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Assessment of the structure, conduct and performance of Scotland's onshore wind, offshore wind and hydrogen sectors

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1 Executive summary

1.1 Background and aims

The Scottish and global net zero transition presents substantial economic opportunities for Scotland. For the Scottish Government to successfully design net zero and economic policy, it must clearly assess and understand relative economic strengths, weaknesses, opportunities, and threats of Scotland's net zero and climate adaptation (NZ&CA) economy. However, the existing data have many gaps, and policymakers often lack the necessary frameworks to make analytically informed decisions on the priorities for economic intervention and just transition policy design.

This report provides baseline data and assessment of the economic potential of the onshore wind, offshore wind, and hydrogen sectors using a novel methodology. We designed the methodology used in our research to be applicable to other sectors in the NZ&CA economy. It breaks down and measures the onshore wind, offshore wind, and hydrogen sectors into distinct economic value chain activities, covering the following activities:

1. Project development
2. Manufacturing
3. Installation
4. Operation and maintenance
5. Specialised consultancy services (present throughout the value chain)
6. End-of-life

More detail on the approach and data sources is provided at the end of this executive summary.

1.2 Sector specific findings

We have undertaken an assessment of each sector independently. These assessments are presented in this section. Table 1 provides headline findings to allow comparison between sectors at a high level, it shows that the onshore and offshore wind sectors in Scotland are currently much more developed than the hydrogen sector.

Table 1: Estimates for turnover and employment by sector

	Onshore wind	Offshore wind	Hydrogen
Turnover (2021)	£2.0bn	£2.6bn	£20mn
Employment (2021)	3,300 FTE	3,100 FTE	100 FTE
Note: These numbers can be compared, for context, with those of the construction sector in Scotland, which has an estimated turnover of £21.1bn and employs approximately 150,400 people in 2021 (Scottish Annual Business Statistics, 2023).			

Our research identifies that the onshore and offshore wind sectors share many strengths, weaknesses, opportunities and threats since the activities and many of the conditions of the sectors are similar. For example, the vast majority of turnover in both sectors comes from installation, operation and maintenance activities (91% for onshore wind and 77% for offshore wind). Differences in these value chain stages between the sectors arise largely due to differences in maturity of the two sectors in Scotland – the higher levels of installed onshore wind capacity results in increased turnover from operation and maintenance (68% of total onshore wind turnover), while for the rapidly growing offshore wind sector, installation represents the highest share of turnover (39% of total offshore wind turnover). Manufacturing is another point of contrast between the sectors; potentially related to the wider array of components available for manufacture, offshore wind provides a much larger share of manufacturing turnover (11% compared to just 2% for onshore wind). For a full breakdown of value chain stages, see Figure 1.

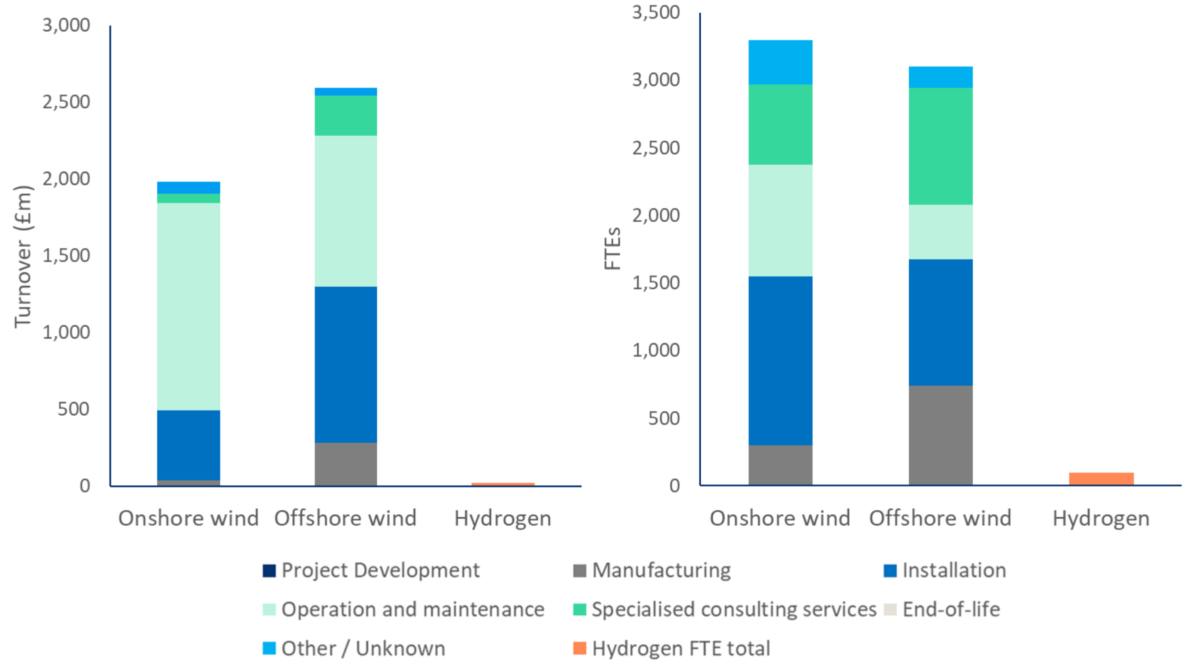

Figure 1: Estimates for turnover (left) and full-time equivalent (FTE) employees (right) per sector and value chain stage for onshore wind, offshore wind, and hydrogen in Scotland for 2021. Project development and end-of-life value chain stages lack classification within LCREE but are likely to be captured within specialised consulting services, a hypothesis validated with stakeholders. The headline message of the graph is that operation and maintenance from the largest part of the turnover of onshore wind; project development for offshore wind, and data is negligible for hydrogen. For FTE, installation is the largest number for onshore wind, and for offshore wind, specialist consulting services and installation are most significant. For hydrogen, numbers are again much smaller, so data is shown in aggregate of FTE total. Source – Ramboll calculation based on LCREE data (ONS, 2023a)

The outlook for the hydrogen sector is relatively uncertain due its immature and unproven nature, and current debate regarding possible future uses. The outlook for the onshore and offshore wind sectors is more certain since they are already established and commercially viable global markets. The onshore and offshore wind sectors have good prospects for strong growth in Scotland, with the biggest economic growth expected in offshore wind, driven by strong domestic and international demand and the need to increase installed capacity.

1.2.1. Onshore wind

Scotland's onshore wind sector is mature and established, both domestically and from an international perspective. Strong domestic growth opportunities are expected in the coming decade thanks both to government targets and market demand for installed capacity, with export opportunities mainly in the nascent end-of-life services.

Table 2 shows both the direct and indirect and induced value of the sector to the economy in terms of turnover, employment and gross value added (GVA).

Table 2: Best available estimates for turnover, employment, GVA and GVA/output in Scotland's onshore wind sector

	Direct	Direct, indirect and induced
Turnover (2021)	£2.0bn[1]	£3.7bn[2]
Turnover (2016-21 range)	£1.1-2.0bn[1]	NA
Employment (2021)	3,300 FTE[1]	13,000 FTE[2]
Employment (2016-21 range)	2,200–3,600 FTE[1]	NA
Gross Value Added (GVA) (2020)	£515m[3]	£1.08bn[3]
GVA / output (turnover) ratio (2020)	0.38[3]	0.43[3]

Note: The results on turnover, FTE and GVA per output are approximations and should therefore be interpreted as the best available estimates rather than precise numbers. Gross value added per output measures the relation between gross value added and the output (similar to turnover) generated by the sector. Ranges provided illustrate the lowest and highest estimated turnover and employment figures across the period 2016-2021.
Sources: [1]LCREE figures for Scotland (ONS, 2023a); [2]Ramboll estimation based on Fraser of Allander's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander, 2022) and LCREE figures for Scotland (ONS, 2023a); [3]2020 figures from Fraser of Allander, 2022.

Onshore wind in Scotland is an established, successful domestic industry backed by a strong policy environment. Scotland's onshore wind sector saw substantial early investment. This continued to the point where the industry was temporarily excluded from the UK Government's Contracts for Difference (CFD) scheme in 2015, which guarantees energy providers a fixed, pre-agreed price for low-carbon electricity. With this exclusion now ended and ambitious installation goals set by Scottish Government, onshore wind deployment is set to grow rapidly in Scotland. This will drive opportunities across the value chain.

Meeting this demand presents significant economic opportunities. **However, to withstand potential bottlenecks and accommodate the sector's anticipated growth, Scotland will need to overcome its supply chain limitations.** Despite relatively early adoption of onshore wind technology, Scotland has not developed a large-scale domestic turbine manufacturer. While some domestic manufacturing of turbine components such as towers, blades and bearings does take place, the lack of scale leaves Scotland largely reliant on imports. There are opportunities for Scotland to increase its manufacturing content through the production and supply of turbine components to large overseas manufacturers, who could then supply the full turbine to Scottish projects (Vivid Economics, 2019). The challenge, however, is breaking into the major turbine manufacturers' well-established supply chains, especially as potential supply chain bottlenecks are projected for turbines and components across Europe and the US (GWEC, 2023).

Overcoming these supply chain challenges to meet domestic demand will become increasingly important in the face of emerging challenges, such as:

- intensified competition for skilled employees with other NZ&CA sectors, each aiming to meet their own installation targets
- increasingly larger and more powerful onshore wind turbines, bringing associated challenges regarding grid connection and capacity, particularly in more remote sites.

Despite the sector's strength in Scotland, relatively few parts of the value chain are easily exportable. In-country knowledge is valuable to onshore wind installation services, as is a local presence for goods and equipment. Similarly, quick access to wind farms is key to minimising downtime and productivity losses. As a result, installation, operation and maintenance are highly localised activities, protecting Scottish companies from international competition on domestic projects but limiting Scottish business export opportunities.

Scotland's main, but limited, export opportunities in onshore wind will therefore likely be either in:

- exporting specialised consulting services in niche areas
- exporting goods and services in the end-of-life activities where Scotland's first-mover advantage is significant.

Scotland's main export opportunities in onshore wind are service based. Some specialised engineering consultancy services are currently done internationally and represent the bulk of current Scottish onshore wind exports. These services focus on project development activities and include wind farm design, wind resource modelling, construction management, and financial due diligence (BVG stakeholder interview).

Moving forward, circularity presents a key export opportunity. Due to the established nature of its onshore wind sector, Scotland's fleet will reach its end-of-life earlier than most nations (Zero Waste Scotland, 2023). If it can learn lessons surrounding repowering, recycling and decommissioning, there is an opportunity for Scotland to become an international market leader in circularity and export this knowledge through consultancy services. An example is the practical considerations of installing larger turbines in place of smaller ones, particularly in more remote areas.

1.2.2. Offshore wind

Rapid expansion in Scotland's installed offshore wind capacity and potential for increased share of Scottish content in the value chain provide opportunities for strong domestic economic growth. Export opportunities are larger in offshore wind than in onshore, and the biggest opportunities are likely in high-value services building on Scotland's comparative advantages such as high-skilled labour force, first-mover advantage in floating offshore wind and established onshore wind and oil and gas sectors.

Table 3 shows the direct, indirect and induced value of the sector to the economy in terms of turnover, employment and GVA.

Table 3: Estimates for turnover, employment, GVA and GVA/output in Scotland's offshore wind sector

	Direct	Direct, indirect, and induced
Turnover (2021)	£2.6bn[1]	£5.2bn[2]
Turnover (2016-21 range)	£0.3-2.6bn[1]	NA
Employment (2021)	3,100 FTE[1]	9,500 FTE[2]
Employment (2016-21 range)	1,200-3,100 FTE[1]	NA
GVA (2020)	£295m[3]	£590m[3]
Gross value added / output (turnover) ratio (2020)	0.48[3]	0.51[3]

Note: The results on turnover, FTE and gross value added (GVA) per output are approximations and should therefore be interpreted as the best available estimates rather than precise numbers. Gross value added per output measures the relation between gross value added and the output (similar to turnover) generated by the sector. Ranges provided illustrate the lowest and highest estimated turnover and employment figures across the period 2016-2021.
Sources: [1]LCREE figures for Scotland (ONS, 2023a); [2]Ramboll estimation based on Fraser of Allander's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander, 2022) and LCREE figures for Scotland (ONS, 2023a); [3]2020 figures from Fraser of Allander, 2022.

Scotland's offshore wind sector is well positioned to capitalise on demand from both domestic developments and export opportunities. There are several similarities with the onshore wind sector, but given the sector's relative immaturity, particularly in floating wind, there is potential for Scotland to realise a first mover advantage. Utilising existing and future adjacencies with other sectors (oil and gas, onshore wind, hydrogen) will be a key enabler. However, the lack of investment in port infrastructure will act as a barrier to realising the potential scale of floating infrastructure demand.

There is significant domestic and international demand for Scottish offshore wind development and expertise, partly driven by a political goal to further expand installed offshore wind capacity, with goals to increase capacity from 2.6GW in 2023 to 8-11GW in 2030 for Scotland alone. If this fourfold increase in installed capacity materialises, it will likely drive continued rapid expansion in the whole value chain in the coming decade.

In addition, the recent ScotWind leasing round revealed market ambition of 28GW of potential generation capacity compared to the approximately 10GW expected by Scottish Government (The Crown Estate Scotland, 2022). This indicates confidence and high investor appetite for Scottish offshore wind developments. It does not, however, automatically map on to direct opportunities for Scotland by default.

Skills, costs and profitability pose challenges in meeting this demand. Like onshore wind, there will be intense competition for skills from other industries and countries who have similarly ambitious deployment goals, and the supply chain will need to scale-up dramatically.

This poses a challenge to companies, which must contend with potential supply chain bottlenecks for key components (Hodgson, 2023; GWEC, 2023). There are also profit margin pressures driven in part by the highly competitive bidding within the UK's CFD environment. The UK Government, seeking to maintain the strong appetite to develop domestic offshore wind projects, recognises these pressures and is currently exploring introducing non-price factors (eg sustainability and capacity building) into future CFD allocation rounds to top up high-scoring bids, but these are unlikely to be introduced before 2025 (DESNZ, 2023c).

Stakeholders noted that challenges in meeting this demand also come from planning timescales, project development capacity and the ability of existing infrastructure to support delivering at this scale.

The level of performance and trade opportunity varies across the value chain. Compared to onshore wind projects, offshore wind projects provide a wider range of components and complexity, and typically have shared challenges across geographies. As a result, value chains tend to be less localised and provide more opportunities for export. RenewableUK (2019) highlights the broad range of exports, such as installation and maintenance of turbines and blades, manufacture of key components, and services like software, surveys and financial and legal that are provided by UK companies in the sector[1]. Scotland can provide such a range of services in part due to its existing reputable skills and knowledge in the offshore and subsea sectors, with opportunities to export this knowledge whether it be in the installation or specialised consulting activities of the value chain. There are, however, activities where Scotland is reliant on imports. This is particularly the case in manufacturing where, like onshore wind, offshore wind is constrained by the lack of a large UK-based turbine manufacturer.

Investment should prioritise easing this reliance by increasing the share of UK content in specific activities. For instance, ORE Catapult (2023) identifies turbine manufacturing and balance of plant as areas where UK content can be at least doubled by 2030. This will support increased resilience in the supply chain and facilitate the scale of planned development.

Key opportunities exist where Scotland can build on existing skills, infrastructure, and competitive advantage. There is Scottish first-mover advantage in offshore wind, particularly floating, and a higher degree of transferability of skills and infrastructure across geographies (eg consulting services and long-term end-of-life). Drawing upon adjacent

[1] including: installing, maintaining, and fabricating turbines and blades; supplying and laying power cables underwater and providing remotely operated vehicles to inspect them; fabricating steelwork for platforms and stairways; producing and fitting components such as lighting systems for turbines; supplying helicopters and crew transfer vessels; designing gearboxes; producing software to maximise power generation; conducting geological surveys; monitoring wildlife; and providing financial and legal services.

sectors there are potential opportunities in terms of skills, knowledge, infrastructure and equipment, including in:

- **Onshore wind:** Collaboration for instance in the development of installation expertise to address future skills gaps. Stakeholders noted that as onshore wind installation is anticipated to peak significantly earlier than offshore wind, there is opportunity to train technicians with onshore turbines before transitioning to offshore wind.
- **Oil and gas**: Scotland's legacy oil and gas sector provides numerous transferable benefits to its offshore wind sector, including subsea and marine services (engineering, installation, maintenance, analytics), infrastructure (floating structures) and port facilities, international experience, and the transitioning of workforce and supply chain. However, scepticism remains regarding short-term workforce mobility especially due to the current high oil price, salary disparities between oil and gas and offshore wind, and the fact that economic activity in the oil and gas sector will remain strong to 2030.

