies, such as batteries, will also be important for the decarbonisation of the building stock. These technologies will be developed externally to the building fabric industry and therefore innovations should centre on finding ways to incorporate them into house designs in a fashion that is compatible with current systems.

Skills and Knowledge sharing

All innovations mentioned in this section will require concurrent innovations in knowledge sharing and training to be advanced.

Knowledge sharing: The current business model across the UK building sector relies upon self-employed contractors and sub-contractors. Competition caused by this structure can prevent knowledge sharing and a lack of consistent use of skills. The sharing of data and knowledge of energy-efficient technologies and materials would speed up the adoption of innovation across the industry. Innovations to achieve this could include data sharing platforms, shared testing, and new qualifications or courses.

Skills and training: Knowledge gaps within the industry's workforce can mean that sustainable materials, components, and installation approaches are often avoided or used incorrectly due to contractors not being familiar with them. This is a factor that has increased the performance gap of the UK buildings sector[24]. Advances in

[23] Markets and Markets (2017), Phase Change Materials (PCM) Market, https://www.marketsandmarkets.com/PressReleases/advanced-phase-change-material-pcm.asp
[24] Committee on Climate Change (2019), UK Housing: Fit for the Future. https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

standardised training are therefore essential to the commercial adoption of innovations in sustainable building fabric.

Prefabricated building envelopes for retrofit

Like modular construction, innovations in prefabricated envelopes for retrofit are those that allow retrofit modules to be constructed offsite in factory conditions and then brought as a single unit to the building location for final assembly/fitting. This differs from the current retrofit model, where building fabrics (e.g. insulation, windows, and materials) arrive at the site and are assembled there. The UK has already worked at a small scale on innovations in the field of prefabricated design, with success already having been proven in the Netherlands and it is therefore a relatively low-risk focus for innovation spending.[25]. Current barriers to the deployment of prefabricated building designs in the UK include a lack of standards, industry skill, local supply chains, and financing options. Innovations that overcome these barriers will increase the deployment of prefabricated designs. This will help the UK building stock to meet emissions targets, by enhancing the guaranteed and improved performance of existing buildings as well as enabling low embodied carbon building fabrics to be incorporated into retrofit designs, at a low cost.

Guaranteed and improved performance: Buildings constructed offsite are precision manufactured, and therefore are more accurately constructed than traditional buildings. This enables them to achieve higher standards and productivity levels compared to traditionally manufactured ones that are frequently hindered by unintended consequences resulting from small human measurement errors. This is exemplified by the performance of retrofitted insulation, particularly for solid walls, which is often compromised in on-site construction due, in part, to a skills deficit in the industry. The errors resulting from this risk the durability of insulation, performance, and creating surface and/or interstitial condensation.

Low embodied emissions: Like modular construction, prefabricated envelopes for retrofit allow for the offsite construction of building modules. Factory construction allows for a more efficient material use within build processes because the factory can use excess materials in other projects and have more effective recycling processes compared to construction sites.

Cost reduction: Offsite construction is less affected by delays that are associated with on-site conditions (e.g. weather). This means that the build programmes for

[25] EnergieSprong UK (2018), EnergieSprong Leaflet: https://www.energiesprong.uk/how-does-it-work

prefabricated envelopes for retrofit are shorter and more dependable and therefore come at a lower cost to consumers.

Box 6. **Industry workshop feedback**

Holding builders accountable for performance gaps: An overarching theme of discussion in the workshop was that builders should face scrutiny over how design estimates match up to the real-time performance of their building projects. Alongside innovations in during- and post-construction monitoring equipment, as well as in-use material monitoring and feedback systems, regulating this kind of testing was highlighted as key.

Low embodied carbon materials: Industry experts highlighted that the UK building sector needs to aim further than operational zero carbon homes in order to reach the government's emissions reduction goal. Most felt that innovations should focus on measuring and lowering the whole-life cycle emissions of specific building materials. The remainder agreed that this was essential for meeting 2050 targets but saw it as more of a long-term goal than some of the other innovations discussed. All agreed that the UK needs to begin testing material innovations in real-life scenarios rather than laboratory conditions.

Renewable energy generation and storage: There was a consensus around the need to force a transition away from connecting buildings to the mains gas supply. Innovations in thermal storage and renewable energy generation materials were highlighted as innovations that could to help to promote this.

Skills: There was agreement amongst experts that insufficient knowledge sharing, and a lack of skills are barriers to sustainable innovation deployment across the building market. This is especially the case for low-carbon retrofit innovations, and experts agreed that without stable funding and better sector establishment, it will be difficult to develop these skills across the UK.

Offsite construction: While all agreed that modular design innovations would have beneficial sustainable building fabric impacts for the UK, industry experts felt that this building and retrofit method is not compatible with the current market. This is because capital costs are too high due to the lack of a supply chain. It was agreed that this would be an effective solution if the current industry structure was more compatible with it.

The industry experts attending the workshop discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates with the opportunity to provide further comments, which have been reflected in this report. Prioritisation of cost reduction and barrier deployment was facilitated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 6. **Innovation mapping for sustainable building fabric**

	New Build, Existing (retrofit), or Both	Objective	Innovation Opportunity	Contribution to Cost Reduction	Contribution to Reducing Deployment Barriers	Technology affected	Feasible Timeframe
Pre-Construction and Design	Both	Performance	Design to achieve guaranteed in-use building performance for new build and retrofit (leveraging SAP)	5	5	Building Fabric, Heating & Cooling	2020s
	New Build	Performance	Unlocking the potential for DfMA; e.g. modular design, 3D printing, local construction labs (enabling parts and replacements to be manufactured to specification on site), and open-source design (e.g. Wiki house)	4	4	Building Fabric	2020s
	Both	Performance	Improved BIM data about building fabric: • With a focus on real-world, accurate data input. • For all buildings, not just publicly funded building projects • Added value from having metadata for fabric that is hidden once construction is complete • To inform future upgrades and reduce opportunity for inappropriate upgrades. • To improve accuracy of (rapid) energy modelling by leveraging detailed metadata	3	3	Building Fabric	2020s
	Both	Circular Economy	Taking a whole-life approach to the specification of building fabric materials in tenders during procurement	4	4	Building Fabric	2020s
	New Build	Circular Economy & Performance	Design for disassembly, retrofit, and future proofing for climate changes. E.g. allowing for addition of external shading, weatherproofing, and energy efficiency improvements	3	3	Building Fabric	2020s

	New Build, Existing (retrofit), or Both	Objective	Innovation Opportunity	Contribution to Cost Reduction	Contribution to Reducing Deployment Barriers	Technology affected	Feasible Timeframe
Materials and Components	New Build (Some retrofits)	Performance- Generation	Integrated energy generation (heat and electricity), particularly for facades, e.g. transpire solar collectors	5	4	Building Fabric, Heating & Cooling	2020s
	Both	Performance - Storage	Thermal storage	4	4	Building Fabric, Heating & Cooling	2020s
	New Build	Performance - Storage	Increased thermal mass in modular and offsite construction methods or alternative solutions, except highly carbon intensive manufacture materials. E.g. Phase Change Materials.	4	3	Building Fabric, Heating & Cooling	2020s
	Existing	Performance - Storage	Implications of removing thermal mass from retrofitting internal wall insulation	3	4	Building Fabric, Heating & Cooling	2020s
	Both	Performance	Novel substitutions and the impact of these on designed performance (thermal, acoustic, and fire prevention)	3	3	Building Fabric	2020s
	Both	Circular Economy	Low embodied carbon materials to coincide with costs. Considering the whole life carbon impact of a material (e.g. transportation, end-of-life) and not just those emitted in the operational life phase	4	4	Building Fabric	2020s

	New Build, Existing (retrofit), or Both	Objective	Innovation Opportunity	Contribution to Cost Reduction	Contribution to Reducing Deployment Barriers	Technology affected	Feasible Timeframe
Build Process	Both	Performance	Unlocking the potential for In-construction testing (e.g. using thermography) and independent checks / verification	5	5	Building Fabric, Heating & Cooling	2020s
	Both	Performance	Post-construction testing of actual performance and tools to verify guaranteed thermal performance of building fabric. E.g. in situ u-value calculations, thermography, co-heating tests, use of smart meter data	5	5	Building Fabric, Heating & Cooling	2020s
	Both	Circular Economy	Understanding energy use and opportunities to minimise additional consumption through optimised programming during building (fabric) work to avoid spikes. E.g. for heating to dry out following wet trades	4	2	Building Fabric, Heating & Cooling	2020s
	Both	Performance	Build as designed and specified to remove opportunities for variation and unintended consequences	3	3	Building Fabric, Heating & Cooling	2020s
	Existing	Performance & Circular Economy	Prefabricated envelopes for retrofit	5	5	Building Fabric, Heating & Cooling	2020s
	Both	Skills & Supply Chain	Skills and training of existing and new stakeholders. Apply this to gaining quality outcomes in: • New and innovative methods of construction and materials • Traditional methods of construction, including pre-1919, and implications of unsuitable building fabric upgrades to avoid unintended consequences. • Retrofitting non-traditional buildings	4	4	Building Fabric, Heating & Cooling	2020s

	New Build, Existing (retrofit), or Both	Objective	Innovation Opportunity	Contribution to Cost Reduction	Contribution to Reducing Deployment Barriers	Technology affected	Feasible Timeframe
Building Operation	Both	Performance	In-use monitoring and feedback to occupants and smart controls of internal environment (heating and cooling, ventilation, fire alarms) to: • Ensure building fabric is at the optimum temperature for the external and internal climate and promotes healthy conditions for both occupants and the building fabric. • Optimise use of building and promote behaviour change. • Trigger alarms following sudden increase in heat or cold to indicate dangerous conditions for the occupant(s), including from a fire	5	4	Building Fabric, Heating & Cooling	2020s
	Both	Skills & Supply Chain	Unlocking potential opportunities to share learning and new knowledge about building fabric innovations	4	4	Building Fabric	2020s
	Existing	All	Unlocking the potential of BIM for maintenance and operation. Having such data to hand could reduce the time and costs associated with gathering this information during the life of the building. It could be used to inform decisions about maintenance, operation, and building improvements	3	4	Building Fabric	2020s
All	Both	Circular Economy	Actual life cycle costs of building fabric to inform where the biggest energy use and costs lie. Is it in the manufacture, construction/ installation, in-use, or end-of-life stage?	3	3	Building Fabric	2020s
	Both	All	Digitisation of designing, constructing, maintaining, and improving building fabric	2	4	Building Fabric	2020s

Source: Carbon Trust for BEIS, Appraisal

Innovation opportunity deep dives

Guaranteed Performance

Innovations that contribute towards closing the performance gap between new build or retrofit designs and their real-world delivery are essential for the UK to achieve guaranteed in-use building performances. Accurate testing of material and installation quality and data collection currently present barriers to addressing the performance gaps of projects and the meeting of low-carbon building regulations. Innovations that enable feedback on building performance to be generated at the following life-cycle stages are therefore likely to offer the best cost and deployment benefits to customers and the UK:

In-construction testing could allow contractors to avoid facing significant costs and/or penalties resulting from the performance of their buildings not matching their design estimates at the end of the build process. In-process testing would allow developers to fix these before they are held accountable and reduce the number of expensive revisions needed. A database of such in-construction test results would also be useful in highlighting materials that consistently underperform. This could be used to inform where R&D on substitute materials needs to occur, as well as areas where industry workers are lacking the correct installation skill and CPD materials need to be developed. Both would facilitate emission reductions.

Post-construction testing innovations can be utilised by regulators in order to hold contractors accountable for performance gaps. Like in-construction testing, a database that presents the performance results of materials in different real-life settings would be a useful tool both for informing R&D spending and developing training materials.

A system of in-use system monitoring and feedback is important as it will enable builders, owners, and regulators to test both the longevity of performance efficiency and how well building fabric innovations suit customer needs. It will also play an important role in ensuring that building occupants are able to correctly control these innovations. Optimum control ensures that systems are used as efficiently as possible and that performance gaps are further limited. Better understanding of renewable/low-emissions energy technologies throughout the UK's general public would further aid deployment by decreasing their perceived investment risk. This would especially be the case if feedback control innovations were designed to provide occupants with high quality and user-friendly data on cost and/or energy savings.

Low embodied carbon materials

Embodied carbon relates to a product or asset's material extraction, manufacture, processing, transportation, and assembly. Depending on the boundary of assessment, it can also include the maintenance, replacement, deconstruction, and disposal/end-of-life of the asset[26]. We are including all stages in the context of this report. The asset's operational emissions are excluded from embodied carbon calculations.

The production of building materials is a very emissions-intensive process and materials are typically not well reused or recycled at the end of their use. In order to reach an 80% reduction in emissions, the UK building sector needs to consider the whole lifecycle of building fabrics. For example, the annual emissions of the global cement production industry, which is the most emissions-intensive building material at present, needs to fall by 16% in order to meet the emission reduction targets set out by the Paris Agreement[27]. This will be impossible without innovation in low embodied carbon materials because demand for cement, due to rapid global economic development, is forecast to increase from 4 to over 5 billion tonnes per year by 2050[28]. The increasing global demand for building materials, coupled with the political pressure to reduce their emissions, means that focussing innovation investment on low embodied carbon materials would not only aid the decarbonisation of the national building sector, but would also provide the UK with a good export opportunity.

To further the development of low embodied carbon material research within the UK it will be important to move beyond controlled studies and begin to develop real-world testing facilities[29]. This will improve the reliability of results and quickly identify the most performance-enhancing innovations. Testing on real building projects will enable contractors to learn about the innovations, as well as their price benefits for a whole building, rather than at the scale of an individual component. An improved understanding by contractors in the sector will narrow the current skills gap and therefore speed up the deployment of these innovations as well as reducing performance gaps that can result from contractor error.

[26] UK Green Building Council (2017), Embodied Carbon: developing a client brief, https://www.ukgbc.org/wp-content/uploads/2017/09/UK-GBC-EC-Developing-Client-Brief.pdf
[27] Beyond 2°C Scenario (B2DS) in International Energy Agency (2017), Energy Technology Perspective 2017: Catalysing Energy Technology Transformations, https://www.iea.org/etp2017/
[28] International Energy Agency (2017), Energy Technology Perspectives 2017; Müller, N. and Harnisch, J. (2008), A blueprint for a climate friendly cement industry, WWF International, http://awsassets.panda.org/downloads/englishsummary__lr_pdf.pdf
[29] Chatham House (2018), Making Concrete Change: innovation in low-carbon cement and concrete, https://www.chathamhouse.org/publication/making-concrete-change-innovation-low-carbon-cement-and-concrete

Alternative Energy Sources

The construction of buildings with integrated energy generation and storage facilities will be essential to reducing the energy demand that the UK building stock places on the national grid. This will be important in meeting the operational performance targets. The following innovation opportunities were highlighted by industry experts as those producing the most potential for UK cost and deployment benefits in this area:

System integrated energy generation innovations will be important to enable the UK building sector to reduce the strain on the electricity and gas grids. Transpired solar collectors are an example of a technology that the UK has already had some innovation experience and success in.[30]. Further innovations could include building integrated PV, solar thermal collectors, and solar facades. It is important that such novel generation innovations are compatible with other technologies, can be retrofitted to reduce the energy demand of existing buildings, and can form coordinated systems with existing energy transitioning, utilising, and monitoring building elements. This will not only decrease installation costs but also prevent components from negatively impacting on the efficiencies of one another. It will therefore reduce the risk of novel innovations enhancing performance gaps. The compatibility of components and systems will also need to span the whole life of the building, from construction to demolition.

Energy storage innovations would allow buildings to be more dependent on renewable energy sources. Renewable energy sources for the generation of building heat and electricity without grid dependency are intermittent in nature because their output is weather dependent. This means that during periods of favourable conditions the technologies create an excess of energy that is wasted and in poor conditions buildings still rely on non-intermittent mains grid energy sources. Innovations that enable buildings to store the renewable energy available to them during times of high availability would reduce their dependence on mains grid non-renewable fuels. The development of construction materials that have energy storage properties will be highly effective in improving the energy performance of buildings in this way. As discussed earlier, an example of this kind of innovation that the UK already has a strong foothold in is PCM. Innovations in this sector should focus on the development of materials, as well as on how they can be retrofitted into existing buildings and implemented into new build designs.

[30] Cardiff University (2014), Transpired Solar Collector Installations in Wales and England, https://orca.cf.ac.uk/58610/1/Brown%202014%20TSC%20in%20Wales%20and%20England%20-%20paper.pdf

Skills and Training

The UK building workforce largely consists of generalised, self-employed operators or sub-contractors. This is a barrier to knowledge retention because it limits the repetitive application of learnt skills in specific environments, building types, or building areas. This is different to continual employment sectors (e.g. factories) where skills are perfected due to their continual use in consistent settings. Skill adoption across the building sector is also reduced due to a lack of knowledge sharing between competing firms and contractors.

In order to minimise unintended consequences of the commercialisation of low-emission and circular economy building innovations, it is important that the skills gap present in the UK building industry is closed. Contractors need to know how to procure, test, prescribe, install, and operate low-emission innovations across all the building types that they construct and/or retrofit. Without this change, no amount of innovation in building materials or processes will be able to close the UK building performance gap or sufficiently reduce construction waste. The spread of this knowledge across the UK will occur from innovations that create, as well as facilitate and promote, the uptake of relevant training courses, qualifications, platforms, and standards. The UK's previous and current successes in IT innovations, creation of online education facilities, and computer science will provide a good foundation and support network for the development of these innovations.

Business opportunities within building fabric

Introduction

Box 7. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the ‘opportunity’; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with building fabric, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.

- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

More detail on the business opportunities methodology is provided in the Appendix.

Energy efficiency improvements in buildings can provide cost savings and are key in meeting global emissions reduction targets. The buildings and construction sectors are responsible for nearly 40% of GHG emissions, which will need to be reduced significantly to meet global climate targets[31]. To illustrate, the UK has set the target of a 71-83% reduction in emissions by 2050 over 1990 levels,

[31] IEA: https://www.iea.org/topics/energyefficiency/buildings/

and the EU target is an 80-95% reduction in emissions over the same period[32,33]. Long-term emissions goals such as these will require almost carbon-neutrality in the buildings sector; building fabric improvements are one of several key ways of reaching these. The IEA estimates energy efficiency improvements, such as insulating measures, could account for over half the potential energy savings in the sector[34]. The UK's Buildings Mission aims to halve the energy use of new buildings by 2030, while the Clean Growth Strategy outlines a host of energy efficiency improvements for commercial and residential buildings[35]. This section looks at how building fabric can contribute to achieving these energy efficiency improvements, and the subsequent opportunity for UK businesses in exporting building fabric products and services following successful innovation as discussed previously.

Buildings construction is a large industry in the UK, with significant export opportunities; however, the UK is currently a net importer of materials[36]. In 2017, the UK construction industry contributed 6% of GDP and 7% of employment. However, the UK trade deficit in construction materials and components grew in 2017, increasing to £9,909 million, with the value of imports more than double the value of exports. In addition, the UK's construction sector remains the least productive industry in the UK and is 20% below the average hourly output for the whole economy. Innovation opportunities identified earlier could help to reduce this deficit.