1.2.3. Hydrogen

Scotland's hydrogen sector is not yet operational at scale, although there is significant interest among a wide range of companies currently operating in other industries. We have followed LCREE's (ONS, 2023a) 'alternative fuels' definition of hydrogen and defined the sector as the goods and services related to the production of energy from hydrogen as well as technologies using hydrogen for distribution and transmission[2]. All forecast scenarios see domestic production capacity of clean hydrogen growing significantly in the next decade(s) (Climate Change Committee, 2020; Scottish Government, 2020c; Thirkill et al., 2022). However, the extent of production growth and the extent to which economic value will be captured domestically will depend on domestic policy and whether local demand increases.

Table 4 shows both the direct and indirect and induced value of the sector to the economy in terms of turnover, employment and GVA. It shows there are significant data gaps in available information on the current value of this sector in Scotland economy.

[2] The LCREE alternative fuels sector definition also includes 'The production, distribution, storage, and commodity trade of 'alternative fuels for low carbon and renewable energy use'. This includes 'blue hydrogen' from natural gas with carbon capture and storage, and 'green hydrogen' electrolytically made from renewable energy'. It also includes other hydrogen-based fuels such as ammonia. It excludes existing high carbon 'grey hydrogen' production from unabated natural gas. While technologies producing, distributing, and transmitting alternative fuels are included in the LCREE definition, technologies developed for the consumption of alternative fuels are excluded.

Table 4: Best available estimates for turnover, employment, GVA and GVA/output in Scotland's hydrogen sector.

	Direct	Direct, indirect, and induced
Turnover (2021)	£20mn[1]	NA
Turnover (2016-21 range)	NA	NA
Employment (2021)	<100 FTE[1]	NA
Employment (2016-21 range)	NA	NA
Gross value added (GVA) (2020)	NA	NA
Gross value added/output (turnover) ratio (2020)	NA	NA

Note: The results on turnover and FTE are approximations and should therefore be interpreted as the best available estimates rather than precise numbers. Data for hydrogen are scarce because the sector is not yet operational at scale. A table like the tables for onshore and offshore wind is included here for completeness.
Source: [1]LCREE figures for Scotland (ONS, 2023a).

The Scottish clean hydrogen sector is not yet operational at scale. As shown in Table 4, the best available data estimates the sector's size at £20mn turnover and less than 100 FTE in 2021. Forecasts however expect the sector to grow and a much larger scope of companies can be identified with the potential to diversify into the sector. The magnitude of growth should be considered uncertain and dependent on government policies.

The potential supply chain of the hydrogen sector will contain a wide range of goods, services and products. The more modular, component-based projects than in the wind sector are likely to create more opportunities for international trade in the supply chain. This exposes more of the value chain to imports, but also creates more opportunities for Scotland to export in niche markets, such as specialised manufacturing within the oil and gas industry that can diversify to hydrogen and establish a competitive advantage.

Multiple weaknesses and threats explain the current lack of performance – particularly lack of domestic demand, weak policy incentives and high electricity costs. A key threat to Scotland's ability to develop comparative advantage in the hydrogen sector is that policy is now more robustly developed in other contexts, particularly the US with the Inflation Reduction Act providing significant tax breaks (Rep. Yarmuth, 2022; Whitehouse.gov, 2022). Similarly in the European Union there is a complex, but well-developed ecosystem of regulations, subsidies and programmes available to make hydrogen projects commercially competitive, in support of the EU target of 10 million tonnes of EU production by 2030 (European Commission, 2022; European Commission, 2023)[3].

[3] See also the European Commission webpages on hydrogen (European Commission, 2023)

These policy support packages are driving commercial scale project development, providing the US and EU with first-mover advantage in the deployment of commercial-scale hydrogen production projects and associated infrastructure.

While this erodes any existing advantages that Scotland has from its long-standing programme of hydrogen project piloting and early-stage research and development, it may present opportunities for Scottish component producers and others involved in the sector to export knowledge or goods overseas.

There is potential for government and industry to address these weaknesses and threats, for example, where feasible, through stimulating domestic demand through policy, building pipelines and taking advantage of offshore wind build out.

Key strengths are the availability of high-quality labour and existing expertise in the oil and gas sector. Niche manufacturers in the oil and gas sector (eg of compressors, valves, pipelines, storage tanks) would be able to diversify relatively easily into the hydrogen sector. Many specialist services from the oil and gas and chemical industries are also applicable to the hydrogen sector and are areas of strength in Scotland.

There are expected to be large demands for hydrogen fuels in north-western Europe (IEA, 2021). Some countries, particularly Germany, have started seeking international contracts for state-subsidised purchase of hydrogen fuels. Scottish hydrogen producers could compete for these contracts, although Scottish producers are unlikely to be the most cost competitive. Scottish hydrogen costs are likely to be impacted by the inherently high costs of transportation for hydrogen fuels, the current lack of pipeline infrastructure in Scotland for hydrogen transportation and Scotland's relatively high electricity costs.

1.3 Common themes across all three sectors

Our research has highlighted several insights that are relevant for the wider Scottish NZ&CA economy.

The biggest export opportunities for Scotland are in cross-sector activities, not in any of the NZ&CA sectors in and of themselves. Scotland generally has a competitive advantage in specialised consulting and technical services, and in offshore engineering and floating structures. Scotland could also develop a first-mover advantage in repowering, decommissioning, and recycling of wind turbines and blades (for both onshore and offshore wind). These services are more easily exportable than activities that largely rely on local availability and on-site delivery, such as installation (particularly onshore wind installation), and operation and maintenance activities.

Additionally, within hydrogen, there is a future possibility of exporting specialised services that share synergies with oil and gas, like project development, and consultancy services such as safety consulting. There may also be opportunities to export hydrogen as a commodity, however fierce competition is expected.

The most important factor for economic development is domestic demand for installed capacity (wind) and production capacity (hydrogen). It is crucial to recognise that successful exports rely on substantial domestic demand capable of underpinning the establishment of these industries. Our research shows that strong UK demand is likely to be necessary for expansion in the sectors when large and rapid investments and scale up is needed. It is evident that the policy environment forms a critical aspect of how this local demand market develops, for instance as is the case between wind and hydrogen currently. Strong demand can help neutralise threats such as technical or commercial uncertainties, eg in the immature hydrogen sector. However, there is a risk of bottlenecks in the parts of value chains with rapid expansion, unfavourable macroeconomic conditions that could discourage investments, or uncertainties in the international policy landscape following Brexit.

Many companies operate across several NZ&CA sectors. Therefore, research into and policy development for specific NZ&CA sectors needs a cross-sectoral focus to understand the interdependencies and shared opportunities and threats between value chains to provide the full picture of the sector(s). For example, as highlighted in stakeholder discussions, a construction company may conduct site preparation and the installation for onshore wind farms, in addition to delivering port infrastructure for the offshore wind value chain. An engineering consultancy may carry out feasibility studies for a hydrogen refuelling hub and support offshore wind developers with site design.

Some activities are naturally more protected from international competition, such as project development, and operation and maintenance. These often require local knowledge and on-site delivery of services, which means that for domestic projects more of the economic value in these activities is captured domestically. For example, an estimated 74% of project development expenditure on eight Scottish onshore wind farms was found to be captured by Scottish companies (BVG, 2017). Consequently, in our research, stakeholders noted that opportunities for Scottish companies seeking to export Scottish goods and services in these areas of the value chain to other countries can be limited.

Our research also found that parts of the value chain, such as specialised consulting services, that do not require local knowledge or manufacturing of components that can be transported are more open for international competition and trade. Consequently, the amount of the economic value generated by Scottish companies is far more varied and dependent on the good or service provided. Captured Scottish content is also influenced by licensing, procurement and contracting arrangements.

The onshore wind value chain is typically the most domestic with large components being installed on-site. About half of the total expenditure for an onshore wind farm's supply chain (including development expenditure (DEVEX), capital expenditure (CAPEX), and operating expenditure (OPEX)) goes to Scotland and a further 15% to elsewhere in the UK (BVG, 2017). For an offshore wind farm, with more internationally tradable products and components, about half goes to the UK (ORE Catapult, 2023). The hydrogen value chain delivers the most manufactured, modular and tradable components of the three value chains, therefore being more open for international trade, and future domestic hydrogen projects will likely contain less domestic content.

The value of Scotland's highly skilled labour force was a reoccurring theme in stakeholder interviews for all three sector analyses. Specifically, Scotland's track record in the offshore oil and gas sector is seen as an important competitive advantage. Companies in the oil and gas supply chain are diversifying into the offshore wind or hydrogen sectors, making use of existing specialist expertise, reputation and experience in successfully exporting niche services in international markets. Such competitive advantages based on a skilled and experienced labour force or first-mover advantage in the offshore wind industry are strengths of the Scottish NZ&CA economy that can overcome the cost disadvantage compared to companies in low-cost countries. However, competition for skills from the oil and gas sector could be challenging if, for example, oil and gas salaries continue to be higher than in the offshore wind sector.

1.4 Options for further Scottish Government action

We provide two sets of recommendations for policy development based on this research: 1) Cross-sectoral and sector-specific recommendations that highlight areas where more information would be useful to help Scotland realise opportunities and overcome threats identified in this research, and 2) Analytical and methodological recommendations aimed to guide future analysis of Scotland's NZ&CA economy on a general or sector level.

It should be noted that due to the dynamic nature of the economy and the opportunities and threats that exist within sectors and markets, that the points made below may change over time.

1.4.1. Cross-sectoral and sector-specific recommendations

- **Consider how Scotland can take maximum advantage in the NZ&CA economy of its key human capital strength and its highly skilled labour force.** Across all the sectors analysed, the high quality of skills in the Scottish labour market was identified as a key opportunity. In general, the high quality of Scotland's tertiary education sector and high quality of STEM graduates are a strength. Specific transferrable skills were also identified in specific areas, including the oil and gas sector, in offshore engineering, in safety training and in engineering and energy consultancy. These are all strong opportunities particularly for the offshore wind and hydrogen sectors. However, the workforce is dynamic in nature with multiple interdependencies, which need to be factored in. Further analysis should investigate how these advantages can further support Scotland's sectoral NZ&CA comparative advantages, how risks such as global competition for skilled staff can be mitigated, and how this can be a valuable economic activity on its own as international workers come to Scotland to receive specialised education and training services.
- **Consider how Scotland can gain and utilise a first-mover advantage in end-of-life services for onshore (and eventually offshore) wind farms**. End-of-life services have been identified as the most promising export opportunity for the onshore wind sector. However, the end-of-life services activities currently contains limited economic activity as well as technical and commercial uncertainties that need to be understood and addressed.

- **Consider how Scotland can strengthen and utilise its first-mover advantage in floating wind.** Floating wind is a more nascent technology than fixed-base offshore wind. Scotland has pioneered commercial scale projects, with the first commercial project in 2017 and two of the largest operational floating wind projects. Within the value chain it is likely that Scotland can establish high-value expertise-based exports. Ongoing work should identify these areas and the firms involved, working with organisations like Offshore Wind Scotland and Offshore Renewable Energy Catapult. It is recognised that Enterprise Agencies are working in this area already.
- **Consider where the greatest potential (if any) is to increase domestic content in the manufacturing activities.** Scottish content in manufactured components for wind farms is currently low, largely because there is no Scottish turbine manufacturer (and hydrogen is not yet operational at scale). Turbine manufacturing is a concentrated international market with high barriers to entry, however the manufacture of other components, structures, and infrastructure, particularly for offshore wind and hydrogen, is not constrained in the same way. The evidence in this research suggests that Scotland is likely to be most successful in increasing Scottish content by manufacturing products such as subsea cables and cable protection systems, steelwork for platforms and stairways and lighting systems (RenewableUK Export Nation, 2019). However, uncertainties remain due to Scotland's high-cost environment, limited track record specifically in turbine manufacturing, and uncertainty around where Scottish supply chains could diversify to produce components competitively.
- **Consider potential measures for growing and increasing certainty in domestic demand for hydrogen fuels**. Domestic demand has been identified as the most important factor for economic development in the value chain. However, domestic demand for hydrogen fuels is currently insufficient for successful development of Scotland's hydrogen sector. Further review of how interventions might remove uncertainties and enable growth in demand is needed to support the growth of the sector.

1.4.2. Analytical and methodological recommendations

- **Use the methodology and results from this research to monitor and evaluate development in the sectors of interest.** The methodology provides a framework for assessing NZ&CA sectors. The result of this research provides a baseline from which development can be monitored and evaluated. The quantitative performance results provide comparable and objective measures to assess development within and across sectors. Given the fast-moving nature of these policy, technology and commercial environments this could be done in a high level way, possibly annually with more detailed reviews on a regular basis. This ongoing assessment of Scotland's strengths, weaknesses, opportunities, and threats could provide useful information for policymaking to ensure Scottish economic development. In the case of the hydrogen sector, the definition and supply chain map for the sector should be kept under review. As the sector develops the economic assessment can become less theoretical and more based in the sector's real-world operation.

- **Conduct a SWOT analysis of Scotland's whole NZ&CA economy** to build on and develop themes that are common for all or many NZ&CA sectors. Our findings suggest that policy may be most effective if it holistically addresses critical themes (such as port infrastructure, job and skills transferability, skills and training, R&D) and findings relevant for several sectors rather than issues in specific sectors.
- **Use findings from the SWOT analysis of Scotland's whole NZ&CA economy (forthcoming) to prioritise future research efforts.** Using the SWOT analysis will help inform which (if any) sectors have the biggest need for greater insights to support policy development.
- **Include a cross-sectoral value chain perspective in future analysis of the NZ&CA economy**. This research has shown that technology-based definitions of NZ&CA sectors (onshore wind, offshore wind, and hydrogen) only partly describe how value chains and companies operate in the real world. Most companies are not vertically integrated throughout the whole sector definition, but instead operate across sectors in their activities (e.g., specialising in project development or manufacturing). Cross-sectoral value chain perspectives can also shed light on skills gaps in certain professions needed in many sectors and may be particularly important if Scotland's biggest export opportunities are in value chain niches. Other cross-sectoral enablers and barriers to NZ&CA economy growth, such as skills, speed of planning consenting, access to external investment, and the stability and attractiveness of the business environment, should also be explored in further detail.
- **Improve the Low Carbon and Renewable Energy Economy (LCREE) survey**. This research, as many other, utilises data from the ONS LCREE survey extensively. While this is the best available single data set to quantitatively describe the onshore wind, offshore wind, and hydrogen sectors, it still carries significant limitations. Improving the survey may be costly, but the benefits could outweigh the costs since this is the most useful and used data set for this type of research. See Chapter 11.1.3 in the main report for our detailed recommendations for improving the LCREE survey.

1.5 Methodology and data

Our analysis is based on the application of a Structure-Conduct-Performance (S-C-P) methodological framework, adapted from that used in the UK Government's 'UK Business Competitiveness and the Role of Carbon Pricing' (Kansy *et al.,* 2020). The methodology also includes a step-by-step guide to aid the analysis and as such can be readily expanded to other sectors, such as solar, tidal, or pumped hydro.

We used the Office for National Statistics' Low Carbon and Renewable Energy Economy (LCREE) database (ONS, 2023a) as a starting point for the analysis. We complement and triangulate these data with additional data sources and stakeholder interviews to arrive at both quantitative and qualitative results on the structure, conduct, and current performance of each of the sectors using a variety of economic indicators. The conclusions build on a wide range of quantitative data, stakeholder interviews, and published literature.

Contents

2 Glossary / abbreviations table

AR4	(Contracts for Difference) Allocation Round Four
AR5	(Contracts for Difference) Allocation Round Five
BEIS	(Department for) Business, Energy & Industrial Strategy
BERD	Business Enterprise Research & Development
CAPEX	Capital expenditure
CCC	Climate Change Committee
CFD	Contracts for difference
DBT	Department for Business & Trade
DESNZ	Department for Energy Security & Net Zero
DEVEX	Development Expenditure
ESO	Energy Systems Operator
ETS	Emissions Trading Scheme
FAI	Fraser of Allander Institute
FTE	Full time equivalent
GDP	Gross Domestic Product
GVA	Gross value added
GWEC	Global Wind Energy Council
HERD	Higher Education Research & Development
IEA	International Energy Agency
IRA	Inflation Reduction Act
LCOE	Levelised Cost of Energy
LCREE	Low Carbon and Renewable Energy Economy
NZ&CA	Net zero and climate adaptation
O&G	Oil and gas
O&M	Operation and maintenance
ONS	Office for National Statistics
OPEX	Operational expenditure
ORE Catapult	Offshore Renewable Energy Catapult
R&D	Research and development
S-C-P	Structure-Conduct-Performance
SIC	Standard Industry Classification
STEM	Science, technology, engineering and maths
SWOT	Strengths, weaknesses, opportunities, threats

3 Introduction

3.1 Methodology and data

In previous research, we have developed a methodology to analyse the competitiveness of a specified sector of Scotland's net zero and climate adaptation (NZ&CA) economy (O'Gorman et al, forthcoming). This methodology can be used to measure the current size and make up of an economic sector of interest. It also uses stakeholder engagement to provide insight into the economic strengths, weaknesses, opportunities, and threats the sector faces.

This methodology builds on the Structure-Conduct-Performance (S-C-P) framework which is commonly used to understand the competitiveness of companies and competition across sectors (Faccarello and Kurz, 2016). For example, the UK Government has used the S-C-P framework to assess business competitiveness and carbon pricing, and references S-C-P in the Office for National Statistics (ONS) Annual Business Surveys (Kansy *et al*., 2020; ONS, 2023e). The methodology presented here builds on the S-C-P framework by including a step-by-step guide and excel tool to aid the analysis and is designed to be reliable across different sectors.

In this research, we have applied the methodology to three sectors of interest – onshore wind, offshore wind, and hydrogen, which were chosen by the Scottish Government. The methodology is designed to be used across different NZ&CA sectors, which means that some sector-specific adaptations have been necessary to carry out the research.

3.2 Conceptual framework and indicators

The S-C-P framework is widely used for analysing the competitive performance of firms and sectors in organisational strategy and competition policy, because it offers a comprehensive and dynamic understanding of a firm or sector. While mostly used at the company level, we used the framework to assess the competitiveness of a sector by modifying indicators at the relevant sector level.

The S-C-P framework components are listed below:

- **Structure** (sometimes referred to as 'conditions') describes the sector-specific external factors that determine the conditions for firms in a sector. These can be categorised into market factors, and input and cost factors.
- **Conduct** describes the actions companies take in in response to the sectoral structure.
- Competitive **performance** reflects the outcome of the conduct of companies in a sector and how the conduct addresses the structural conditions of the sector.
- The framework also includes additional external factors such as the domestic **policy environment** and the **macroeconomic environment** that influence a sector's competitiveness.

The key underlying assumption in the framework is that competitive performance, defined as "the capacity and ability of a firm or sector to gain and maintain a profitable, sustainable market share relative to its rivals" (Kansy *et al.,* 2020 pg. 3) is determined largely by the sector's conduct as a response to the sector structure. This means that the competitive performance of a sector is influenced by the actions that companies take in response to external conditions, as well as broader structural aspects of the market in which they operate.

We have analysed the following indicators to understand the structure, conduct, and performance of the sector in question. The indicators we used are set out in Table 5.

Table 5 Relevant indicators and themes based on the modified S-C-P framework.

Framework components	Indicators[4]
Performance	Turnover, gross value added (GVA), number of businesses, full time equivalent (FTE) employment, exports, imports
Conduct	Productivity, R&D expenditure, investment intensity
Structure	Market factors: domestic demand, international demand, global market share, barriers to entry/export/import
	Input and cost factors: labour supply, material supply, transport infrastructure and costs, equipment costs, cost of capital
Policy environment	Sector policy and regulation, political goals and strategies, trade policy, regulatory, administrative, and political environment
Macroeconomic environment	Economic growth forecast, interest rate, exchange rate and currency strength, cost level

3.3 Sector definition and foundational data set to measure performance

We define NZ&CA sectors as including the economic value chain stages needed for the entire lifecycle of the end product. For onshore wind, offshore wind, and hydrogen, this includes the value chain stages required to get the production of electricity or hydrogen in operation (includes project development, manufacturing, and installation), keep production capacity in operation (operation and maintenance), repower, decommission, or recycle the production capacity after its technical or commercial end of life (end-of-life services), and finally the additional services supporting the other value chain stages (specialised consulting

[4] See the Appendix sections 11.2.2, 11.3.2, and 11.4.2 for more detailed descriptions of the indicators.

services). The actual electricity generated is not included in the sector definition or the scope of the analysis.

We use the UK ONS's Low Carbon and Renewable Energy Economy (LCREE) database as the foundational data source and starting point for defining each sector (ONS, 2023a).

We judge LCREE to be the best currently available source for quantitative data on the low carbon economy as it presents a regularly updated, publicly available breakdown of each sector's performance metrics. LCREE also includes the sector's standard industrial classification (SIC) code-backed value chain stages which can be mapped against those used in this report, and it is widely referenced in the literature. However, there are limitations to the LCREE data, notably its self-reported nature, suppression of data for confidentiality reasons, lack of comprehensive country-specific value chain breakdowns, and inclusion of Hydrogen under "alternative fuels"[5]. Other data sources must therefore complement LCREE.

This project also undertook a literature review and used interviews with nine stakeholders (excluding Scottish Government sector teams) to triangulate, validate, and interpret the quantitative results provided by LCREE. Performance metrics in particular were triangulated against other data such as Fraser of Allander Institute's (FAI) "Economic Impact of Scotland's Renewable Energy Sector" (Fraser of Allander Institute, 2022), Vivid Economics' "Quantifying benefits of onshore wind to the UK" (Vivid Economics, 2019), and Scottish Renewables' "Scotland's Renewable Energy Industry Supply Chain Impact Statement" (Scottish Renewables, 2021) to provide further detail into areas such as indirect and induced turnover and FTEs, GVA figures, and supply chain breakdowns.

3.4 Assessing Strengths, Weaknesses, Opportunities, and Threats (SWOT)

A strengths, weaknesses, opportunities, and threats (SWOT) analysis is a common tool used by organisations and businesses to understand their market position, which in turn helps them make more informed strategic decisions. The aim of the SWOT analysis for this research was to contextualise and accurately portray the economic prospects of the sectors.

The SWOT analysis presented in this project provides insight into 'structure' (S) and 'conditions' (C), as well as policy and macroeconomic environment aspects of the S-C-P framework.

- **Strengths and weaknesses** refer to internal factors that companies in a sector can control, which correspond to the conduct, and to some extent, performance indicators in the methodological framework.
- **Opportunities and threats** refer to external factors outside the control of companies in a sector, which correspond to the structure, policy environment, and macroeconomic environment indicators.

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[5] For a more detailed overview of how LCREE data was used in this study, as well as its recognised limitations, see Appendix 11.1

The starting point for the SWOT analysis was the output of the quantitative performance assessment. However, most of the information needed required additional data collection from a combination of desk-based research of qualitative and quantitative data and interviews[6], for example with industry experts and sector policy leads which was key to understand the sectors in depth[7].

The SWOT analysis provides an understanding of which indicators and aspects of the sector are most important or need focussed attention from the sector or policymakers. To arrive at these conclusions, we assessed each indicator along two dimensions:

1. **Importance** of the indicator captures how integral the indicator is to the economic success of the sector. For example, domestic demand has been noted as important for all three analysed sectors because strong domestic demand will be and has been important to scale up the sectors to commercially mature levels. On the other hand, macroeconomic indicators such as interest rate are generally deemed less important as they are less sector specific.
2. **Magnitude** of the indicator measures the impact of the indicator, for example whether the evidence makes it a threat or an opportunity, and how much of a threat or opportunity the indicator is. For example, domestic demand is noted as a strong opportunity for onshore and offshore wind, because evidence points toward high domestic demand in the future. Conversely, future domestic demand for hydrogen is more uncertain and possibly too low to support rapid sector development, so domestic demand is therefore labelled a threat for hydrogen.

We benchmarked the measured indicators for the sector of interest against other sectors in Scotland or in other countries. The results of this benchmarking are presented at a whole-sector level (eg onshore wind) unless otherwise stated. In some instances we present indicators at a value chain level (eg installation).

4 Application of the methodology on three sectors

The analysis focuses on three key sectors selected by the Scottish Government: onshore wind, offshore wind, and hydrogen. One important reason is the sectors' significant expected support for low carbon energy jobs in the coming decades according to an analysis in the Draft Energy Strategy and Just Transition Plan (Scottish Government, 2023a). According to that analysis, which estimates jobs based on actual energy generation (the more energy generation the more jobs), the onshore and offshore wind sector currently supports about half of Scotland's low carbon energy jobs, while hydrogen currently generates no jobs because there is no or limited current hydrogen production, see Figure *2* (Scottish Government, 2023a). However, as our research into the three sectors' value chains

[6] See Annex 11.1.4 for a full list of interviewed sector experts.
[7] While efforts were made to engage with as many stakeholders as possible, the total number of interviews was limited by the project's scope. A longer timeframe would enable more stakeholder engagement for any future studies.

show, a large share of the activity and jobs in the sectors' value chains occur in project development, manufacturing, and installation before energy generation is in operation.

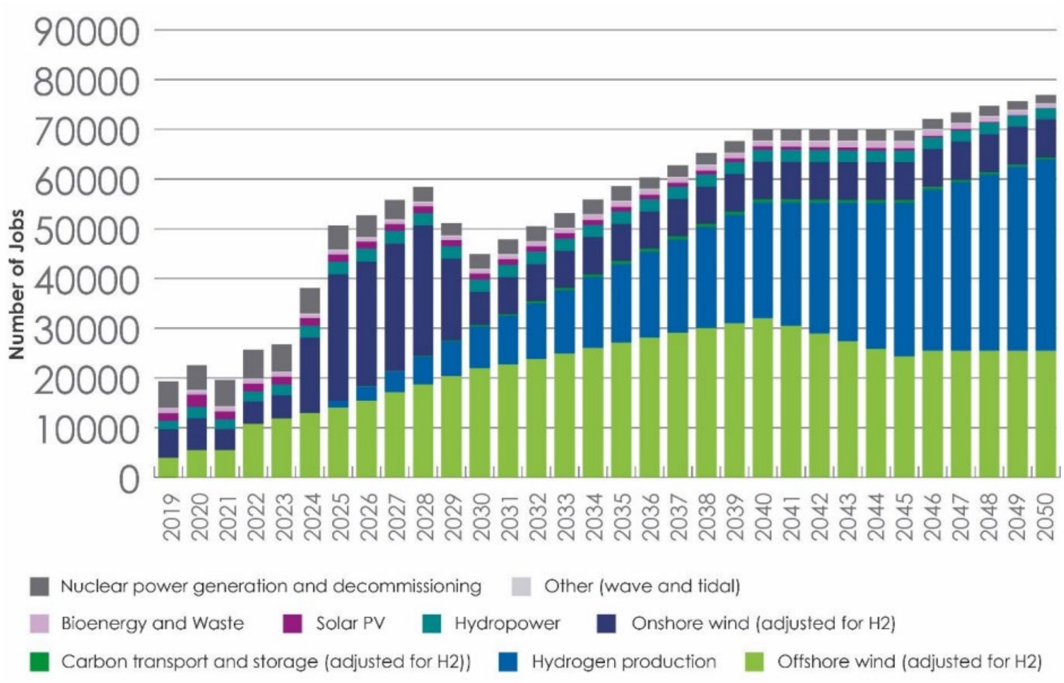

Figure 2 Low-carbon energy production sector jobs (direct + indirect). *Source: Taken from Scottish Government (2023a) Draft Energy Strategy and Just Transition Plan, figure 26, based on EY analysis using Energy Systems Catapult Balanced Options Scenario.*

This image shows jobs across all low carbon sectors, including nuclear, wave and tidal, bioenergy and waste, solar, hydropower, offshore wind, carbon transport and storage, hydrogen production and onshore wind have all grown in number from 2019 to the current date. It also shows projections from 2023 until 2050, again showing an overall increase in nearly all sectors. The only exception is offshore wind, which is projected to stabilise in terms of job numbers and decline slightly from a peak in 2040, and onshore wind which shows a peak in 2024-2030 and then a decline and stabilisation to 2050.

Having established the importance of onshore wind, offshore wind, and hydrogen in Scotland's energy landscape and job market, we delve deeper into the current status and future projections for each sector. While wind energy has a more mature market presence, hydrogen is in the early stages of development, yet holds significant promise for the future.

Electricity generation from onshore wind is far more established in Scotland than offshore wind. The first onshore wind farms became operational in the late 1990s and accelerating to the point where there is currently approximately 9GW of installed onshore wind capacity in Scotland compared to approximately 2.6GW of offshore wind, which has only started to meaningfully increase in installed capacity over the last 5 years. The government ambition is to achieve installed onshore wind capacity of 20GW by 2030 and increase offshore wind fourfold to 8-11GW by 2030 (Scottish Government, 2023a). In 2021, the combined wind sectors produced just under 20,000GWh of electricity, which equates to 41% of the total electricity generated in Scotland during the year. For an illustration of both sectors' currently installed capacities and future projections, see Figure *3*.

Hydrogen remains a nascent sector in comparison, with no large scale installed or operational production. Currently, just 0.8MW (0.0008GW) of production capacity is under construction, 20MW (0.02GW) has planning submitted, and 3.8MW (0.0038GW) is listed as "application withdrawn" in the Renewable Energy Planning Database (Department for Energy Security and Net Zero, 2023a). Given that the Scottish Government has production targets for 2030 of 5GW of hydrogen produced from low carbon or renewable energy, and 25GW by 2045, this means rapid and substantial development is needed to meet the targets (Scottish Government, 2023a). The hydrogen sector's currently installed and future projected capacities are also illustrated in Figure *3*.

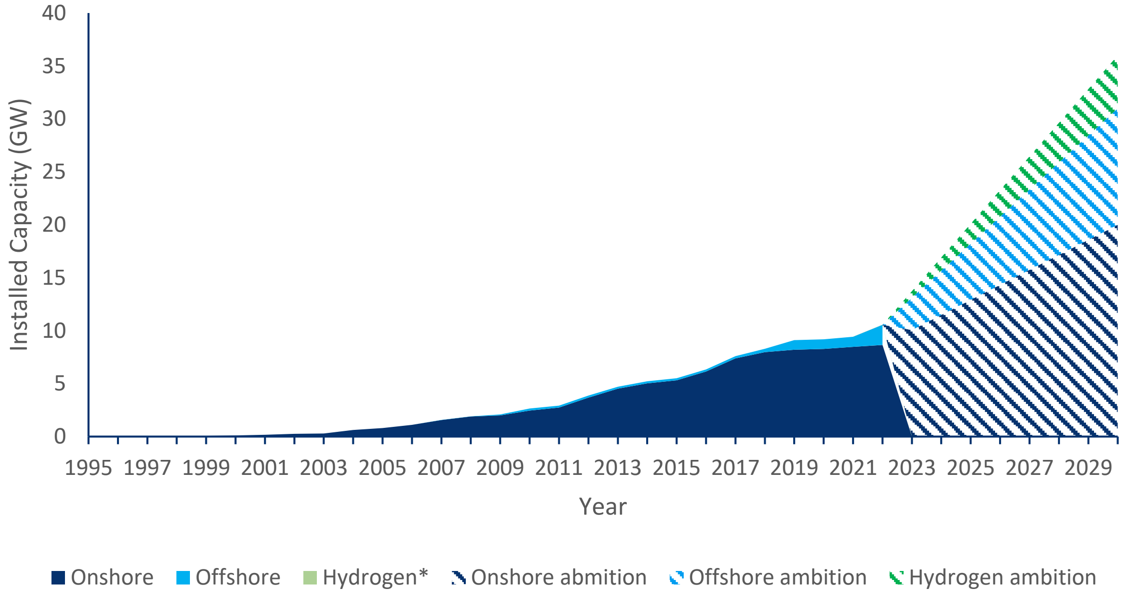

Figure 3 Historic and future ambitions installed capacity for onshore wind, offshore wind, and hydrogen in Scotland. Source: installed capacity extracted from Renewable Energy Planning Database (DESNZ, 2023a, future ambition drawn based on stated Scottish Government targets. Note: Full coloured areas represent historic installed capacity while dashed areas represent linear forecasts towards government set ambitions.