The UK's old building stock will require significant retrofitting by 2050, offering a domestic opportunity to deploy building fabric for energy efficiency purposes. This could subsequently help develop exportable expertise in retrofit goods and services. However, international competition is strong in this area. Countries such as Germany, Austria, and Sweden are several years ahead in constructing low-carbon domestic buildings, having built up significant domestic supply chains that export significant volumes of low-carbon (prefab) building materials across Europe.

The building fabric market is large, complex, and varied. The export analysis includes four key aspects:

[32] CCC (2016), "UK climate action following the Paris Agreement": https://www.theccc.org.uk/wp-content/uploads/2016/10/UK-climate-action-following-the-Paris-Agreement-Committee-on-Climate-Change-October-2016.pdf
[33] European Commission: https://ec.europa.eu/clima/citizens/eu_en
[34] IEA: https://www.iea.org/topics/energyefficiency/buildings/
[35] BEIS (2018) The Grand Challenge missions https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions
[36] ONS (2018) https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/articles/constructionstatistics/number192018edition

- **Pre-construction and design** focusses on innovations that could help buildings to both perform as specified by build plans and to be constructed from low-carbon materials. The business opportunities analysis concentrates on the global export of design and retrofit services, such as BIM.
- **Build process** includes real-time monitoring of construction but is primarily concerned with offsite (prefab) construction. While the innovation section considers other areas, the business opportunities within build process are focused on offsite construction, as this is the only area expected to be traded at meaningful scale internationally. Prefab is a significant export opportunity, as prefab elements are relatively high value add and have a greater value-to-weight ratio, and hence are more likely to be traded than basic materials.
- **Building operation** is focussed on reducing energy use. Export opportunities within building operation focus on monitoring products such as smart controls and systems, as these represent a large opportunity for reducing energy demand and a sizeable market.
- **Materials and components** considers the market for low embodied carbon materials and smart, energy-efficient materials. This includes PCM and natural insulation materials.

The export opportunity analysis excludes two elements of the building fabric sector:

- **Services including installation and operation and maintenance are only considered in the domestic analysis.** These tend to be performed locally and are therefore unlikely to present a large export opportunity. However, within the UK these services will represent a large proportion of the jobs supported within the sector and are captured in the domestic analysis.
- The export of **know-how and intellectual property (IP)** is a key opportunity for UK businesses. This analysis does not consider these opportunities, for example those associated with licensing IP for manufacture in China. This is because the focus of this analysis is on the potential for innovation to support UK jobs and GVA, which is likely to be minimal for IP export. Similarly, the export of building standards, such as the sustainable building code BREEAM, presents domestic job opportunities.[37]. However, this export is unlikely to be driven by innovation in the building fabric sector and has therefore been excluded.

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports

[37] https://www.breeam.com/

- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

Box 8. **The UK's current building fabric industry**

- UK strengths include IT systems (for smart homes), BIM, engineering services expertise, and insulation materials (although typically with high embodied carbon).
- Key competitors include Germany, Austria, the Netherlands, and Sweden within Europe, with strengths in low-carbon buildings and retrofits. China and the US represent the greatest competitors in the rest of the world (RoW).

Market overview

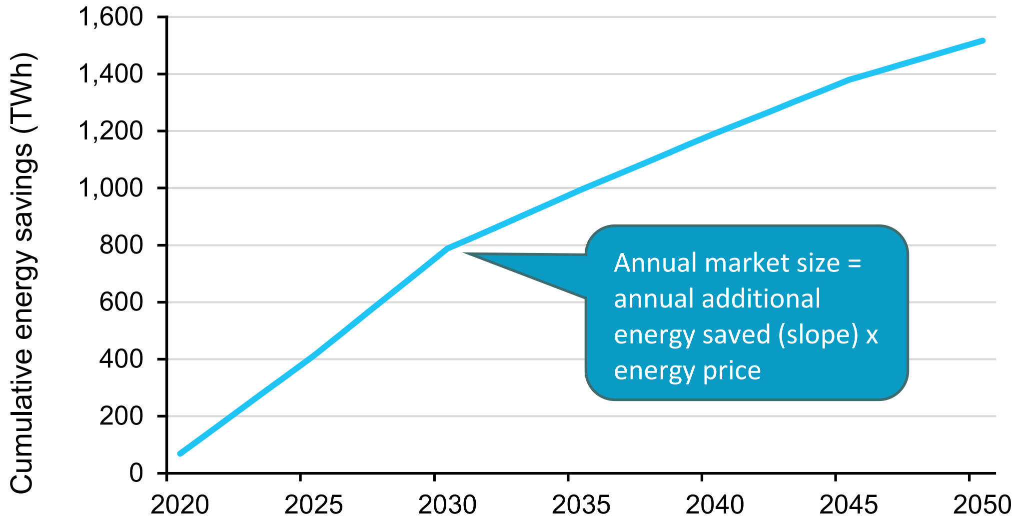
The global market for construction materials is large, with a turnover of £701 billion in 2017.[38]. The market is growing rapidly, with annual growth of 6.8% since 2013. However, much of the market for materials is unlikely to be traded and hence not accessible for UK exporters. This is primarily because of the bulk and weight of construction products, which mean long-distance trade is often not competitive compared to local production. However, of the construction materials market, building fabric for energy efficiency purposes is a growing segment, and will increasingly offer export opportunities given the typically higher value-to-weight ratio.

The annual turnover of building fabric for energy efficiency improvements is expected to reach £56 billion by 2030, as annual improvements to building fabric yield a saving of 77 Terawatt hour (TWh) per year. This market peak is driven by the IEA's 2-degree scenario and is highly dependent on the level of global climate action. Figure 1 shows the cumulative energy savings in the IEA's 2-degree scenario; the annual increase in energy savings reflects deployment of new energy efficiency measures and, indirectly, market turnover. The market size estimate assumes that consumers, possibly supported by government schemes, invest 25% of the potential value of energy savings from building fabric improvements into

[38] Ken Research (2018); https://www.kenresearch.com/manufacturing-and-construction/construction-materials/construction-materials-global-industry/149768-97.html

them[39]. It is well established that consumers are not willing to pay the full value of efficiency improvements given hassle costs and other behavioural barriers; indeed, significant government support is likely to be required[40,41]. We hence estimate an annual market turnover of £21 billion in 2050, peaking at £56 billion around 2030 when the greatest annual deployment of building fabric (77 TWh heat savings per year) is predicted.

Figure 1 **Derivation of the global building fabric market for energy efficiency**



Source: *IEA Energy Technology Perspectives & Vivid Economics analysis*

Within the overall market considered (£56 billion by 2030), approximately £15 billion is likely to be traded. We estimate tradeable export opportunities per category as below.

- The tradeable market for **pre-construction and design** is estimated to grow to £8.1 billion by 2030. The total market is expected to be £32 billion. However, although energy modelling software is tradeable globally, design and retrofit services are often delivered domestically and hence we estimate only 25% is traded globally.

[39] This follows the assumption made in the corresponding technology innovation needs assessment (TINA). The assumption is broadly consistent with a payback period of 2-3 years for basic renovations. This has been estimated given typical payback periods of 10-11 years in similar Green Deal renovations: DECC, 2011, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/43019/3506-green-deal-consumer-research-prs.pdf
[40] Previous UK schemes such as the Green Deal and the Energy Company Obligation have indicated willingness to pay for future energy savings is very low: National Audit Office, 2016, https://www.nao.org.uk/wp-content/uploads/2016/04/Green-Deal-and-Energy-Company-Obligation.pdf.
[41] However, given the cost-effectiveness of energy efficiency savings, it is expected that government support for such measures will increase over the period to meet climate targets: European Commission, https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/financing-renovations.

- The tradeable market for **build process** is estimated to reach £2.5 billion by 2030, of an expected total market of £7.1 billion. Offsite construction tends to involve lightweight materials, but current trade patterns indicate distance is still a key determinant of exportability. Hence, we estimate 60% of the EU market is tradable, and 30% of the rest of the world.
- The tradeable market for **building operation** is estimated to grow to £3.9 billion by 2030, while the total market is estimated to be £13 billion. Some services, such as audits, will be largely limited to local providers, but the market for more specialist services is global. Therefore, we estimate 35% of the EU market and 30% of the rest of the world will be accessible for UK exports.
- The tradeable market for **materials and components** is estimated to be £0.7 billion in 2030, of an expected £3.2 billion total market. Many low-carbon materials will be traded, but it is likely that distance will remain a limiting factor in determining exportability. Hence, we estimate that 60% of the EU market will be tradeable, but only 15% of the rest of the world.

Europe is a key market for exports of building fabric, given the high heating demand and proximity to the UK. Northern Europe has relatively high levels of heat demand due to its climate and above average incomes. In addition, the upfront costs of energy efficiency measures are more affordable than in poorer countries given the affluence of these nations. Europe is also attractive given its proximity and relative similarities in building stock compared with the rest of the world[42]. Materials and components tend to be heavy relative to their value, meaning the UK is less likely to be competitive in distant markets such as Asia and the US. However, newer materials used in offsite construction and insulation are known for being lightweight relative to traditional building materials, while services such as pre-construction and design and smart operation services are globally exportable.