Figure 3 shows that installed capacity for onshore wind has grown consistently since 1995 to 2023 and is projected to grow to around 20 gigawatts in 2030. It shows that offshore wind started growing much later, around 2009, and as a result has a much smaller share of actual and projected capacity, rising to around 10GW of projected capacity in 2030. The figure also shows figures for hydrogen, with targeted installation in 2030 representing around five GW of capacity.

5 Comparing the offshore wind, onshore wind and hydrogen sectors in Scotland

This chapter compares our research findings for the onshore wind, offshore wind, and hydrogen sectors. It offers a convenient overview of results across these sectors. We have included this section to provide a summary and comparison of the key sectors and to introduce the following three chapters in which the sectors are analysed in greater detail. This chapter thus represents background data for the key sectors which underpin the SWOT analysis.

5.1 Comparison of current performance

Onshore and offshore wind sectors in Scotland are currently much more developed compared to the hydrogen sector. The onshore wind sector in Scotland had a total turnover estimated at almost £2.0bn and about 3,300 FTEs in 2021, and the offshore wind sector had an estimated turnover of about £2.6bn and about 3,100 FTEs. The gross value added per output ratio is slightly higher in the offshore wind (0.48) than in the onshore wind (0.38), which indicate that the offshore wind sector adds more economic value within the value chain for each £ of revenue than the onshore sector. The estimates for economic activity in the nascent hydrogen sector carries greater uncertainty but point toward turnover of about £20mn and 100 FTEs.

The figures and tables presented in this section provide an overview of key performance metrics for the selected sectors. Figure *4* illustrates the turnover and FTEs for each sector, broken down into their respective value chain stages (hydrogen is presented as an overall total, being far smaller than the wind sectors).Table *6* illustrates the best available estimates for turnover, employment, and GVA/output for each sector. Table *7* provides a breakdown of turnover and FTE values for each sector, split by value chain stage where possible.

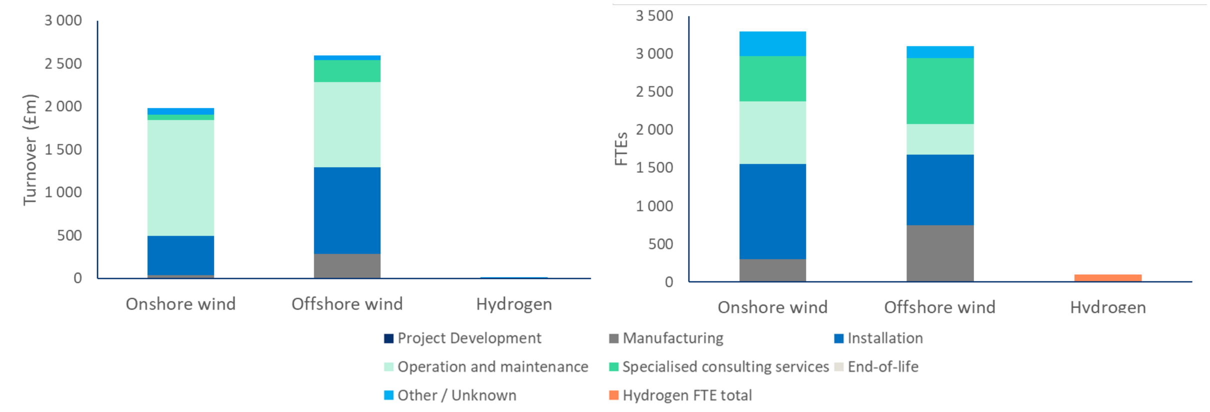

Figure 4: Estimates for turnover (left) and FTE employees (right) per sector and value chain stage for onshore wind, offshore wind, and hydrogen in Scotland for 2021. Source: Ramboll calculation based on LCREE data (ONS, 2023a).

Figure 4 shows turnover (in £m) and employment (in FTEs) for the onshore wind, offshore wind, and hydrogen sectors. Onshore wind data are split by value chain stage, illustrating that, of the almost £2bn of turnover, the most valuable are operation and maintenance, followed by installation, and of the 3,300 FTEs, the largest share is in installation (followed by operation and maintenance, then specialised consulting services). Offshore wind data are also split by value chain stage; its ~£2.6bn of turnover is largely made up of installation and operation, and its 3,100 FTEs are primarily made up of installation and specialised consulting services. Hydrogen shows almost no turnover value, and only 100 FTEs; its data is not split into value chain stage. For full methodology and data information, see Appendix 11.

Table 6: Best available estimates for turnover, employment, and GVA/output in Scotland's onshore wind, offshore wind, and hydrogen sectors. Sources: Ramboll calculations based on LCREE (ONS, 2023a) and FAI, 2022.

	Onshore wind	**Offshore wind**	**Hydrogen**
Turnover (2021)	£2.0bn[1]	£2.6bn[1]	£20mn[1]
Turnover (2016-21 range)	£1.1-2.0bn[1]	£0.3-2.6bn[1]	NA
Employment (2021)	3,300 FTE[1]	3,100 FTE[1]	<100 FTE[1]
Employment (2016-21 range)	2,200–3,600 FTE[1]	1,200-3,100 FTE[1]	NA
Gross value added / output (turnover) ratio (2020)	0.38[3]	0.48[3]	NA

Note: The results on turnover, FTE, and gross value added (GVA) per output are approximations and should therefore be interpreted as the best available estimates rather than precise numbers. Gross value added per output measures the relation between gross value added and the output (similar to turnover) generated by the sector.
Source: [1] = LCREE figures for Scotland (ONS, 2023a). [2] = Ramboll estimation based on the Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (FAI, 2022) and LCREE figures for Scotland (ONS, 2023a).[3] = 2020 figures from the Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (FAI, 2022).

Table 7: Breakdown of performance metric estimates for the onshore wind, offshore wind, and hydrogen value chains in Scotland. Source – Ramboll calculations based on LCREE (ONS, 2023a).

	Onshore wind		**Offshore wind**		**Hydrogen**	
Value chain stage	**Turnover**	**FTE**	**Turnover**	**FTE**	**Turnover**	**FTE**
Project Development	NA*	NA*	NA*	NA*	NA*	NA
Manufacturing	£40m	300	£285m	744	£2.2m	NA
Installation	£456m	1,250	£1,012m	930	£2.8m	NA
Operation & Maintenance	£1,349m	830	£986m	403	NA	NA

Specialised Consulting Services	£60m	600	£259m	868	£6.2m	NA
End-of-life	NA*	NA*	NA*	NA*	NA*	NA
Other/unknown	£79m	330	£52m	155	£8.8m	NA
Total	**£1,984m**	**3,300**	**£2,594m**	**3,100**	**£20m**	**<100**
Ramboll Calculations based on LCREE Scotland figures (ONS, 2023a). Value chain figures obtained for Scotland by scaling back UK figures from 2019-2021 to cover confidential figures and increase reliability. Value chain proportions then applied to Scottish overall turnover and FTE figures for the sector. * = Likely contained within Specialised Consulting Services.						

5.1.1. Projection towards 2030 and beyond for the sectors

UK and Scottish government ambitions and high demand, particularly for onshore and offshore wind and possibly for hydrogen, will drive growth in the value chain towards 2030 and beyond.

The onshore wind sector has set installation ambitions for 2030 which imply an increased rate of growth to that of the last 15 years. It is therefore reasonable to expect about the same proportion of economic activity in project development, manufacturing, and installation stages in the coming decade as is currently observed. However, as the number and age of turbines increases, the need for, and therefore share of, operation and maintenance activity will increase. Additionally, as older wind farms approach the end of their technical and economic lifetime, economic activity in the end-of-life stage will increase, likely through specialised consulting services and R&D to develop environmentally and commercially viable ways of decommissioning and recycling wind farms.

For the offshore wind sector, with its aggressive installation targets and anticipated growth in the coming decade, significant activity is to be expected in the project development, manufacturing, and installation stages of the value chain in the coming decade. Once wind farms are in operation, the operation and maintenance stage will see continued and steady economic activity through many years. The currently almost non-existent end-of-life stage is anticipated to develop considerably later than for onshore wind due to offshore wind's later adoption, though we would expect there to be shared knowledge and synergies generated between the two.

Projections for the hydrogen sector are currently uncertain and are largely contingent on demand. The existing limited domestic demand is likely to impede the sector's progression. There are examples of strategic actions taken by policymakers and industry leaders to bolster the sector. These encompass actions like boosting demand, allocating funds for hydrogen R&D, and improving infrastructure – such as the Scottish government's proposal to invest £2.7 billion in a new hydrogen pipeline linking Scotland and Germany.

The anticipated global increase in hydrogen demand is predicted to surpass the current production plans. To be on track for net zero emissions by 2050, the global demand for hydrogen should reach 180 Mt in 2030. However, the global production in 2021 amounted to 94 Mt of which less than 1 percent was green hydrogen. (IEA, 2022) This discrepancy could present a unique opportunity for Scotland's hydrogen sector, particularly if producers can secure access to cost-effective electricity, ideally not procured via the conventional grid due to the currently high costs compared to other IEA countries. (Scottish Government, 2022c) Therefore, despite the current uncertainty, strategic interventions and global market trends could potentially pave the way for the sector's development.

5.1.2. Turnover

The established nature of the onshore wind sector is exhibited in its turnover breakdown. According to Ramboll calculations based on LCREE data (ONS, 2023a), operation and maintenance makes up the vast majority (68%) of the sector's turnover, illustrating the number of turbines already installed and in need of operation and maintenance activities. Installation is second (23%), reflecting the continued ambition from government to accelerate installation levels and more than double the sector's electricity generation by 2030. Manufacturing is notably low, due in part to the relatively low volumes of turbine manufacturing in Scotland, and specialised consulting being low could reflect that the sector is approaching a mature operational stage and the highly domestic nature of the sector and its potential lack of export opportunities due to the importance of local knowledge in project development in particular.

Despite having a slightly lower number of full-time equivalents (FTEs), the offshore wind sector surpasses its onshore counterpart in terms of turnover. This disparity is underpinned by the significantly higher turnover observed in manufacturing, installation, and specialised consulting within the offshore wind sector.

Although the offshore wind sector is currently less established than onshore wind, its rapid growth in installed capacity, exemplified by the substantial proportion of installation turnover (39%), suggests the potential for significant future turnover. Operation and maintenance turnover maintains a substantial 38% proportion, though it falls short of onshore wind figures due to the relatively lower number of operational offshore wind turbines.

The hydrogen sector is not yet operational at scale, and the turnover and FTE numbers are small. While we provide a value chain breakdown for turnover, the turnover in each value chain stage is so small that it does not add many insights into the current and future activity in the sector.

5.1.3. Employment (FTEs)

FTEs are generally more evenly spread out across the value chains than turnover. In onshore wind, this is largely driven by a high turnover per FTE, and likely productivity, of operation and maintenance jobs as they make up just 25% of total FTEs, again according to Ramboll calculations based on LCREE data (ONS, 2023a). Most FTEs work in installation (38%), and specialised consulting services, a labour-intensive value chain stage, also has a larger share of the FTEs than the turnover.

In offshore wind operation and maintenance also provide a larger share of turnover (38%) than FTEs (13%), suggesting high productivity. Installation again makes up the highest proportion of offshore wind jobs (30%), reflecting the rapid expansion of installed capacity. Manufacturing (24%) and specialised consulting services (28%) both also make up significant proportions of offshore wind FTEs.

5.2 Comparison of SWOT and key insights

The onshore and offshore wind sectors naturally share many strengths, weaknesses, opportunities, and threats since the value chain stages and many of the conditions of the sectors are similar. The outlook for the hydrogen sector is relatively uncertain due its immature and unproven nature, and the dynamic moment the sector is currently undergoing. The outlook for the onshore and offshore wind sectors are more certain since they are already established and commercially viable. The onshore and offshore wind sectors have good prospects for strong growth in domestic economic activity, with the biggest growth expected in offshore wind, driven by the strong domestic demand and need to increase installed capacity.

In the tables below we have aggregated the most important results from the SWOT analyses for each individual sector. The tables provide high-level comparison between the sectors, while detailed results from the SWOT analyses can be found in chapters 6.4 (onshore wind), 7.4 (offshore wind), 8.4 (hydrogen), 9 (themes relevant for all sectors), and appendix sections 11.2.2, 11.3.2, and 11.4.2 for onshore wind, offshore wind, and hydrogen, respectively.

5.2.1. Domestic demand

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity	Strong domestic demand, installation ambitions, and favourable policy environment		
Weakness/ Threat	Risk for bottlenecks in the value chain limiting the ability to meet demand		Too low and uncertain domestic demand for hydrogen fuels.

5.2.2. Sector policy

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity	Favourable policy environment		
Weakness/ Threat	Potential risk of focus funding and policy attention shifting to new NZ&CA technologies		Policy environment not sufficient to stimulate demand

5.2.3. Labour quality

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity	Labour force with long sector experience. Scotland generally has a highly skilled labour force	Labour force with more sector experience than most countries. Opportunity to draw on onshore wind and oil and gas experience. Scotland generally has a highly skilled labour force	Opportunity to draw on onshore wind and oil and gas experience. Scotland generally has a highly skilled labour force
Weakness/ Threat	Risk of skills gap when many sectors compete for the same skills. Higher wages in the oil and gas sector may deter shifts to NZ&CA sectors.		

5.2.4. Geographic and local barriers to entry

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity	Parts of the value chain are largely protected from international competition (chain in project development, installation, and operation and maintenance)		
Weakness/ Threat	These value chain stages are difficult to export for the same reason		

5.2.5. International first-mover advantage/disadvantage

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity	Opportunity to gain first-mover advantage in end-of-life services	Existing first-mover advantage in floating wind	
Weakness/ Threat	Scotland has no turbine manufacturer. Scotland generally has a comparative disadvantage in manufacturing (high-costs economy and limited manufacturing experience in this context)		Other countries have more developed hydrogen sectors.

5.2.6. Trade policy and Brexit

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity			
Weakness/ Threat	Brexit and other international trade policy (e.g., IRA) risks raising barriers for trade for Scottish companies.		

5.2.7. Macroeconomic environment

	Onshore wind	Offshore wind	Hydrogen
Strength/ Opportunity			
Weakness/ Threat	Challenging business cycle, high interest rates, and generally high cost-level in Scotland		

6 The onshore wind sector

6.1 Main findings

Onshore wind in Scotland is an established, successful domestic industry backed by a strong policy environment. Scotland's onshore wind sector saw strong early investment, to the point where the industry was temporarily excluded from the UK Government's Contracts for Difference (CFD) scheme which guarantees energy providers a fixed, pre-agreed price for low-carbon electricity. With this exclusion now ended, and installation ambitions set by the UK Government, onshore wind deployment is set to grow rapidly in Scotland, driving opportunities across the value chain provided it can accommodate the anticipated growth.

To withstand potential bottlenecks and accommodate the sector's anticipated growth, Scotland will need to overcome its supply chain limitations. Despite its relatively early adoption of onshore wind technology, Scotland has not developed a large-scale domestic turbine manufacturer. While domestic manufacturing does take place, this leaves Scotland largely reliant on imports at an important value chain stage (turbines can make up over two-thirds of the total cost of an onshore wind farm (Deloitte, 2014 as referenced in Spice Spotlight's May 2023). There are opportunities for Scotland to increase its manufacturing content through the production and export of turbine components, which can then be assembled abroad for use in Scottish projects (Vivid Economics, 2019). The challenge, however, is breaking into the major turbine manufacturers' already well-established supply chains, especially as potential supply chain bottlenecks are projected for turbines and components across Europe and the US (GWEC, 2023).

Despite the sector's strength in Scotland, relatively few parts of the value chain are easily exportable. Local, site-specific knowledge is valuable to onshore wind installation services, as is a local presence for goods and equipment. Similarly, quick access to wind farms is key to minimising downtime and productivity losses. As a result, both installation and operation and maintenance are highly localised value chain stages, protecting Scottish companies on domestic projects but limiting export opportunities. Consequently, onshore wind is not seen as the net zero sector with the most export potential (a view of this research but also of stakeholders contacted) and therefore may not be the most appropriate for export-oriented public policy and investments.

Scotland's main export opportunities in onshore wind are service based. Some specialised engineering consultancy services are currently done internationally and represent the bulk of current Scottish onshore wind exports. These services focus on the project development stage and include wind farm design, wind resource modelling, construction management, and financial due diligence (BVG stakeholder interview).

Moving forward, circularity presents a key export opportunity. Due to the established nature of its onshore wind sector, Scotland's fleet will reach its end-of-life earlier than most nations (Zero Waste, Scotland, 2023). There are opportunities for Scotland to become an international market leader in circularity and export this knowledge through consultancy services. There may be areas to develop based on prior experience in repowering, recycling, and decommissioning (e.g., the practical considerations of installing larger turbines in place of smaller ones, particularly in more remote areas).

6.2 Introduction to the sector

Scotland's onshore wind sector is relatively mature, both domestically and from an international perspective. Installation began in the late 1990s and has seen particularly rapid uptake since 2010, to the point where Scotland has almost 9GW of installed capacity (Scottish Government, 2022b) in an industry contributing an estimated 3,300 direct full time equivalent (FTE) jobs and up to £2bn in direct turnover to the Scottish economy (ONS, 2023a). As a result, Scotland boasts strong capabilities across the value chain, from its local expertise in installation and operation and maintenance to its exported, international project development services, and the nation is well-positioned to benefit from future growth in the sector's currently nascent end-of-life value chain stage.

Onshore wind's importance to the UK's net zero goals has been highlighted by the Climate Change Committee, who note in the Sixth Carbon Budget Report that "all [carbon reduction] scenarios see new onshore wind generation being deployed by 2050" (CCC, 2020, page 28). This importance is not lost on Scottish Government and, despite the temporary exclusion of onshore wind from the CFD scheme from 2015, results from September 2021's bidding round revealed that nine projects totalling approximately 1GW of new onshore wind projects were successful, with all nine located in Scotland (Wind Europe, 2022a).

The recent Onshore Wind Policy Statement 2022 (Scottish Government, 2022b) revealed that Scotland has (as of June 2023) 9.4GW of installed onshore wind, with a further 7.0GW in planning / consenting, 4.1GW awaiting construction, and 1.6GW under construction. This total would meet the ambition of 20GW of installed capacity by 2030. However, as BVG (2023) note, a proportion of the existing stock will require decommissioning or repowering, and some of the projects in the pipeline will not advance to construction due to a range of technical or commercial factors. As such, Scotland will continue to need new projects.

Reaching Scottish Government's installation goals presents challenges. Scotland does not currently manufacture most turbines installed domestically, and increased competition for turbines and components may hit harder as a result. The sector faced significant challenges in both 2021 and 2022, with rising input costs, supply chain constraints and slow permitting processes impacting turbine manufacturing companies across Europe and the USA (Hodgson, 2022). With 2023 anticipated to carry similar challenges, supply chain bottlenecks for turbines and components are anticipated (GWEC, 2023), and Scotland may need to maximise its manufacturing capabilities to realise its deployment ambitions.

The current UK national grid has limited capacity in many remote areas with significant renewable resources, and the National Grid projects that Scotland's peak demand for electricity will at least double within the next two decades. According to the National Grid Electricity System Operator, over £21bn of investment into GB transmission infrastructure will be required to meet 2030 targets, with over half involving Scottish Transmission owners SSEN and SPEN (National Grid ESO in Scottish Government, 2022b). On-site battery storage and hydrogen have been identified as possible solutions, but remain in development (Hawker *et al.,* 2022; Scottish Government, 2022b).

Competition for skills from similarly ambitious countries and other net zero sectors (particularly offshore wind), is another key challenge. The Global Wind Energy Council estimate that over half a million wind technicians will be needed globally by 2026 (GWEC, 2022), and UK offshore wind employment alone is expected to increase by over 220% by 2030 (Offshore Wind Energy Council, 2023). Meeting both sectors' targets requires coordination, potentially using onshore wind farms as training sites for offshore wind installation (a suggestion recommended by stakeholders interviewed), which will peak later. There will also be competition with other sectors to attract skilled staff. This includes electrical backgrounds (e.g., automation, aviation), which are in high and growing demand, meaning the onshore wind sector will need to remain competitive against typically higher-paying industries. Pushing STEM training would enable Scotland to develop the pipeline of potential wind technicians to mitigate this risk, and developing Scotland as a hub for wind technician training could also strengthen the domestic pool of workers.

6.3 Current performance of the sector and value chain

6.3.1. Definition of the sector and value chain

This research adapts wind value chain categories from Wind Europe's flagship report (Pineda *et al.,* 2020), which categorises the wind energy industry's supply chain according to the life cycle of a power plant: planning, manufacturing, installation, operation & maintenance, and end-of-life (Wind Europe, 2020). These categories are used, except for planning, which is renamed to project development due to nomenclature differences between the UK and Europe[8]. Other breakdowns of wind value chain categories do exist, e.g., BVG's (2017) expenditure figures are used where appropriate to illustrate the respective sizes of each value chain stage[9]. Most LCREE data categories fall into one of the

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[8] In the UK, planning is more typically seen as a part of the project development phase, whereas in Europe the inverse is prevalent.
[9] BVG's expenditure category breakdowns are as follows: DEVEX (project development and management), CAPEX (turbine, civil works, electrical works), and OPEX (transmission operation, maintenance and service (OMS), wind farm operations maintenance and service (OMS), and decommissioning).

selected value chain stages, apart from specialised consultancy services which, although concentrated in the project development stage, are present throughout the value chain and are thus analysed separately.

6.3.2. Turnover, employment and GVA

According to LCREE data, onshore wind in Scotland has had turnover varying between £1.1-2.0bn and employed between 2,200-3,600 FTEs during 2016-2021 (ONS, 2023a) (Figure *5*)[10]. Direct turnover per FTE averaged £601,000 across the value chain for the latest data year (2021). However, wide confidence intervals should be noted in all calculations. We have validated these results in stakeholder interviews and our literature review; however, the numbers lack triangulation with other quantitative sources.

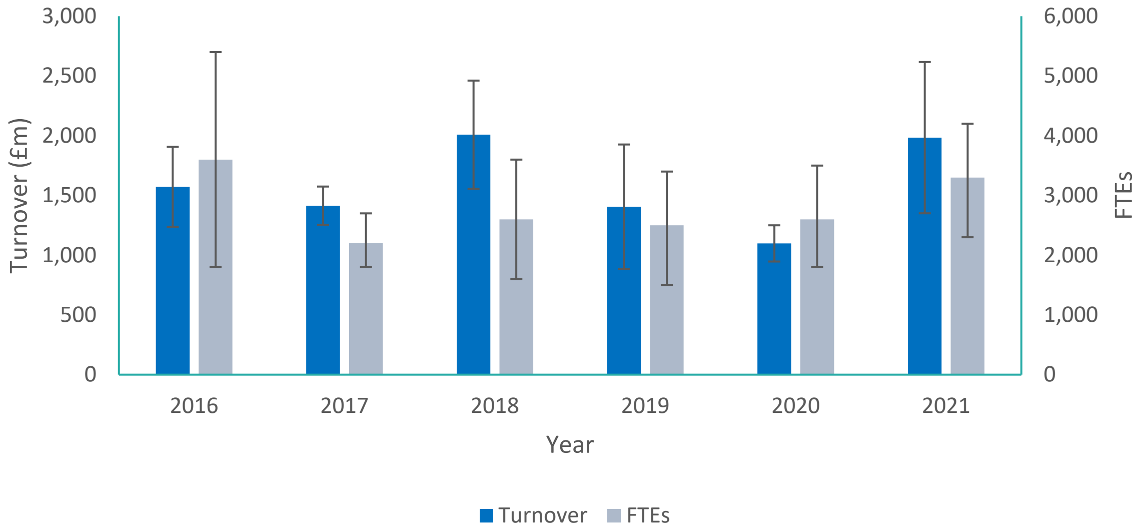

Figure 5: Onshore wind turnover and FTEs in Scotland, 2016-2021. Source - LCREE (ONS, 2023a).

Figure 5 illustrates LRCEE data (ONS, 2023a) for onshore wind turnover and FTEs from 2016 to 2021. It shows that turnover for onshore wind ranges between £1.1bn and £2.0bn, and FTEs range from 2,200 to 3,600 FTEs across the same period. However, wide confidence intervals limit the precision of each estimate.

LCREE figures provide estimations of direct turnover and FTEs. To indicate the GVA of the sector, the additional economic activity supported within the onshore wind supply chain, and the impacts of increased employment and wage spending, FAI's Economic Impact of Scotland's Renewable Energy Sector (2022)[11] was used. Direct, indirect, and induced figures are presented in Table *8*.

[10] Current estimated number of businesses across the whole onshore wind value chain is 2,500 according to LCREE, but significant variance surrounds this figure (500-4,000), and its similarity compared to the estimated number of direct FTEs (3,300) suggests potential gaps in reporting.
[11] These data were available for 2020 only, and so were scaled in line with the increase of turnover and FTEs of LCREE data between 2020 and 2021, respectively. This assumption does rely on the increase of LCREE data from 2020 to 2021 being representative of the indirect and induced increase of FAI figures.

Table 8: Latest direct, indirect, and induced turnover, full-time equivalent (FTE), and GVA estimates for Scottish offshore wind.

Performance metric	Direct	Indirect	Induced
Turnover (2021)	£1,984mn[1]	£1,066mn[2]	£629mn[2]
FTEs (2021)	3,300[1]	4,800[2]	4,800[2]
Turnover/FTEs (2021)	£601,000[1]	£224,000[2]	£132,000[2]
GVA (2020)	£515mn[3]	£300mn[3]	£260mn[3]
GVA/Output ratio (2020)	0.38[3]	0.42[3]	0.61[3]

[1] = LCREE figures for Scotland (ONS, 2023a).
[2] = Ramboll estimation based on Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander Institute, 2022). The FAI study provides data for 2020 only; as such, the proportions of indirect and induced data to the 2020 data was applied to the 2021 direct LCREE data.
[3] = 2020 figures from Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander Institute, 2022).

6.3.3. Imports and exports

Where data are available, onshore wind imports have been consistently estimated to be higher than exports (Figure 6); although both are small in comparison to total sector turnover. Large variation surrounding each year's estimate and confidentiality cloud the precision of this conclusion, however the trend remains largely consistent in the LCREE data. The trend of imports outvaluing exports may be due to a lack of an established turbine manufacturer in Scotland resulting in some years with large import values due to imports of turbines. BVG (2017; 2018) estimate the current proportion of UK-supplied turbine content to be just 3.5%, potentially rising to 10% by 2030; far below their estimations for the overall value chain (66% currently, rising to 70% by 2030). This may leave Scotland especially reliant on imports during years of especially high demand for the development and building of onshore wind projects.

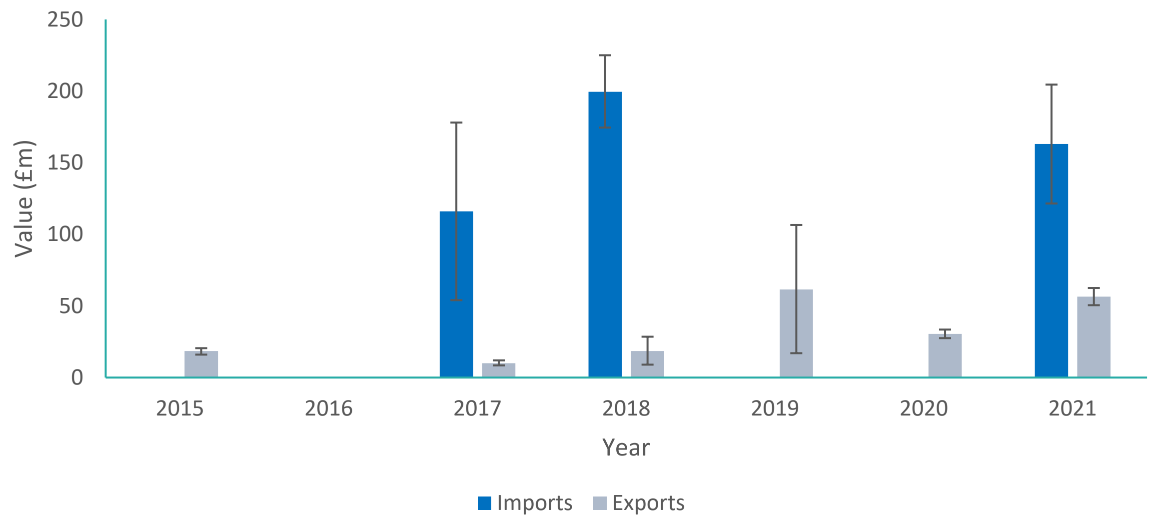

Figure 6: Scottish onshore wind imports and exports, 2015-2021. Source - LCREE (ONS, 2023a). Where data are absent, they are listed as confidential within LCREE.

Figure 6 shows LCREE (ONS, 2023a) data for onshore wind imports and exports from 2015 to 2021. It shows that import data, available for 2017, 2018 and 2021, are considerably higher than each year's export data equivalent. Import data range from £116m to £200m, while the highest export data figure (2019) is just £62m. Nonetheless, confidential data and wide confidence bars limit the precision of each estimate.

6.3.4. Value chain breakdown

LCREE provides value chain breakdowns of turnover and FTE data at a UK level only. Within the value chain data, there are also data points within each year which are "suppressed for confidentiality reasons" (ONS, 2023a). To determine the direct performance make-up of the Scottish onshore wind value chain and cover confidential data points, LCREE value chain data were aggregated across 2019-2021 to obtain more reliable breakdowns. Proportions for each value chain stage were then applied to total Scottish turnover and FTE figures, with the value chain breakdown across the UK assumed to be representative of that within Scotland (a hypothesis validated with stakeholders). Value chain breakdowns for turnover and FTEs are presented in Figure *7* and Figure *8*, respectively. Further metrics for each value chain stage, and the percentage of local, Scottish and UK content found by BVG (2017) in their assessment of eight Scottish wind farms, are presented in Table 9 and Table 10, respectively. After the quantitative data follows the main conclusions for each value chain stage.

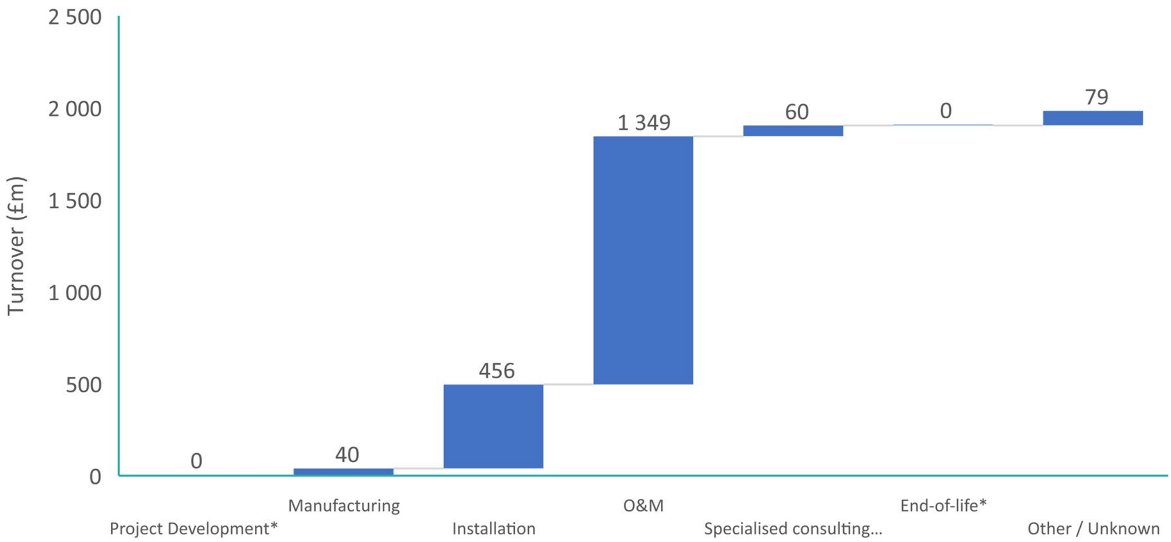

Figure 7: Direct turnover in Scottish onshore wind industry for 2021. Source - Ramboll interpretation of LCREE figures (ONS, 2023a). * - turnover for project development and end-of-life is likely contained within specialised consulting services.