The large-scale deployment of energy efficiency building fabric depends on strong climate change action at the national and international levels. Decarbonisation targets, such as the EU's target for an 80% reduction in emissions by 2050 and the UK CCC's 71-83% target over the same period, will require almost all existing buildings to undergo deep retrofits[43]. In the IEA's beyond 2 degrees scenario, the reduction in heat demand in buildings almost doubles compared with the 2-degree scenario. This is driven by even higher uptake of efficiency measures,

[42] Buildings Performance Institute Europe (2011) http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf
[43] European Commission: https://ec.europa.eu/clima/citizens/eu_en; CCC (2016) UK climate action following the Paris Agreement: https://www.theccc.org.uk/wp-content/uploads/2016/10/UK-climate-action-following-the-Paris-Agreement-Committee-on-Climate-Change-October-2016.pdf; Buildings Performance Institute Europe (2017) 97% of buildings in the EU need to be upgraded: http://bpie.eu/publication/97-of-buildings-in-the-eu-need-to-be-upgraded/

which builds economies of scale and drives further innovation in efficiency improvements. This leads to a doubling in total market size in the period to 2050. This contrasts with minimal action in the IEA's reference technology scenario, which would see export opportunities for building fabric muted relative to the baseline scenario considered.

Figure 2 **The current and future building fabric market**

Current market for building fabric

- *Production:* The global market for energy efficiency is expected to reach £56 billion by 2030
- *Trade:* Building fabric is largely deployed domestically, with relatively limited trade
- *Markets:* Building fabric for retrofit purposes is focussed in countries with a historical building stock such as the UK and Western Europe, while new build process will be mostly deployed in developing countries

Tradability of market

- *Goods:* Materials and components are traded locally, while prefabricated buildings tend to be lighter and can be traded over greater distances
- *Services:* Design and modelling services are globally traded; installation and maintenance can be performed locally due to a lack of specialised knowledge
- *Trends:* Innovative production techniques or goods may lead to higher levels of trade

Trends in deployment

- *Global:* Large short-term increase in deployment to be followed by gradual implementation globally
- *Growth pattern:* Deployment of energy efficiency measures will peak in the medium-term (by 2030), with steady deployment in the following years
- *Uncertainty:* Deployment relies on increased interest from households and businesses than currently observed; the IEA reference scenario has minimal deployment of building fabric to 2050

Global and regional market size to 2050

- *Growth trend:* Strong growth in the coming decade given long-term nature of energy efficiency measures and 2030 targets of many countries
- *Key markets:* Europe will strongly demand energy efficiency measures in the short-term, but the majority of demand comes from the rest of the world

Source: Vivid Economics

UK competitive position

The UK has an active building fabric industry, but currently has a trade deficit in relevant goods suggesting it is not an overall competitive strength. The UK imports over twice the value it exports in construction materials and components, leading to a £10 billion trade deficit in 2017.[44]. This is reflected in the UK's revealed comparative advantage (RCA) of 0.24 in the materials sector (any RCA < 1 is said to reveal a comparative disadvantage). There are, however, areas of competitive strength. The UK is a net exporter of insulation and retrofit services, though exports

[44] ONS (2018) https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/articles/constructionstatistics/number192018edition

of £174 million are small relative to the £110 billion global insulation market[45,.46]. In addition, expert consultation suggests that the UK's position as a net exporter reflects domestic weakness in demand, rather than export strength.

Regional European competition is strong, with several countries developing significant supply chains around energy-efficient building fabric. Within Europe, Germany, and Austria have pushed the low-carbon building industry, developing strengths in retrofitting and "near-zero carbon buildings". Germany has been one of Europe's most successful countries in stimulating energy efficiency refurbishments, targeting 1 million homes per annum through the state bank Kreditanstalt für Wiederaufbau (KfW), which has public-private co-financing ratios of up to 1:9[.47]. The Netherlands is another regional competitor, with its offsite construction industry capturing 9% of the total EU market following high levels of domestic deployment. Other competitors include Poland and Lithuania, with strengths in the manufacture of windows and doors driven by low labour costs and innovations encouraged by their cold climate.

The UK's existing building stock provides domestic opportunities to develop retrofit expertise and built a domestic low-carbon building supply chain. Globally, 50% of the current building stock will still be in place by 2050[.48]. This number is substantially greater for the UK (85%), and is similarly high in Europe, highlighting a greater need for retrofit[.49]. Given this, the UK has an opportunity to develop expertise in retrofit services and materials.

The UK is expected to be particularly competitive in pre-construction and design. The relative UK competitiveness across the four building fabric markets considered are:

- **Pre-construction and design** represent a UK strength. The UK has developed expertise in BIM, while retrofit services such as design and implementation could develop domestically given the UK's existing building stock. Under a high innovation scenario, we consider 18% an ambitious, but plausible, UK share of the EU market (Table 7).

[45] Carvalho & Fankhauser, 2017, "UK export opportunities in the low-carbon economy"; http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2017/04/Carvalho-and-Fankhauser-2017.pdf
[46] Ricardo Energy & Environment (for CCC), (2017), "UK business opportunities of moving to a low-carbon economy": https://www.theccc.org.uk/wp-content/uploads/2017/03/ED10039-CCC-UK-Bus-Opportunities-Draft-Final-Report-V7.pdf
[47] Climate Strategy and Partners(2012) "Financing Mechanisms for Europe's Buildings Renovation"; https://www.eurima.org/uploads/Eurima-Financing_Mechanisms.pdf
[48] Smith, 2018, "Sustainable Retrofitting — Global Strategies & Implementation Issues": http://www.academicstar.us/UploadFile/Picture/2018-5/20185241186227.pdf
[49] Federation of Master Builders (2013): http://cic.org.uk/admin/resources/federation-of-master-builders.pdf

- **Building operation**, particularly around smart controls, is also a potential UK strength by 2050. The UK has a mature smart controls and systems market, and this is linked with the IT industry, a UK strength. The UK could plausibly capture 12% of the EU market by 2050.
- **Build process** offers a moderate export opportunity for the UK, with a 9% share of the EU market under a high innovation scenario. The UK currently exports building standards and expertise in this area. In addition, the UK has seen growth in offsite manufacturing. This is currently valued at 7% of the UK construction market and is expected to grow.[50]. However, there is significant competition in offsite construction innovations, with substantial uptake in Germany and the Netherlands. Opportunities within build process are detailed in the deep dive on offsite construction.
- The UK has a limited competitive advantage in **materials and components.** Even in an optimistic scenario, the UK's future share is estimated to be limited to 6% of the EU market. Expert consultation indicates inconsistent demand has led to weakened domestic supply chains and dependence on imports. In addition, the UK has a limited share of the current EU market for construction materials (2%) and given market maturity this is unlikely to change significantly.

Figure 3 **The UK's competitive position in trade in goods**

Current UK competitiveness

- *Market shares (materials, offsite construction):*
  EU *(excl. UK)* ~ 2%, 1.7%
  RoW ~ 0.9%, 1.4%
- *Strengths:* Active construction industry has established a supply chain of building materials
- *Weaknesses:* Limited domestic deployment of energy efficiency measures so far; large trade deficit on imported materials

Key EU competitor - Germany

- *Market shares (materials, offsite construction):*
  EU ~ 19.4%, 6.7%
  RoW ~ *7.9%*, 4.5%
- *Strengths*: Innovative deployment of low-carbon buildings has encouraged a supply chain for materials
- *Weaknesses:* Relatively high costs

2nd EU competitor – Netherlands

- *Market shares (materials, offsite construction):*
  EU ~ 5.9%, 8.9%
  RoW ~ *0.9%*, 7.3%
- *Strengths*: Large prefab industry exporting globally
- *Weaknesses:* No identified strengths outside prefabs, relatively high costs

Global Competitor - China

- *Market shares (materials, offsite construction):*
  EU ~ *4%, 10.3%*
  RoW ~ *31.7%, 23.2%*
- *Strengths*: Largest global exporter of construction materials; some expertise in energy generating and storage facades, e.g. PV facades and smart windows
- *Weaknesses:* Different regulatory standards to the UK's key export market (Europe)

Source: *Vivid Economics*

[50] KPMG: https://assets.kpmg/content/dam/kpmg/pdf/2016/04/SmartConstructionReport.pdf

Box 9. **Industry workshop feedback regarding business opportunities**

- The current trade deficit in construction materials offers opportunities to develop supply chains through import substitution before exporting. Export opportunities are likely to be enhanced by an increase in domestic deployment.
- Offsite construction is already responsible for 10% of new builds, and represents a viable business opportunity, though local competition from Germany and Netherlands is strong.
- The UK's boom and bust construction industry (with unstable demand) is not conducive to domestic supply chains, leading to import dependency.

Table 7. **Export market shares and innovation impact – building fabric**

	Tradeable market (£m)		Current market share	2050 outlook *with* strong learning by research			
	2030	2050		Market share	Captured turnover (£m)	GVA (£m)	Rationale for the impact of innovation
Pre-construction and design	**EU: 1,490** RoW: 6,600	**EU: 440** RoW: 2,300	**EU: 5%** RoW: 3%	**EU: 18%** RoW: 14.6%	**EU: 80** RoW: 340	**2030: 450** 2050: 220	Innovation boosts BIM among other services; the UK achieves twice the Netherlands share in build process given the UK's relative strength in construction services
Build process (prefab)	**EU: 780** RoW: 1,700	**EU: 285** RoW: 740	**EU: 1.7%** RoW: 1.4%	**EU: 8%** RoW: 7.3%	**EU: 25** RoW: 50	**2030: 100** 2050: 50	Growth in domestic off-site construction is tempered by significant international competition; the UK reaches the Netherlands' current market share
Building operation	**EU: 820** RoW: 3,100	**EU: 330** RoW: 1,500	**EU: 4%** RoW: 2%	**EU: 12%** RoW: 10%	**EU: 40** RoW: 140	**2030: 180** 2050: 120	Smart systems linked with UK strength in IT; the UK reaches twice the Netherlands share in materials and components given the UK's strength in construction services
Materials and components	**EU: 350** RoW: 390	**EU: 80** RoW: 100	**EU: 2%** RoW: 0.9%	**EU: 6%** RoW: 1%	**EU: 4** RoW: 1	**2030: 8** 2050: 2	Some niche innovations applicable globally, but in a highly competitive sector; the UK reaches the Netherlands' current market share

Note: *Future market shares are not a forecast, but what UK business opportunities could be. The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in a workshop. Table is based on IEA scenario from the 2017 Energy Technologies Perspective. The scenario used in this table is the 2 degrees scenario, which is the standard reference throughout the business opportunities section. Further information on the methodology behind this table can be found in the Methodological Appendix.*

Source: *Vivid Economics*

UK business opportunities from export markets

Box 10. **Interpretation of business opportunity estimates**

The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2-degree world and reflect a UK market share in a scenario with significant UK innovation activity.[51] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Growth of UK exports could add over £720 million GVA per annum and 9,100 jobs by 2030. Demand for energy efficiency improvements is expected to peak in the 2030s, growing the global market for building fabric.[52]. The increase in UK-captured turnover relies on the strong assumption that the UK grows its market shares of offsite construction and materials and components to the Netherlands' current shares. Given the UK's relative strengths in services and IT systems, the shares of pre-construction and design and building operation are assumed to exceed those of materials and components or build process. These shares are fully detailed in Table 7. Note that increased competitiveness in this sector may increase market shares in the wider construction industry; while not in the scope of this EINA, an overview of the potential impact is discussed in Box 11.