This figure shows a breakdown of onshore wind turnover data into its value chain stages. It shows that operation and maintenance accounts for £1.35bn of a total £1.98bn turnover, with installation the second-highest contributor at £456m. No other value chain stages contribute over £79m in turnover.

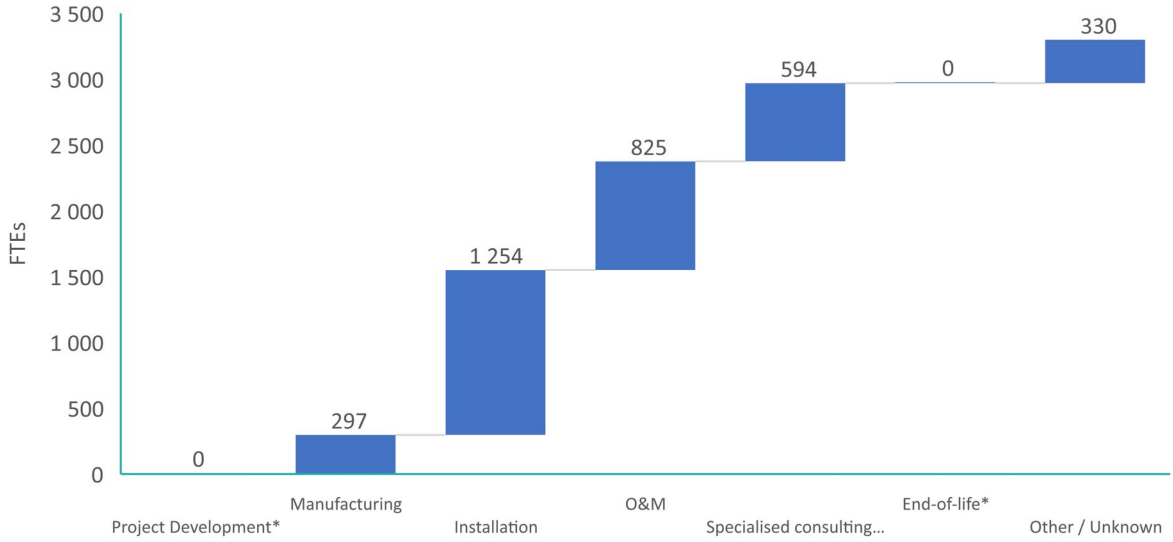

Figure 8: Direct FTEs in Scottish onshore wind industry for 2021. Source - Ramboll interpretation of LCREE figures (ONS, 2023a). * - FTEs for project development and end-of-life are likely contained within specialised consulting services.

This figure shows a breakdown of onshore wind FTE data into its value chain stages. It shows that installation accounts for 1,254 of a total 3,300 FTEs, with operation and maintenance the second-highest contributor at 594 FTEs. Specialised consulting services contribute 594 FTEs, other/unknown 330 FTEs and manufacturing 297 FTEs.

Table 9: Breakdown of performance metric estimates for the onshore wind value chain in Scotland. Sources - Vivid Economics (2019) and Ramboll calculations based on LCREE (ONS, 2023a).

	Metric			
Value Chain Stage	**Turnover**	**FTE**	**Turnover / FTE**	**GVA / FTE**
Project Development	NA*	NA*	£84,200[1]	£61,600[1]
Manufacturing	£40m[2]	300[2]	£91,300[1] £133,600[2]	£65,700[1]
Installation	£456m[2]	1,250[2]	£122,200[1] £363,800[2]	£60,600[1]
Operation & Maintenance	£1,349m[2]	830[2]	£649,500[1] £1,634,900[2]	£186,900[1]
Specialised Consulting Services	£60m[2]	600[2]	£100,200[2]	NA
End-of-life	NA*	NA*	NA	NA
Other/unknown	£79m[2]	330[2]	£240,400[2]	NA
Total	**£1,984m[2]**	**3,300[2]**	**£601,000[2]** (average)	**NA**

[1] = Vivid Economics, 2019 *Quantifying the benefits of onshore wind to the UK* (UK figures).
[2] = Ramboll calculations based on LCREE Scotland figures (ONS, 2023a). LCREE value chain figures obtained for Scotland by scaling back UK figures from 2019-2021 to cover confidential figures and increase reliability. Value chain proportions then applied to Scottish overall turnover and FTE figures for the sector, with the value chain breakdown of the wider UK assumed to be representative of that within Scotland.
* = Likely contained within Specialised Consulting Services.

Table 10: Summary of content by geographic region aggregated across eight Scottish wind farms. Source - BVG (2017).

Category	Region	% content of TOTEX	% content of category
Development expenditure (DEVEX – linked to project development for our project)	Local Scottish UK	0.2% 1.5% 2.0%	11.6% 74.4% 93.6%
Capital expenditure (CAPEX – linked to manufacturing and installation for our project)	Local Scottish UK	1.1% 9.3% 12.5%	2.3% 25.0% 33.8%

Operational expenditure (OPEX – includes decommissioning and linked to operation and maintenance for our project)	Local Scottish UK	15.2% 40.6% 51.5%	25.1% 67.0% 85.1%
Total expenditure (TOTEX)	Local Scottish UK	16.5% 51.4% 66.0%	16.5% 51.4% 66.0%

Onshore wind projects tend to be relatively localised in their project development. In comparison to offshore wind, onshore wind projects tend to rely more on local expertise (e.g., for environmental surveys). On eight Scottish wind farms assessed by BVG (2017), Scottish firms were estimated to supply 74% of development expenditure; within this figure, firms local to each site were responsible for 12% of total DEVEX. Quantifying the performance of the project development stage is complicated by the lack of a dedicated project development value chain stage in LCREE data, however turnover, FTEs, etc for this stage are likely contained within specialised consulting services.

Scotland lacks a large-scale turbine manufacturer, limiting its domestic manufacturing capabilities for onshore wind. This limits onshore wind even more than offshore wind – only approximately 9% of total FTEs in onshore wind were involved in manufacturing in 2021, compared to approximately 24% for offshore wind – and is likely due to the turbine itself making up a larger percentage of the total cost of a wind farm (more than two thirds according to Deloitte, 2014). Opportunities for Scotland to increase domestic content in manufacturing for onshore wind centre around turbine components. These components can potentially be exported to large overseas turbine manufacturers for use in UK projects, which would increase UK turbine content to 10% in 2030 from just 3.5% in 2018 (BVG, 2018). Where the growth of UK manufacturing may be limited, however, is in a potential lack of skills due to competition from other industries or countries seeking to also scale up their own manufacturing capabilities.

Installation will be economically important while Scotland works to meet its installed capacity ambitions. Installation currently provides the highest share of total FTEs (approximately 38%) in the onshore wind sector but collaboration with offshore wind may need to take place to facilitate the achievement of both sectors' installation ambitions. This value chain stage offers fewer export opportunities for onshore wind compared to offshore wind, due to the range of challenges faced by different countries' offshore wind installations. BVG (2017) found that civil works[12] was a primarily domestic value chain stage in the onshore wind sites they analysed. Some 66% of the value of civil works content was

[12] BVG (2017), page 9, define civil works as "the activity by civil contractors and their suppliers; covering roads and drainage, crane pads, turbine foundation, meteorological mast foundations, cable trenches and buildings for electrical switch gear, SCADA equipment and its installation, and a maintenance and spare part facility."

provided by Scottish firms, 5% of which was provided by firms local to each site. Electrical works were found to be less domestic – just 18% of the value of electrical works content was supplied by Scottish firms (of which 1.8% was local).

Operation and maintenance (O&M) provides the highest productivity per FTE for onshore wind by some distance. This finding was validated by stakeholders, who noted that the sudden breakdown of turbine equipment leads to a significant loss of productivity, which often vastly outweighs the cost of the broken component. Scottish firms were estimated to supply 67% of O&M expenditure (OPEX) on the wind farms analysed by BVG, with local firms supplying 25% of this value (BVG, 2017).

Specialised consultancy services provide export opportunities for Scottish companies, which are currently exporting knowledge and skills related to many different value chain stages, particularly those which share transferrable skills from Scotland's other net zero industries. Key consultancy services exported by Scottish companies include expertise in wind farm design, wind resource modelling, construction management and financial due diligence (BVG stakeholder interview).

The end-of-life value chain stage is rapidly evolving but provides a potential first-mover advantage for Scotland. Data on end-of-life for onshore wind is lacking due to the lack of a dedicated end-of-life value chain stage in LCREE data. Scotland has a key opportunity here however to utilise its first mover advantage provided by its ageing fleet. Scotland can learn lessons surrounding repowering and decommissioning, e.g., the practical considerations of installing larger turbines in place of smaller ones. Stakeholders considered that the best sites were the ones where turbines were first installed, because these are more capable of handling the biggest turbines than more remote sites.

6.4 Strengths, weaknesses, opportunities, and threats of the sector and value chain

6.4.1. SWOT overview and key insights

Overall, onshore wind is a strong, established sector in Scotland which will continue to provide economic benefits and employment across the primarily domestic value chain, provided Scotland can address potential skills shortages and invest sufficiently in its potentially limiting grid capacity (Table *11*). However, this is not the net zero sector with the most opportunities for exports (which are likely to continue to be largely limited to services).

Table 11: SWOT analysis overview for onshore wind.

Strengths	Weaknesses
• First-mover advantage, already established sector with a strong base of companies, experience, and skills to build on (performance and labour quality)	• Scotland has a general comparative disadvantage in manufacturing, particularly turbine manufacturing – a concentrated international market with high barriers to entry • R&D expenditure relatively low
Opportunities	**Threats**
• Domestic value chain is protected from international competition (local geographical markets, geographical barrier to entry) • Favourable policy environment and strong commitments drive demand and project delivery irrespective of macroeconomic environment (sector policy environment) • Ambitious installation targets, reflecting high domestic demand and a strong opportunity for the sector (domestic demand) • Scotland's fleet will reach end-of-life sooner than most, presents opportunities for first-mover advantage in decommissioning / repowering / recycling • All countries have a skills gap – possibility to export with high profitability (labour force)	• Many parts of the value chain cannot be exported (local geographical markets, geographical barriers to entry) • Threat that attention and funding will shift towards offshore and other, newer, net zero technologies leaving an investment gap • High labour costs and skills gaps pose a threat to growth and performance in the sector, particularly regarding competition with offshore wind, which pays higher (labour force) • Services that need to be delivered on-site translate into high transport costs and importance of local knowledge limit export opportunities in certain value chain stages (project development, installation, O&M) • Brexit has created a comparatively more challenging trade environment given several key competitor markets are in the EU (trade policy) • Unfavourable macroeconomic environment (economic growth forecast, interest rate, etc.) may slow investments in the sector, though this isn't unique to onshore wind

6.4.2. SWOT insights per category

Conduct: R&D expenditure, investment intensity and productivity

Scotland's R&D expenditure is characterised by strong Higher Education R&D (HERD) and relatively weaker Business Enterprise R&D (BERD) (Scottish Government, 2020b). The relatively established nature of Scotland's onshore wind industry works against it in this regard, as funding is increasingly concentrated towards more nascent technologies and offshore wind. Investment intensity is another potential threat, although its importance is highly dependent on the value chain stage. Some parts of the value chain will require ongoing investment (cranes, equipment, O&M processes, etc.), while other areas (e.g., consulting) are less dependent on investment intensity. Targeted investment, through R&D or otherwise, will be needed to realise the opportunities presented by e.g., end-of-life, a largely unexplored value chain stage. Should investment materialise, these indicators can become strengths, and it should be noted that BERD in Scotland has increased in recent years, and private sector investment into onshore wind is also expected from companies not currently working in the sector (Scottish Enterprise, 2022).

Structure and conditions: Input and cost factors

Labour costs in the UK are relatively high (OECD, 2023). This doesn't change substantially across value chain stages, but the importance of wage costs (as an input cost) does change. Some parts of the value chain are more cost-dependent or cost-competitive, for instance demand for specialised consulting services is less price-sensitive given the level of expertise than manufacturing, for example, where high labour costs limit Scotland's international influence. Labour costs may also emerge as a key threat as the forecasted skills gap in the sector becomes more apparent. Labour costs may be offset, however, by labour quality, which is noted as an opportunity due to the high availability of skilled people in Scotland relevant to the onshore wind industry. In certain parts of the value chain (particularly installation, O&M) there will also be synergy with the offshore wind sector, enabling the transfer of skilled employees and associated advantages.

Onshore wind is a capex-intensive industry, where the wind farm is expensive to build and relatively cheap to maintain (this of course varies across the value chain – specialised consulting services are not capex-intensive for example). Non-labour costs for onshore wind include equipment costs, transport costs, and costs of capital. Both equipment and transport costs are considered slight threats for onshore wind, given the need to install larger and more powerful turbines and a potential lack of equipment in the form of larger cranes and haulage vehicles both all of which limit potential export opportunities.

Structure and conditions: market conditions

Market conditions are highly favourable to the development of onshore wind in Scotland. Domestic demand is particularly strong, reflecting confidence in the sector and in Scottish projects and companies. Provided potential issues surrounding grid constraints and future skills shortages can be addressed, the current demand appetite should enable the achievement of Scotland's installation goals. International demand is similarly strong – in Europe alone, demand for electricity will more than double by 2050, and onshore wind is expected to outweigh all other electricity generation types in 2050 (Fraile *et al.*, 2021), providing opportunities to export Scottish knowledge and skills.

Domestic policy environment

Scotland's policy environment is generally favourable to the development of onshore wind, although trade policy has been noted as challenging due to the impacts of Brexit (Scottish Government, 2022b). We assess regulatory stability and strength, sector-level subsidies or taxes, and political goals or strategies to be strengths or opportunities for Scotland. Although they do not all translate into competitive advantage, and it is unclear how the readmission of onshore wind into CFD will impact competition with other industries, each of these indicators are conducive to a favourable environment for the development of onshore wind projects as they provide stability and increase investor confidence in the future of the sector.

Macroeconomic environment

The macroeconomic environment is consistent across all sectors and is classified here using the indicators exchange and interest rates, cost level, and economic growth forecast. Scotland's current macroeconomic environment is relatively weak, with a weak exchange rate, high interest rate, high-cost level, and slow economic growth prospects. See section 9.1 for more details.

7 The offshore wind sector

7.1 Main findings

Scotland's offshore wind sector is well positioned to capitalise on demand from both domestic developments and export opportunities. There are several similarities with the onshore wind sector, but given the sector's relative immaturity, particularly in floating wind, there is potential for Scotland to realise a first mover advantage. Utilising existing and future adjacencies with other sectors (oil and gas, onshore wind, hydrogen) will be a key enabler.

There is large domestic and international demand for Scottish offshore wind development and expertise, partly driven by a political goal to further expand installed offshore wind capacity. Scotland has some of the most ambitious installation objectives globally, with goals to increase capacity from 2.6GW in 2023 to 8-11GW in 2030 (Scottish Government, 2023a). Should this fourfold increase in installed capacity materialise, it would drive continued rapid expansion in the whole value chain. It does not, however, automatically map on to direct opportunities for Scotland by default.

UK offshore wind ambitions were dealt a blow with the recent CFD Allocation Round Five (AR5) results, with no offshore wind bids attracted for the first time (DESNZ, 2023e; Millard and Pickard, 2023). It remains to be seen how the UK or Scottish governments will react to this development, given that leasing rounds prior to AR5 indicated high confidence investor appetite for Scottish offshore wind development. The ScotWind leasing round in 2022 revealed market ambition of 28GW of potential generation capacity compared to the approximately 10GW expected by Scottish Government (The Crown Estate Scotland, 2022).

Skills, costs, and profitability pose challenges in meeting this demand. Like onshore wind, there will be fierce competition for skills from other industries and countries who have similarly ambitious deployment targets, and the supply chain will need to scale-up drastically. There are also profit margin pressures associated with the UK's CFD environment, with industry claiming a lack of support given high inflation levels (Pitel, 2023).

The UK Government has been exploring introducing non-price factors (e.g., sustainability and capacity building) into future CFD allocation rounds to top-up high-scoring bids, but these are unlikely to be introduced before 2025 (DESNZ, 2023c).

The level of performance and trade opportunity varies across the value chain. Compared to onshore wind projects, offshore wind projects provide a wider range of components and complexity, and typically have shared challenges across geographies. As a result, value chains tend to be less localised and provide more opportunities for export. RenewableUK (2019) highlights the range of exports provided by UK companies in the sector, including: installing, maintaining, and fabricating turbines and blades; supplying and laying power cables underwater and providing remotely operated vehicles to inspect them; fabricating steelwork for platforms and stairways; producing and fitting components such as lighting systems for turbines; supplying helicopters and crew transfer vessels; designing gearboxes; producing software to maximise power generation; conducting geological surveys; monitoring wildlife; and providing financial and legal services. Scotland can provide such a range of services in part due to its existing reputable skills and knowledge in the offshore and subsea sectors, meaning opportunity for exports in the installation and specialised consulting stages. There are still, however, value chain stages where Scotland is reliant on imports (particularly in manufacturing where, like onshore wind, offshore wind is constrained by the lack of a large UK-based turbine manufacturer). Investment should prioritise easing this reliance through increasing the share of UK content in specific value chain stages (e.g., ORE Catapult (2023) identifies turbine manufacturing and balance of plant as areas where UK content can be at least doubled by 2030) in order to increase resilience in the supply chain and facilitate the scale of planned development.

Key opportunities exist where Scotland can build on existing skills, infrastructure, and competitive advantage. There is Scottish first-mover advantage in offshore wind (particularly floating) and a higher degree of transferability of skills and infrastructure across geographies (e.g., consulting services, and long-term end-of-life). Drawing upon adjacent sectors there are potential opportunities in terms of skills, knowledge, infrastructure, and equipment:

- **Onshore wind:** Collaboration opportunities exist, for instance in the development of installation expertise to address future skills gaps. Stakeholders consulted noted that as onshore wind installation is anticipated to peak significantly earlier than offshore wind, there is opportunity to train technicians with onshore turbines before transitioning to offshore wind.
- **Oil and gas**: Scotland's legacy oil and gas sector provides numerous transferable benefits to its offshore wind sector, including subsea and marine services (engineering, installation, maintenance, analytics), infrastructure (floating structures) and port facilities, international experience, and the transitioning of workforce and supply chain. However, scepticism remains on short-term mobility especially due to the current high oil price, salary disparities between oil and gas and offshore wind, and the fact that economic activity in oil and gas sector will remain strong to 2030.

7.2 Introduction to the sector

Scotland's offshore wind sector is world-leading thanks to early adoption of the technology and rapid expansion leading to the UK at one point having more capacity installed than any other country (although China has recently caught up: Buljan, 2023; UK Research and Innovation, 2022). Nonetheless, the sector is still relatively nascent compared to Scotland's well-established onshore wind sector.

Most of the offshore wind, across various stages of development, is concentrated on the East coast of Scotland. Current operational offshore wind amounts to over 2.6GW and ScotWind has leased options for another 28 GW (BEIS, 2021). While it must be noted that the realisation of all of these developments is highly unlikely due to the various stage gates which must be passed before installation, they amount to a reported potential pipeline of up to 42GW of offshore wind by 2035, over half of which is intended to be floating wind capacity, which would place Scotland in the top ten global offshore wind markets (Offshore Wind Scotland, 2023).

To enable deployment of offshore wind in Scotland, the Offshore Wind Policy Statement outlines priorities for the sector including a call for the UK government to address the Contracts for Difference (CFD) auction and how projects are allocated, transmission networks and charges, skills and supply chain to name a few (Scottish Government, 2020a).

7.3 Current performance of the sector and value chain

7.3.1. Definition of the sector and value chain

This research follows the approach taken for the onshore wind analysis (section 5) and adapts wind value chain categories from Wind Europe's flagship report (2020), into the categories: project development, manufacturing, installation, operation & maintenance, specialised consulting services and end-of-life (figure and further details in section 6.3.1). Most LCREE data categories fall into one of the selected value chain stages, apart from specialised consultancy services which, although concentrated in the project development stage, are present throughout the value chain and are thus analysed separately. Analysis by value chain stage is presented in section 7.3.4, with further details in appendix section 11.3.1 of this report.

7.3.2. Turnover, employment, and GVA

According to recent LCREE data, offshore wind in Scotland has had turnover estimated between £260m - £2,600m (2018-2021 due to confidential data 2016-2017) and employed between 1,200-3,100 FTEs (2016-2021) (ONS, 2023a) (Figure 9)). Turnover per FTE averaged £840,000 across the value chain for the latest data year (2021); however, high confidence intervals should be noted in all calculations, and while these results have been validated through stakeholder interviews and a thorough literature review, the numbers lack triangulation with other quantitative sources.

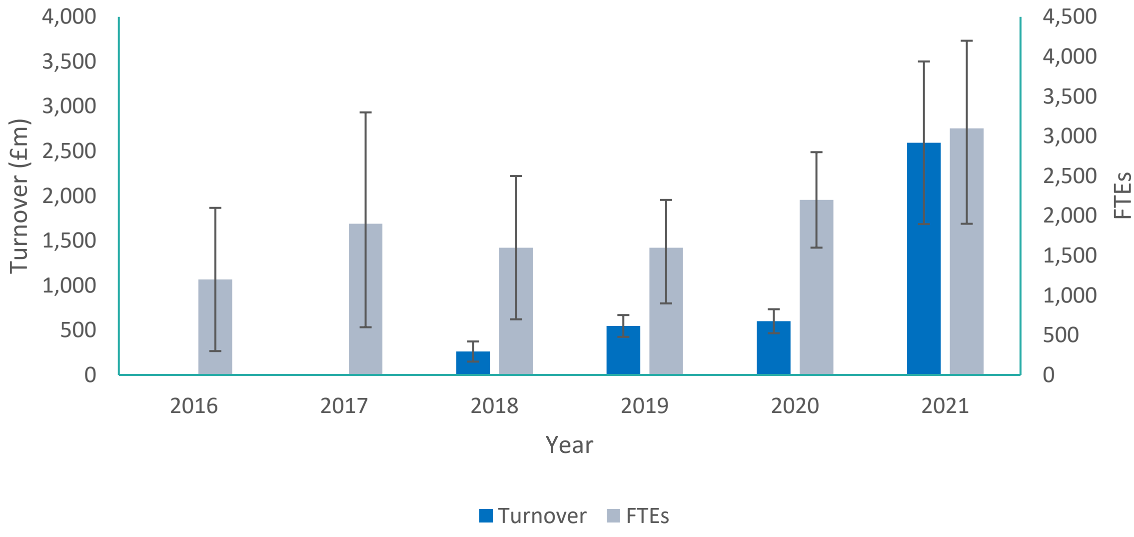

Figure 9: Offshore wind turnover and FTEs in Scotland, 2016-2021. Source - LCREE (ONS, 2023a).

Figure 9 illustrates LRCEE data (ONS, 2023a) for offshore wind turnover and FTEs from 2016 to 2021. It shows that turnover for offshore wind, available from 2018 onwards, increased from £263m to £2.6bn, and FTEs, available for 2016-2021, have increased from 1,200 to 3,100.

LCREE figures provide estimations of direct turnover and FTEs. To indicate the GVA of the sector, the additional economic activity supported within the offshore wind supply chain, and the impacts of increased employment and wage spending, FAI's *Economic Impact of Scotland's Renewable Energy Sector* (Fraser of Allander Institute, 2022) [13] was used. Direct, indirect, and induced figures for 2021 are presented in Table 12.

Table 12: Latest direct, indirect, and induced turnover, full-time equivalent (FTE), and GVA estimates for Scottish offshore wind.

Performance metric	Direct	Indirect	Induced
Turnover (2021)	£2,594mn[1]	£968mn[2]	£1,626mn[2]
FTEs (2021)	3,100[1]	2,600[2]	3,800[2]
Turnover/FTEs (2021)	£837,000[1]	£372,000[2]	£429,000[2]
GVA (2020)	£295mn[3]	£110mn[3]	£185mn[3]
GVA/Output ratio (2020)	0.48[3]	0.49[3]	0.61[3]

[1] = LCREE figures for Scotland (ONS, 2023a).
[2] = Ramboll estimation based on Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander Institute, 2022). The FAI study provides data for 2020; as such, the proportions of indirect and induced data to the 2020 data was applied to the 2021 direct LCREE data.

[13] These data were available for 2020 only, and so were scaled in line with the increase of turnover and FTEs of LCREE data between 2020 and 2021, respectively.

[3] = 2020 figures from Fraser of Allander Institute's Economic Impact of Scotland's Renewable Energy Sector – 2022 Update (Fraser of Allander Institute, 2022). Calculated as total GVA / economic output (similar to turnover).

7.3.3. Imports and exports

Due to the absence of UK or Scottish turbine manufacturers[14], Scotland's offshore wind sector is reliant on imports to scale up certain sections of its value chain and meet its domestic demand. Import estimates in the offshore wind sector increased significantly in 2021, as large developments (e.g., Moray East) were approved (Figure 10). Export data for Scotland in 2021 were confidential, however data for the UK, England and Northern Ireland suggest Scottish exports were significant. Across the period 2016-2012 there is no clear pattern or trend relating to imports and exports, given the sector is still in early stages of maturity this is to be expected. While the exact breakdown of Scottish content in UK content is uncertain, there is a commitment from industry, as part of the Offshore Wind Sector Deal with the UK Government, to increase UK content in wind farms to 60% in 2030 from 48% currently (ORE Catapult, 2023; Table 13).

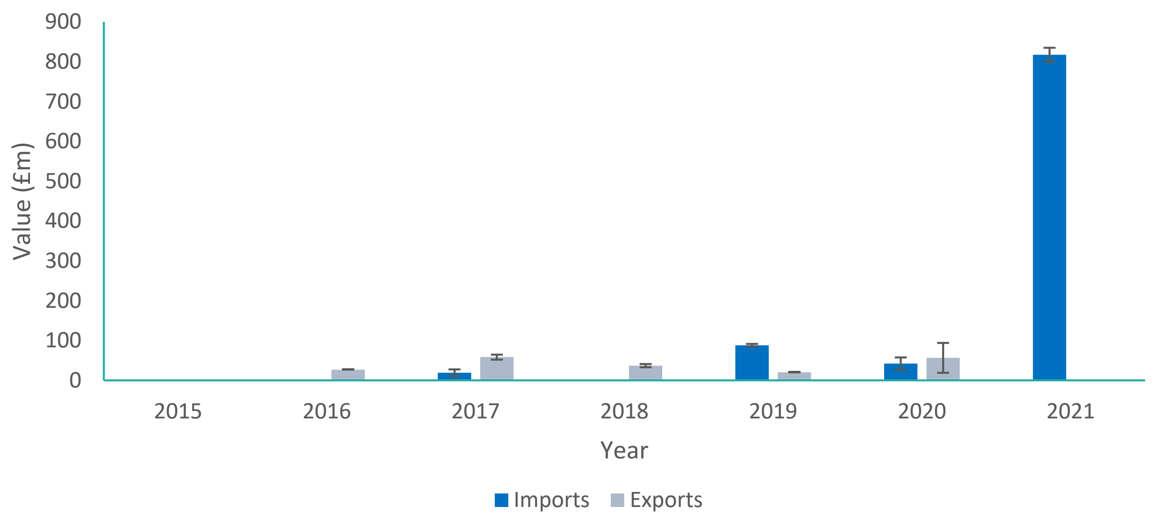

Figure 10: Scottish offshore wind imports and exports, 2015-2021. Source - LCREE (ONS, 2023a). Where data are absent, they are listed as confidential within LCREE.

Figure 10 shows LCREE (ONS, 2023a) data for offshore wind imports and exports from 2015 to 2021. It shows that both import and export data have largely remained below £88m since 2015, but that imports data rose drastically to over £800m in 2021. Data is not complete however, and notably lacks export data for 2021, and both import and export data for 2015.

[14] While there are no turbine manufacturers in Scotland, major British wind developers (SSE and RES) are both UK headquartered and in the top 25 wind farm developers globally.

Table 13: Offshore wind farm content: now and by 2030. Source - ORE Catapult (2023). 2030 estimates are based on aspirations outlined in the UK Government's Offshore wind Sector Deal (BEIS, 2020a).

Time period	Currently (2023)		2030	
UK / total	UK	Total	UK	Total
Development and project management (linked to project development for our report)	2%	3%	2%	3%
Turbine (linked to manufacturing for our report)	5%	21%	10%	26%
Balance of plant (linked to manufacturing for our report)	2%	13%	7%	13%
Installation and commissioning (linked to installation for our report)	5%	14%	5%	11%
Operation, maintenance and service (per annum) (linked to operation and maintenance for our report)	33%	43%	34%	43%
Decommissioning (linked to end-of-life for our report)	2%	7%	2%	5%
Total	**48%**	**100%**	**60%**	**100%**

7.3.4. Value chain breakdown

About 600 to 1,100 Scottish companies operate in the offshore wind value chain (Xodus in Scottish Renewables, 2021; Scottish Industry Directories, 2023; ONS, 2023a[15],[16]). To determine the direct performance make-up of the Scottish offshore wind value chain, LCREE data at a UK level were assessed for their value chain breakdown and aggregated across 2019-2021 to obtain more reliable splits across the value chain and account for confidential data. Value chain breakdowns for turnover and FTEs are presented in Figure 11 and Figure 12, respectively; further metrics for each value chain stage are presented in Table 14. After the quantitative data follows the main conclusions for each value chain stage.

[15] These figures are not exhaustive as data is based on memberships and survey responses. There are also enabling companies in the supply chain that will not necessarily report or recognise their activity in one or more of 17 defined sectors (for instance logistics companies).

[16] Current estimated number of businesses across the whole offshore wind value chain is 1,000 according to LCREE (ONS, 2023a), but significant variance surrounds this figure (<500-2,000), and its similarity compared to the estimated number of direct FTEs (3,100) suggests potential gaps in reporting.

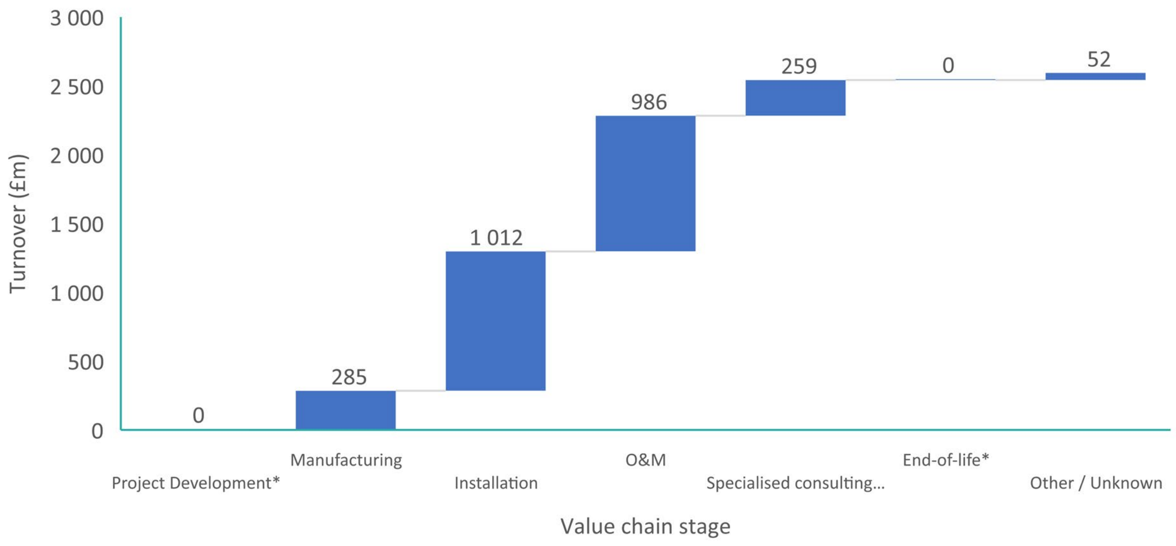

Figure 11: Direct turnover in Scottish offshore wind industry for 2021. Source - Ramboll interpretation of LCREE figures (ONS, 2023a). * - turnover for project development and end-of-life is likely contained within specialised consulting services.

Figure 11 shows LCREE (ONS, 2023a) data for offshore wind turnover in 2021. It shows that installation and O&M have the largest turnover in 2021, with the total turnover coming out to £2,594 million.