Export opportunities may decline after the 2030s, supporting £390 million of GVA per annum and around 4,000 jobs by 2050. The peak of export opportunities during the 2030s is driven by the expected size of the retrofit market. By the 2050s, this market will gradually decline in Europe, the UK's main export market, as most of the building stock will have been retrofitted. This outcome is driven by the IEA's 2-degree scenario, which assumes early deployment of energy efficiency measures, and will change under alternative timeframes.

[51] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.
[52] Driven by the IEA's 2-degree scenario assumptions of early deployment to meet 2030 GHG emission targets and reduce costs early.

Services for pre-construction and design represent the greatest UK export opportunity. This is due to the UK's existing strengths in consulting services and modelling energy systems, along with the relatively large traded market for these services (see Table 7). Innovations in guaranteeing in-use performance of buildings and BIM (discussed in the Inventory of innovation opportunities) enable the UK to increase competitiveness and capture a large share of the global export market. Exports of pre-construction and design increase GVA by over £450 million per annum and support 5,700 jobs in the early 2030s. A breakdown of GVA and jobs by component is shown in Figures 4 and 5.

Within goods exports, opportunities are concentrated in building operation and the build process. By the early 2030s building operation could add £180 million to GVA per annum and support 1,900 jobs, while build process could add £90 million to GVA annually and support 1,400 jobs. This assumes the UK can export offsite construction components globally following high innovation in efficient offsite construction techniques. Exports within building operation are primarily around the export of smart systems and home hubs, using the UK's expertise in IT systems and early smart meter deployment.

Operation and maintenance services, while presenting a domestic opportunity for large-scale deployment, are not expected to add significantly to UK business from exports. Much of installation, operation, and maintenance is assumed to be performed locally, as local supply chains exist for the construction industry across the world.

GVA and employment opportunities are dependent on coordinated, international climate action. Results reported are under the 2-degree scenario, the IEA's central scenario. Under the IEA's reference technology scenario, climate action remains much weaker, and the market for energy efficiency building fabric is minimal, providing limited job opportunities. Conversely, in the beyond 2-degree scenario the expected market size is almost doubled, adding over £1.4 billion to GVA per annum and almost 18,000 jobs by 2030.

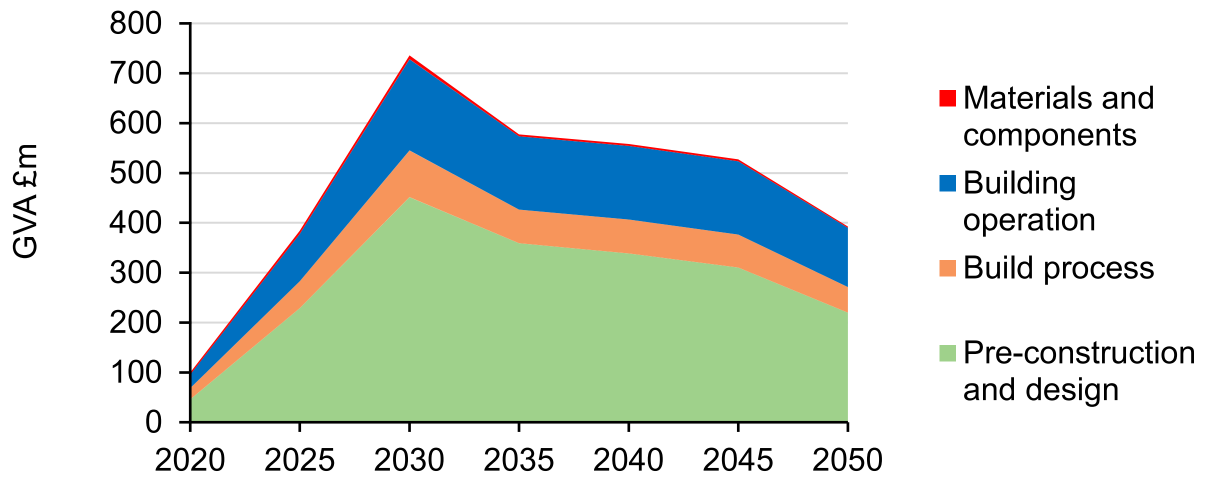
Box 11. **Potential impact on the wider construction industry**

UK GVA and job opportunities in the wider construction industry are likely to be significant. Given that construction industries are primarily domestic, the export opportunities associated with building fabric are relatively modest. However, domestic business opportunities associated with building fabric are likely to be relatively large (compared to other EINA sub-themes).

There are likely to be significant export opportunities in the wider construction industry. These indirect opportunities are outside the scope of this analysis, but it is conceivable that the UK's strength in building fabric translates into a broader strength in construction exports. This is a large market and could support significant UK GVA and jobs. To illustrate, the UK exported £1.8 billion in construction services in 2018, representing 4% of a global market of around £54 billion.[53]. Increasing the UK market share of this market would significantly add to GVA.

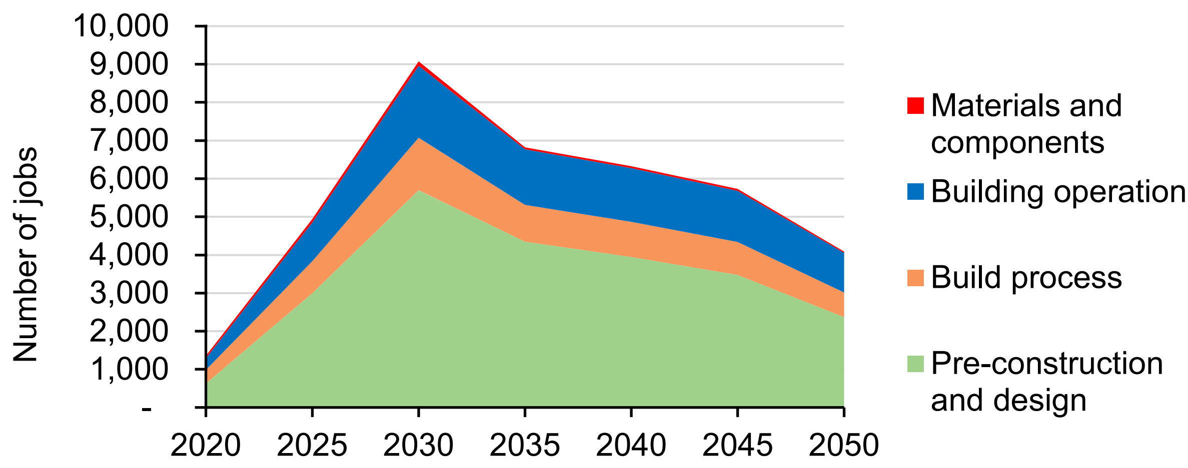
[53] House of Commons: https://www.parliament.uk/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral%20Analyses/8-Sectoral-Analyses-Construction-and-Related-Engineering-Report.pdf

Figure 4 **GVA from export markets by component – building fabric**



Source: Vivid Economics analysis based on methodology in Appendix 2

Figure 5 **Jobs supported from export markets by component – building fabric**



Source: Vivid Economics analysis based on methodology in Appendix 2

UK business opportunities from domestic markets

Discussion

High levels of retrofit and low-carbon construction in the period to 2050 are expected to present domestic business opportunities within building fabric. The UK Committee on Climate Change's (CCC) 'Core' scenario reduces emissions from buildings from 85 MtCO2e today to 20 $MtCO_2$ by 2050, a 77% reduction, in order to meet an 80% economy-wide emissions reduction over 1990 levels.[54]. Meeting this will require almost all existing buildings to be upgraded.[55]. In its 'Further Ambition' scenario towards net zero, CCC analysis suggests reducing building emissions to 4 $MtCO_2$. This would effectively require *all* buildings to be upgraded, including buildings where this is costly, such as heritage buildings. The BEIS "Industrial Strategy" targets halving the energy use of new buildings by 2030 compared to current standards.[56]. To achieve these targets, domestic deployment of low-carbon goods and services within building fabric presents additional opportunities to those identified in the export analysis.

In addition to the domestic deployment of the goods and services identified in the export analysis, construction and retrofit services are sized domestically. Domestic business opportunities within building fabric are analysed as 5 main components:

- **pre-construction and design** focuses on design and retrofit services such as building information modelling (BIM) and architectural services;
- **build process** focuses on manufacturing associated with offsite construction (prefabricated buildings), and on more efficient construction and retrofit techniques;
- **building operation** considers the opportunities to use smart controls to reduce building costs;
- **materials and components** includes low embodied carbon materials and smart, energy efficient materials, and;
- **construction and retrofit installation services,** which includes the labour required for installation and construction of the above measures.

Construction and retrofit installation services associated with the main components present a substantial domestic business opportunity. These were excluded from the export analysis as they tend not to be traded. These services are

[54] UK CCC (2019) Net-Zero Technical report: https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf
[55]CCC (2016) UK climate action following the Paris Agreement: https://www.theccc.org.uk/wp-content/uploads/2016/10/UK-climate-action-following-the-Paris-Agreement-Committee-on-Climate-Change-October-2016.pdf; Buildings Performance Institute Europe (2017) 97% of buildings in the EU need to be upgraded: http://bpie.eu/publication/97-of-buildings-in-the-eu-need-to-be-upgraded/
[56] BEIS (2019) The Grand Challenge Missions: https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges

focused on the installation of low-carbon materials and components in new buildings and retrofits, offsite construction and the installation of smart building controls within building operation. Retrofits and low-carbon building are largely expected to complement ongoing construction activity rather than displace it, meaning this is additional to baseline labour demand within the construction industry.

The share of the building fabric market captured by domestic businesses is expected to be high, driven by low tradability in goods and UK competitiveness in services. Across the components considered within building fabric, market shares are outlined in Table 8 and detailed below:

- UK businesses currently capture 99% of domestic architectural services, driven by a strong domestic industry.[57]. Given this strength, the UK is assumed to capture a 90% share of the domestic **pre-construction and design** services market.
- The UK currently captures a 94% share of the prefabricated buildings market.[58]. It is assumed the UK captures a 90% share of the wider **build process** market.
- The UK currently manufactures 43% of the domestic demand for electricity meters[58]. This is used as a proxy for the current share of the **building operation** market due to limitations in PRODCOM data. Given the UK's broader strengths in IT systems and services, the UK is expected to capture 75% of the building operation market by the mid-2030s.
- The UK currently produces 75% of the building materials used in UK construction by value.[59]. The UK is assumed to capture this share of low-carbon **materials and components** throughout the period assessed.
- **Construction and retrofit** is expected to be mostly captured by domestic industry, as installation and construction is likely to be carried out by UK businesses and sole traders. UK businesses are expected to capture 95% of the domestic market.

Domestic business opportunities within low-carbon building fabric could support almost £6 billion GVA per annum and 82,000 jobs by the mid-2030s. This substantially exceeds the estimated export opportunity, which peaks at £720 million GVA per annum and 9,100 jobs around the same time (Figure 6 and Figure 7). The large share of the domestic market captured by UK businesses leads to the larger domestic opportunity, while the domestic market also supports over 6,000 associated construction and retrofit installation jobs. Table 8 shows the breakdown of GVA by component in 2030

[57] Greater London Authority (2018) London's Architecture Sector: https://www.london.gov.uk/sites/default/files/wp93-architecture_paper_2018.pdf
[58] Prefabricated buildings and electricity meter shares come from PRODCOM database analysis.
[59] Construction Products Association (2019) Brexit – Impact on Construction Products: http://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2019/01/CPA-Brexit-Jan-19.pdf

and 2050, along with the total market turnovers and market shares that generate these numbers. While these numbers are significant, it should be noted that the wider UK construction sector contributed an estimated £138 billion to the UK economy and employed 3.1 million workers in 2016, the majority of which was supported by domestic deployment.[60].

The greatest domestic opportunity is within build process, supporting £2.1 billion GVA per annum and 31,000 jobs by the mid-2030s. This is contrary to export opportunities, which are expected to be greater in pre-construction and design services and building operation. In total, goods account for 76% of the domestic business opportunities (excluding installation) by the mid-2030s, in comparison with just 39% of the export opportunities. As services are expected to be more widely traded, the UK captures a larger share of the export market relative to goods, while distance and weight considerations limit the export opportunities associated with offsite construction and materials and components.

The timing of the market peak is highly dependent on the timing of domestic climate action. The roll out of UK retrofits has been aligned with the IEA's 2-degree scenario for this analysis, peaking in the mid-2030s.[61]. This closely aligns with CCC recommendations for widespread energy efficiency retrofits from the mid-2020s. In addition, a net-zero target requires additional action than modelled in this analysis, and would increase the business opportunities accordingly. On the other hand, if the UK does not increase annual retrofits from the low levels seen in 2017, then the associated market opportunities could be significantly lower than presented in this analysis.[62].

[60] House of Commons: https://www.parliament.uk/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral%20Analyses/8-Sectoral-Analyses-Construction-and-Related-Engineering-Report.pdf

[61] Note, this is a minor departure from the ESME model's roll out timeline, which peaks in 2050.

[62] UK CCC (2018) Progress report to Parliament: https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf

Quantitative results

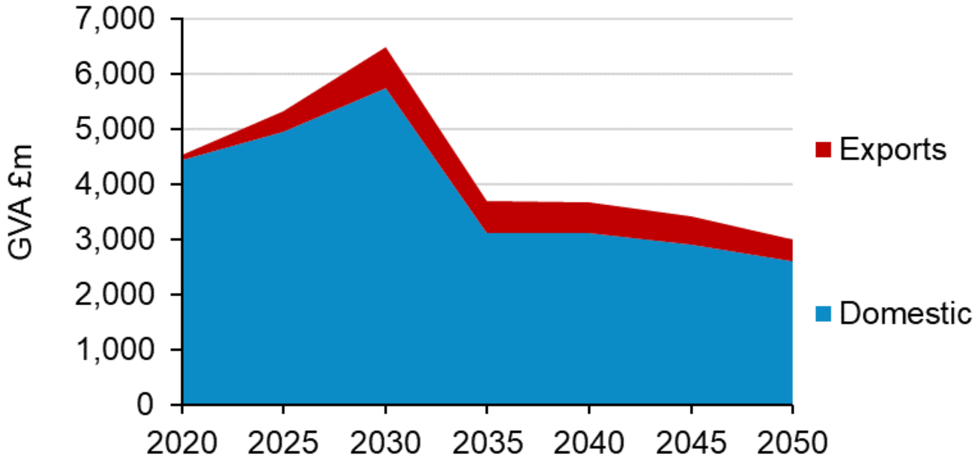
Table 8. **Domestic market shares and innovation impact – building fabric**

Technology	Domestic market (£m)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Pre-construction and design	**2030: 2,300** 2050: 1,000	99% (architecture)	90%	**2030: 2,100** 2050: 900	**2030: 1,100** 2050: 500	The UK builds on its highly competitive position in the architectural and construction design sector to achieve 90% of the domestic pre-construction and design market.
Build process	**2030: 3,600** 2050: 1,600	93% (prefabricated buildings)	90%	**2030: 3,200** 2050: 1,400	**2030: 2,100** 2050: 900	The UK captures 90% of the domestic build process market given established domestic capacity.
Building operation	**2030: 2,700** 2050: 1,200	43.4% (electricity meters)	75%	**2030: 1,700** 2050: 900	**2030: 1,100** 2050: 600	The UK grows its existing market share to achieve 75% of the market by the mid-2030s, building on strengths in IT systems and services.
Materials and components	**2030: 700** 2050:300	75%	75%	**2030: 500** 2050: 200	**2030: 200** 2050: 100	The UK builds on its wider share of the construction materials industry to achieve a 75% share of the domestic market following high innovation.
Construction and retrofit	**2030: 3,000** 2050: 1,300	95% (estimate)	95%	**2030: 2,800** 2050: 1,200	**2030: 1,200** 2050: 500	The UK market share remains at 95% by 2050 as this component is assumed to be low tradability.

Note: * Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.

Source: *Vivid Economics*

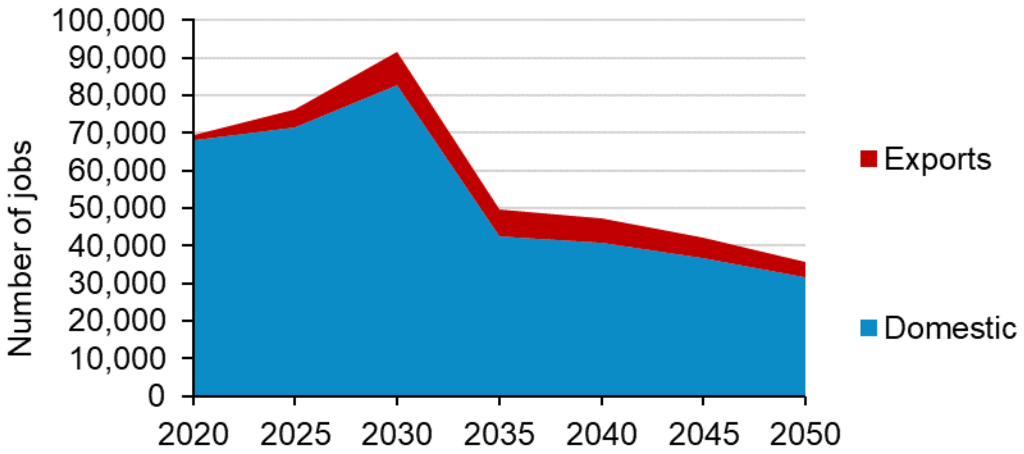
Figure 6 **GVA from export and domestic markets – building fabric**



Note: *Values are in constant prices.*

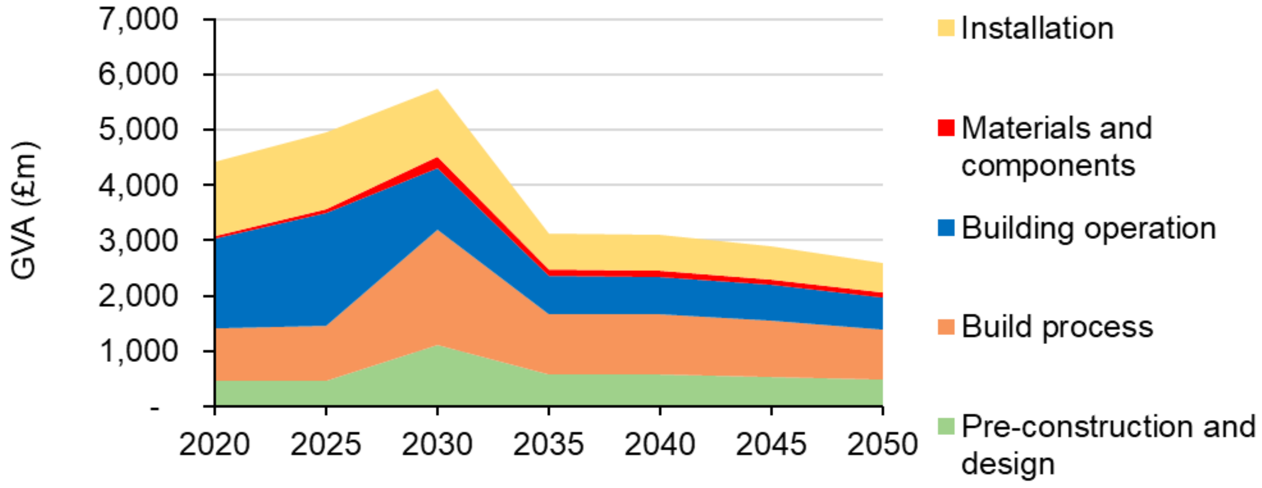
Source: *Vivid Economics*

Figure 7 **Jobs supported from export and domestic markets – building fabric**



Source: *Vivid Economics*

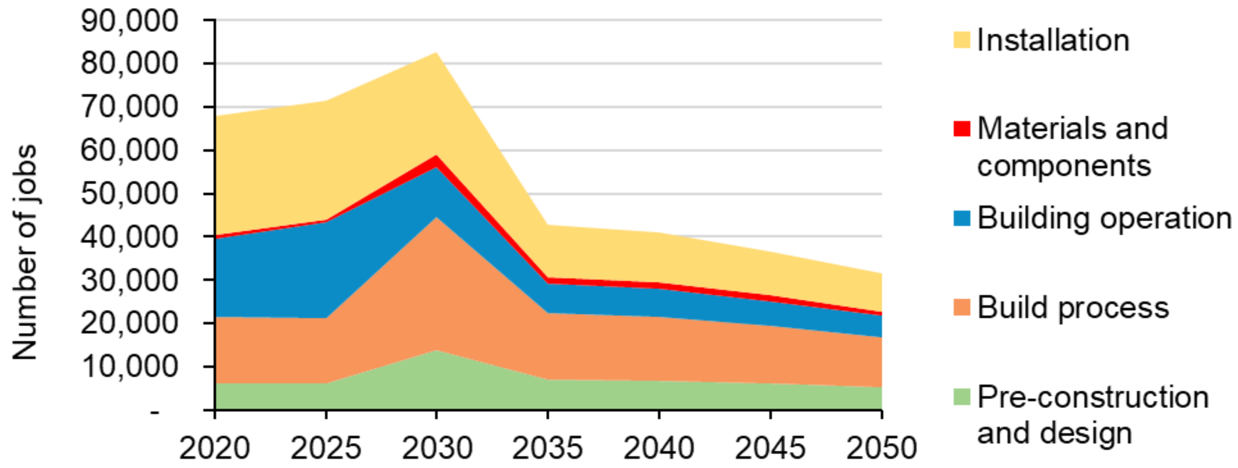
Figure 8 **GVA from domestic markets by component – building fabric**



Note: Values are in constant prices.

Source: Vivid Economics

Figure 9 **Jobs supported from domestic markets by component – building fabric**



Source: Vivid Economics

Business opportunity deep dive: Offsite construction (prefab)

The deep dive in offsite construction reflects that this component presents the greatest business opportunity within goods and offers sufficient literature to provide a detailed review beyond that available for the services business opportunities.
Design for manufacture and assembly of prefabricated buildings is a growing market, with expected growth driving increases in efficiency to make offsite construction cost effective against traditional building methods. The global prefabricated buildings market was valued at £69.3 billion in 2012, compared with the £8.2 trillion construction market[63,64]. The European prefabricated buildings market was valued at £24.2 billion in 2012, with Italy's domestic market accounting for 25.4%. Italy is followed by Germany, France, and the UK with respective shares of 12.7%, 10.7%, and 9.2%. A recent report on smart construction techniques finds that overall costs are likely to be around 6% higher, reflecting the higher added complexity of design development[65]. However, evidence suggests the estimated 6-month time saving (on a 5-year project) can provide net benefits through reduced cost inflation and savings on the interest on borrowing. Other benefits include improved cost and time predictability due to fewer weather disruptions, reduced noise disruption during construction, and improved health and safety.

The UK could plausibly ramp up European offsite construction exports over the next 15 years to 9%, comparable to the Netherlands' market share. Offsite manufacturing is valued at 7% of the UK construction market, with this likely to increase as practices improve[66]. The UK has existing strengths in BIM; application of BIM to the offsite construction market offers a viable path for the UK development of competitiveness in this sector[67]. However, the UK's RCA of 0.19 in this sector suggests offsite construction is not a strength of the UK at present. The UK currently captures a limited export share of 1.7% of the EU market and 1.4% of the rest of the world.

Expanding the UK's market share in offsite construction will depend on developing a domestic supply chain capable of competing with strong overseas competition. The Netherlands is the largest exporter of offsite construction, capturing 9% of the EU market. There is additional competition from the Czech Republic, Estonia, Germany, and Slovenia, who together are responsible

[63] Business Wire: https://www.businesswire.com/news/home/20140123005885/en/Research-Markets-Global-Prefabricated-Buildings-Market
[64] Construction Intelligence Centre (2018): https://www.reuters.com/brandfeatures/venture-capital/article?id=48295
[65] KPMG: https://assets.kpmg/content/dam/kpmg/pdf/2016/04/SmartConstructionReport.pdf.
[66] Ibid.
[67] ECMAG: https://www.ecmag.com/section/your-business/prefabricated-construction-growing-popularity

for 30% of the EU market. In addition, the offsite construction market is globally competitive due to the typically lighter weight of materials; China captures 10% of the EU market. Finally, expert consultation has suggested the UK should look to deploy domestically in order to develop a supply chain capable of exporting.[68]. This involves overcoming some barriers, such as unsuitable land rights, with fewer detached plots of land available compared with the Netherlands. The UK also has a lower standard of quality than competitors such as Germany, making it difficult to export to these markets. A broader discussion of barriers to innovation within building fabric is discussed in the following section.

[68] Workshop evidence.

Market barriers to innovation within building fabric

Introduction

Box 12. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

HMG support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 9, along with an assessment of whether HMG needs to intervene.

Market barriers for building fabric

The government plays a key role in overcoming market barriers to improvements in buildings energy efficiency. The market generally underinvests in energy efficiency in buildings owing to a set of underlying market barriers, such as insufficient (or insufficiently certain) carbon pricing into energy costs, principal-agent problems (associated with landlord-tenant relationship), imperfect information about the costs-benefits, and high transaction costs (e.g. in identifying opportunities, securing upfront capital)..

Innovation in building fabric for residential, commercial, and public sector properties that leads to increased energy efficiency is essential to reducing GHG emissions in the UK. Government support for innovation in buildings energy efficiency is needed in part due to this wide array of underlying market barriers, and the difficulty in correcting for these fully through pure market correcting measures. In addition, as with innovation more broadly, government intervention is necessary to overcome basic problems that innovators have in recovering the full benefits of their investments in innovation owing to “spill-over” effects whereby others can often copy their advances. HMG supports innovation in the sector through the “Industrial Strategy” Construction Sector Deal and its £170 million Transforming Construction challenge programme. Focus areas are building faster at lower cost, improving building performance, and new approaches to procurement[69].

Table 9 lists the main market barriers affecting innovation in building fabric, along with an assessment of whether HMG needs to intervene. For each identified market barrier, an assessment of the need for government intervention is provided. The assessment categories are low, moderate, severe, and critical.

- **Low** implies that without HMG intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without HMG intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
- **Severe** implies that without HMG intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for the UK market.
- **Critical** implies that without HMG intervention, innovation, investment, and deployment will not occur in the UK.

Table 9. **Market barriers preventing or slowing innovation in building fabric**

Market barrier	Relevant for	Need for HMG support
Building standards are designed for minimum compliance[70]. This leads to a focus on meeting the minimal criteria at lowest cost. While they can help to accelerate deployment of existing innovations, they are less effective incentivising new innovations and upskilling that push performance beyond the standards, especially beyond currently best available technologies.	All components	Critical

[69] Innovate UK (2018) Transforming construction https://innovateuk.blog.gov.uk/2018/07/06/transforming-construction/ ; UKRI (n.d.) Transforming construction https://www.ukri.org/innovation/industrial-strategy-challenge-fund/transforming-construction/ ; HMG (2018) Construction Sector Deal https://www.gov.uk/government/publications/construction-sector-deal ; Infrastructure and Projects Authority (2017) Transforming Infrastructure Performance https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664920/transforming_infrastructure_performance_web.pdf ;
See overview of UK policy at IEA (n.d.) Policies and Measures database: Buildings https://www.iea.org/topics/energyefficiency/policies/buildings/

[70] McLeod, R. S., Hopfe, C. J. and Rezgui, Y. (2012) An investigation into recent proposals for a revised definition of zero carbon homes in the UK, Energy Policy, 46, pp. 25–35.

Refurbishing domestic buildings incurs a high 'hassle cost'. Such costs often relate to underlying behavioural norms and building-specific idiosyncrasies. For example, retrofits are often triggered by external factors, such as remodelling the bathroom, and are difficult for industry to predict. Therefore it is important to understand how to influence homeowners behaviours and decisions in order to stimulate demand and make them more likely to carry out retrofits.	Pre-construction and design; Build process	Critical
Lack of skills of modern methods of construction in the industry, which are needed to implement novel technologies. Training in new innovations is an underlying barrier across industries, because the trained employees can take their skills elsewhere making it hard to capture the full benefits of training.[71]. Industry reported that this is made considerably worse in the construction sector due to high turnover, limited requirements to demonstrate experience and accreditation, lack of on-going training, and insufficient formal skills dissemination across the sector. Recruiting and retaining skilled staff is a challenge, in part due to the construction industry not providing attractive career options for young talent.	Build process	Severe
High upfront costs for improved building energy efficiency. Despite the potential energy cost benefits, high capital costs can be a significant barrier, and difficulties accessing (or being willing to access) finance can be hard to. For non-domestic buildings, this is compounded by the fact that energy efficiency is normally not a material business concern relative to other investment decisions.	Materials and components	Severe
Limited understanding about the benefits of improved building energy efficiency lead to insufficient incentives for interventions. There remains a lack of consumer awareness about energy-saving materials and technologies, and the benefits they provide. This includes lack of awareness of cost savings, as well as a narrative for energy efficiency that focusses primarily on minimising costs alone, rather than a fuller set of benefits related to saving costs alongside maximising health, improving comfort, and other benefits.	Pre-construction and design, Building operation	Moderate

Source: *Vivid Economics analysis and stakeholder input*

[71] HM Treasury (2015) National Infrastructure Plan for Skills https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/464354/NIP_for_skills_final_web.pdf

Box 13. **Industry workshop feedback**

Industry experts raised several areas that require HMG support:

- The ‘hassle cost’, or disruption caused by retrofits, is enhanced by the negative experiences of previous installations. Consumers remember retrofits that took longer than expected or were more disruptive than anticipated. To improve the experience of households and therefore encourage them to undertake retrofits, a higher standard must be achieved. This requires strengthening local skills to identify the right time for retrofits, to advise households on the most appropriate and cost-effective interventions and, crucially, to implement them to a high standard and on time.

- HMG recognises the skills gap as a barrier to innovation. The new PAS2035 and revised PAS2030, amongst other purposes, aim to raise standards in the delivery of retrofits by introducing additional skills requirements. For example, installers carrying out work as part of government schemes are required to be registered with a licenced industry body, designs have to be carried out by an architectural technologist, architect or chartered surveyor (depending on the project), and all retrofits must be led by a trained project manager.[72].

- Industry raised that public savings from retrofits have been demonstrated multiple times, but this has not led to a stronger narrative supporting retrofits as a financial investment. Existing evidence tends to be scattered and therefore difficult to generalise. Case studies demonstrate cost savings, but they are often situation-specific. A comprehensive assessment, considering existing evidence, could demonstrate the financial case more clearly.

[72] BSI (n.d.) PAS 2035 PAS 2035:2018 Specification for the energy retrofit of domestic buildings https://standardsdevelopment.bsigroup.com/projects/2017-04146 ; Passive House (2018) New UK retrofit standard will mandate ventilation & post occupancy checks https://passivehouseplus.ie/news/projects/new-uk-retrofit-standard-will-mandate-ventilation-post-occupancy-checks

International opportunities for collaboration

There are potential international opportunities to collaboratively innovate. Systematic gathering of international case studies and a synthesis of best practice and mistakes could accelerate innovation and deployment. Multilateral opportunities for learning and knowledge sharing exist, including the IEA's Energy in Buildings and Communities Programme.[73].

[73] See International Energy Agency's Energy in Buildings and Communities Programme website at http://www.iea-ebc.org/

Appendix 1: Organisations at expert workshop

- Cardiff University
- Cavity Insulation Guarantee Agency
- Centre for Alternative Technology
- Chartered Institute of Building Services Engineers
- De Montfort University - Institute of Energy and Sustainable Development
- Department for Business, Energy and Industrial Strategy
- Energiesprong & Melius Homes
- Kingspan
- National House Building Council
- Prewett Bizley Architects
- Solid Wall Insulation Guarantee Agency
- SPECIFIC Information and Knowledge Centre
- ThermaCool
- University College London
- Usable Buildings Trust
- Welsh Government
- Willmott Dixon

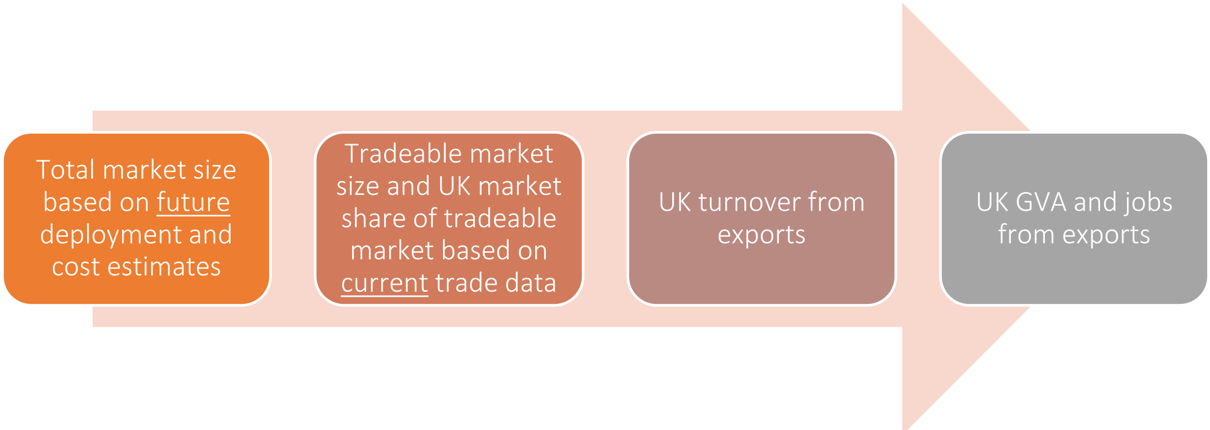
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 10 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

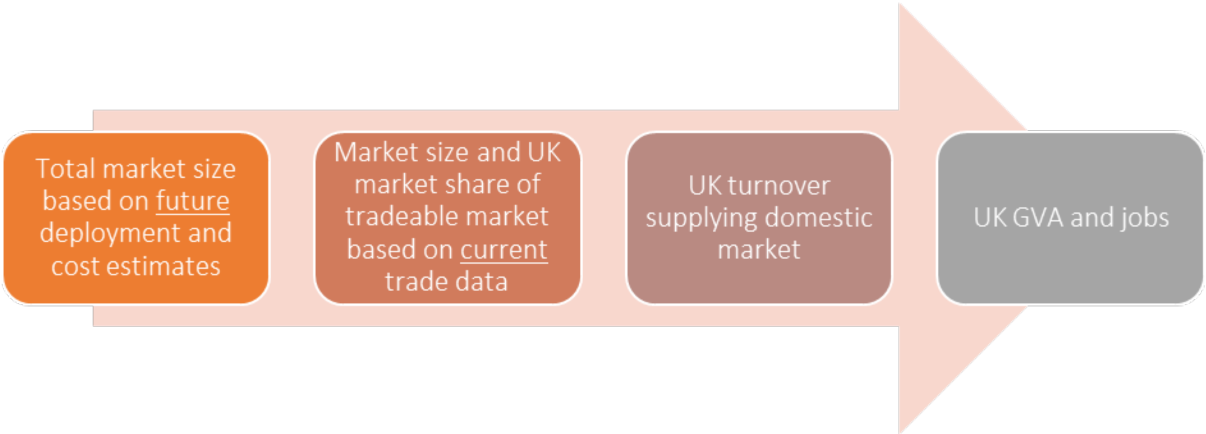
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[74] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
    - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
    - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[74] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 11 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
  - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
  - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
  - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of

jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
    - An estimate of the total turnover and GVA associated with the service
    - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[75] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[75] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Additional notes

Market turnover: The annual market size is calculated by multiplying the heat savings associated with annual deployment of building fabrics in ESME modelling with energy prices. Annual heat savings are calculated based on the number of energy-efficient dwellings that are built and retrofitted each year. The annual reduction in energy due to building fabric deployment is multiplied by the net present value (NPV) of energy savings to obtain a total value of energy savings. The market size estimate assumes that consumers, possibly supported by government schemes, invest the potential value of energy savings from building fabric improvements into them.[76]. It is well established that consumers are not willing to pay the full value of efficiency improvements given hassle costs and other behavioural barriers; indeed, significant government support is likely to be required[77],[78]. This is a relatively greater assumption than used in the export analysis, where only 25% of the NPV of energy savings was used to determine market size. This is because the UK is more likely to require deep retrofit and construction action than other countries given the high contribution of buildings to UK total emissions.

[76] This follows the assumption made in the corresponding technology innovation needs assessment (TINA). The assumption is broadly consistent with a payback period of 2-3 years for basic renovations. This has been estimated given typical payback periods of 10-11 years in similar Green Deal renovations: DECC, 2011, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/43019/3506-green-deal-consumer-research-prs.pdf

[77] Previous UK schemes such as the Green Deal and the Energy Company Obligation have indicated willingness to pay for future energy savings is very low: National Audit Office, 2016, https://www.nao.org.uk/wp-content/uploads/2016/04/Green-Deal-and-Energy-Company-Obligation.pdf.

[78] However, given the cost-effectiveness of energy efficiency savings, it is expected that government support for such measures will increase over the period to meet climate targets: European Commission, https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/financing-renovations.

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment:

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 10. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

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