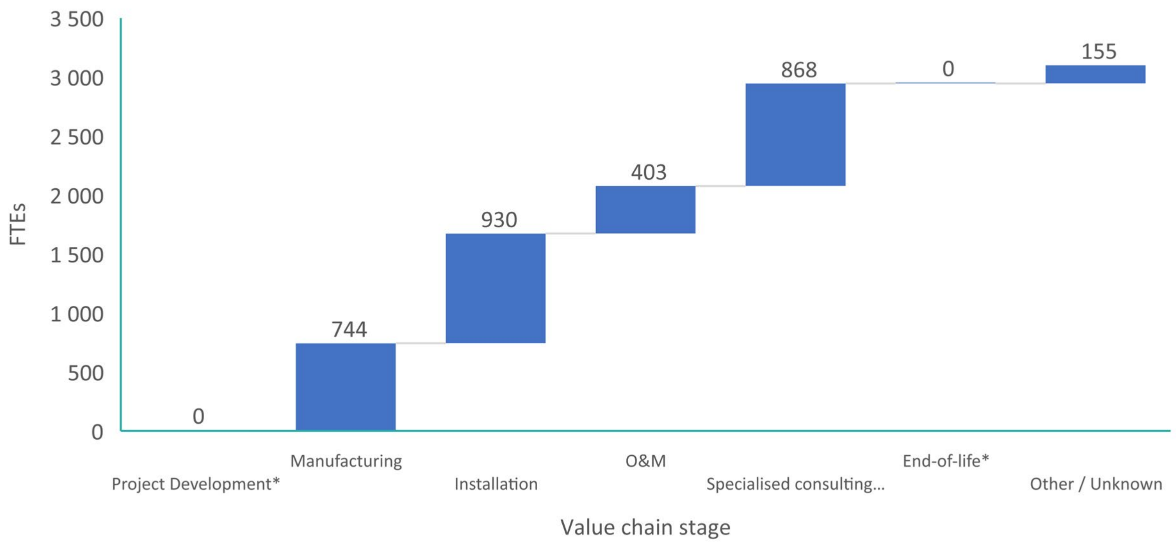

Figure 12: Direct FTEs in Scottish offshore wind industry for 2021. Source - Ramboll interpretation of LCREE figures (ONS, 2023a). * - FTEs for project development and end-of-life are likely contained within specialised consulting services.

Figure 12 shows LCREE (ONS, 2023a) data for offshore wind FTEs in 2021. It shows that installation has the largest number of FTEs in 2021, followed by specialised consulting and manufacturing in second and third. Total FTE in offshore wind in 2021 was 3,100.

Table 14: Breakdown of performance metric estimates for the offshore wind value chain in Scotland. Sources - Vivid Economics (2019) and Ramboll calculations based on LCREE (ONS, 2023a).

	Metric		
Value Chain Stage	**Turnover**	**FTE**	**Turnover / FTE**
Project Development	NA*	NA*	NA*
Manufacturing	£285m	744	£383,500
Installation	£1,012m	930	£1,087,800
Operation & Maintenance	£986m	403	£2,446,000
Specialised Consulting Services	£259m	868	£298,800
End-of-life	NA*	NA*	NA*
Other/unknown	£52m	155	£334,700
Total	**£2,594m**	**3,100**	**£838,800** (average)

* = Likely contained within Specialised Consulting Services.
Value chain figures obtained for Scotland by scaling back UK figures from 2019-2021 to cover confidential figures and increase reliability. Value chain proportions then applied to Scottish overall turnover and FTE figures for the sector.

There is significant activity in the project development stage, which is set to increase, given demand currently exceeding planning assumptions for instance, the ScotWind leasing round revealed ambition of 28GW compared to the ~10GW expected by Scottish Government, ScotWind projects are expected to be delivered "from the late 2020s onwards" (The Crown Estate Scotland, 2022). Quantifying the performance of this stage is complicated by the lack of a dedicated project development value chain stage in LCREE data, however research suggests project development skills and services are more exportable in the offshore sector than in onshore. Stakeholders also cited level of data and knowledge sharing in this stage as a key strength for Scotland enabling competitive advantage, for instance the Marine Data Exchange (The Crown Estate, 2023b).

Offshore wind projects provide more manufacturing opportunities for Scottish companies than onshore wind projects – and manufacturing supports a higher proportion of FTEs within the offshore wind value chain (~24% of total FTEs). This is due to the wider array of components and infrastructure involved in an offshore wind farm, meaning that turbines make up a smaller overall percentage of the total cost. Furthermore, Scottish companies can leverage expertise in other areas of offshore manufacturing and draw upon experience in hosting some of the world's first floating wind farms as well as its established oil and gas sector, this includes subsea cables and cable protection systems, steelwork for platforms and stairways and lighting systems (RenewableUK Export Nation). Offshore Renewable Energy Catapult, based on aspirations outlined by the Offshore wind Sector Deal (BEIS, 2020a), estimate there is scope to double UK content in turbines, from 5% currently to 10% by 2030 (ORE Catapult, 2023, Table 13).

Installation is a particularly important value chain stage for offshore wind, as Scotland strives to hit its installed capacity targets. Installation already provides the highest shares of turnover and FTEs. For the UK to hit its 2030 target, the rate of offshore wind turbine installation needs to triple (Moore, 2022). Again, subsea and oil and gas experience provides opportunity for competitive advantage. This value chain stage offers more export opportunities for offshore wind compared to onshore wind (RenewableUK, 2019), due to the similar challenges faced by different offshore wind installations. For example, RenewableUK (2019) highlight the Norfolk-based company Seajacks, awarded a contract in 2019 to transport and install more than a hundred giant turbines in Taiwan using its specialist vehicles.

Operation and maintenance provide the highest turnover per FTE in the offshore wind value chain. This finding was validated by stakeholders, who also noted, as with onshore wind, that the sudden breakdown of turbine equipment leads to downtime and a significant loss of productivity which often vastly outweighs the cost of the broken component. This is a more domestic value chain service with O&M typically carried out by local companies or contractors due to proximity to the site, exhibited in part by the relatively high percentage (33%) of UK content (defined as the value of all supplies sourced from the UK that accrues as earnings from employment or business profits) used in current O&M expenditure (OREC, 2023).

Key export opportunities for Scotland lie in specialised consultancy services. Exporting knowledge and skills related to many different value chain stages, particularly those which share transferrable skills from Scotland's legacy oil and gas sector and world-leading floating wind industry, allows Scotland to capitalise upon a first mover advantage. RenewableUK highlight that the Orkney-based European Marine Energy Centre (EMEC) has exported its knowledge to 18 countries since 2003. Expertise in wind farm design, wind resource modelling, construction management and financial due diligence are in particularly high demand (BVG stakeholder interview). Stakeholder interviews also confirmed the significance of the international opportunities for Scottish offshore consulting services, stating that even the largest, established developers and energy companies do not have all the skills they need in-house.

Scotland has a key opportunity in the end-of-life stage to apply lessons learned from decommissioning its oil and gas infrastructure and its relatively older onshore wind fleet. Data on end-of-life for offshore wind is lacking due to offshore wind fleets globally still being relatively young, however the ORE Catapult (2021) cites a "real opportunity in decommissioning offshore wind farms" creating a circular economy and long-term employment.

7.4 Strengths, weaknesses, opportunities, and threats of the sector and value chain

7.4.1. SWOT overview and key insights

Significant opportunities exist for Scotland's offshore wind sector, with potential to draw upon existing strengths to realise opportunities and to overcome threats presented by the macroeconomic environment and substantial uncertainty (Table 15). Over the next ten years the sector is likely to become an increasingly important part of Scotland's NZ&CA economy and a key enabler of the transition to renewable energy. Targeted investment and action is required to enable delivery of current goals and realisation of export potential, with supporting infrastructure such as ports and the availability of skills posing potential threats.

Table 15: SWOT analysis overview for offshore wind.

Strengths	Weaknesses
• One of the main strengths for Scotland in offshore wind its first-mover advantage and established position. For instance, HyWind being the world's first floating wind farm. • There are existing strengths in the oil and gas sector which have the ability to be transferred and become strengths in offshore wind, in particular parts of the value chain (labour quality, equipment and transport). However, this strength is more likely to be realised in the longer term, given oil and gas is still an active sector. • Given the potential scale of local projects (e.g. ScotWind) the domestic value chain is somewhat protected from international competition	• Scotland has a general comparative disadvantage in manufacturing, meaning a reliance on imports. • The Scottish wind sector has no turbine manufacturer and with a concentrated international market there are high barriers to entry. • High CAPEX and cost pressure across the value chain means the sector is not yet seen as profitable. • Parts of the value chain cannot be exported due to local geographical conditions • R&D expenditure is currently lower than expected (and more academic than private)
Opportunities	**Threats**
• Scotland and the UK have some of the most ambitious offshore wind installation targets globally, reflecting exceedingly high domestic demand and a strong opportunity for the sector. • Although the recent AR5 results are concerning, demand for UK and Scottish offshore wind has been strong in recent years, evidenced by the level of international demand for ScotWind contracts. If UK-based content can increase in certain value chain stages, there is significant growth potential. • All countries have a skills gap and Scotland is well positioned with possibility to export with high profitability.	• Availability of labour and skills poses a threat to growth and performance in the sector. • Lacking investment in supporting infrastructure and a need for clear direction-ports not currently able to accommodate the scale of floating infrastructure. • Skills and infrastructure from the oil and gas sector, while transferrable to an extent, are not immediately available to meet demand for offshore installation. • The current unfavourable macroeconomic environment (economic growth forecast, inflation, interest rate, etc.) appear to have disincentivised investments in AR5, though these challenges are not unique to the sector and it remains to be seen how the Scottish and UK governments react. • Brexit has created a comparatively more challenging trade environment given a number of key competitors are in the EU.

7.4.1. SWOT insights per category

Conduct: R&D expenditure, investment intensity, and productivity

Anecdotal findings from stakeholder interviews suggest that R&D expenditure is lower than is necessary to capitalise on identified opportunities in the sector (first mover advantage in floating wind, adjacencies with green hydrogen). In addition, there is evidence to show higher levels of academic R&D as opposed to private sector R&D (Scotland's Inward Investment Plan, 2020). Anecdotally, there are some company and project-specific pilots of newer technologies (floating/subsea), though research has not been able to confirm or verify the scale of this. It was also noted by stakeholders that while semi-commercial pilots with high levels of R&D and innovation exist, developers are protective over their learnings.

The level of investment intensity is highly dependent on the specifics of the value chain, but is viewed as a weakness in this analysis in terms of mobilising infrastructure (e.g. ports) to deliver on plans. Stakeholder interviews referenced the US as a comparison in this case, describing their government investment as more aggressive in enabling and ensuring readiness, and not just in response to the Inflation Reduction Act (IRA).

Structure and conditions: Input and cost factors

Costs and quality of labour in Scotland's offshore wind sector are key in this analysis and crucial to realising economic opportunities. Scotland's labour market is skilled and reasonably expensive, with some variation across the value chain. While the competitiveness of Scottish wages does not vary substantially across value chain stages, the relative importance of wage costs (as an input cost) does change. Some parts of value chain are more cost-dependent/cost-competitive, for instance demand for specialised consulting services being less price-sensitive given the level of expertise. 79% of jobs in this sector are deemed to be highly skilled, technical and management roles, and UK offshore wind employment alone is expected to increase by over 220% by 2030 (Offshore Wind Energy Council, 2023). This presents an opportunity for Scotland. Scotland was also identified as having strong education sector strengths in this area, for example with the Energy Transition Partnership, and education and skills in this sector could provide valuable exports.

There are challenges in accessing sufficient skilled labour, so while exporting Scottish expertise is an opportunity there is the risk of displacing or moving employment to international markets. In some parts of the value chain, there is particular synergy with the oil and gas sector, and particular ability to bring across skilled employees. This provides a competitive advantage, though not unique to the Scottish economy. There is also a potential threat here as the transition away from oil and gas is not imminent, and it is possible these skills could be locked up in a lucrative oil and gas professions for years to come (both in Scotland and internationally), so the scale and speed of transferability is debatable.

Structure and conditions: market conditions

Market conditions present opportunities for offshore wind in Scotland, though the impact of global market share depends on the value chain stage. Domestic demand reflects confidence in the sector and Scottish projects (evidenced by Scotwind, "by far the world's largest commercial round for floating offshore wind" (Scottish Government, 2022a)). This strong domestic demand for installed offshore wind capacity (the sector's end product) presents significant opportunity driving the sector forward. Offshore Wind Scotland (2023) describes a potential pipeline of up to 42GW (almost 25GW of which being floating), all of which is noted as potentially deliverable before 2035. This highlights ongoing demand for Scottish offshore wind for at least the next decade and likely beyond, although the recent CFD AR5 results are concerning for the immediate future of the sector in the UK (DESNZ, 2023e).

International demand also presents a significant opportunity for Scotland, particularly in floating offshore wind (DESNZ, 2022a; McNally, 2022). Stakeholder interviews highlighted manufacture of floating technologies as an opportunity given subsea experience (such as cables, platforms), earlier phases of development and there being no clear winner yet. Adjacencies with green hydrogen were also raised as opportunities to explore. As opposed to onshore wind, there is greater exportability across the value chain, e.g. project development and installation, as challenges are more similar across geographies. In relation to domestic demand, international demand is of slightly less importance at this time, given the extent and priority of delivering Scottish projects.

Domestic policy environment

The domestic policy environment in Scotland is favourable to the development of offshore wind, though Brexit and trade policy challenges could pose a threat. The scale of political goals and commitments in Scotland (and the UK), though not directly translating to competitive advantage, are continuing to enable demand for projects despite challenging macroeconomic conditions. UK political support for offshore wind has been cited as a key enabler of investment and deployment of projects, and identified as a lesson that the government should apply to other net zero technologies (Tony Blair Institute, 2022).

The scale of commitments in Scotland's sector policy and regulation presents an important opportunity, driving demand for projects despite challenging macroeconomic conditions. In recent years, the CFD initiative has provided a competitive environment to drive down costs of projects and stimulate innovation – AR4 (DESNZ and BEIS, 2022) illustrated strong demand from industry, backed by government, to install onshore wind, fixed offshore wind and floating offshore wind. However, September 2023's AR5 saw no new offshore wind project bids for the first time, with industry citing a lack of support by UK authorities in the high inflation environment (Pitel, 2023). It remains to be seen how the UK and Scottish Governments will react to this development, and indeed whether and to what extent other projects in the pipeline are impacted (DESNZ, 2023e; Millard and Pickard, 2023).

Macroeconomic environment

The macroeconomic environment is consistent across all sectors and is classified here using the indicators exchange and interest rates, cost level, and economic growth forecast. Scotland's current macroeconomic environment, being largely tied to the UK as a whole, is relatively weak, with a weak exchange rate, high interest rate, high-cost level, and slow economic growth prospects. See section 9.1 for more details.

8 The hydrogen sector

8.1 Main findings

The Scottish clean hydrogen sector is not yet operational at scale. The best available data estimates the sector's size at £20mn turnover and less than 100FTE in 2021. Forecasts however expect the sector to grow, and a much larger scope of companies can be identified with the potential to diversify into the sector. The magnitude of growth should be considered uncertain and dependent on government policies.

The potential supply chain of the hydrogen sector will contain a wide range of goods, services and products. More modular, component-based projects than in the wind sector, create more opportunities for international trade in the supply chain. This exposes more of the value chain to imports, but also creates more opportunities for Scotland to export in niche markets where it can establish a competitive advantage.

Multiple weaknesses and threats explain the current lack of performance in the hydrogen sector. These include lack of demand, weak policy incentives, and high electricity costs. A key threat to Scotland's ability to develop comparative advantage in the hydrogen sector is that policy is now more robustly developed in other contexts, particularly the US with the Inflation Reduction Act providing significant tax breaks (Rep. Yarmuth, 2022; Whitehouse.gov, 2022). Similarly in the EU there is a well-developed ecosystem of regulations, subsidies and programmes available to make hydrogen projects commercially competitive, in support of the EU target of 10 million tonnes of EU production by 2030 (European Commission, 2022).

The overseas policy support packages are driving commercial scale project development, providing the US and EU with first-mover advantage in the deployment of commercial-scale hydrogen production projects and associated infrastructure.

While this may diminish existing advantages that Scotland has from its long-standing programme of hydrogen project piloting and early-stage research and development, it may present opportunities for Scottish component producers and others involved in the sector to deploy knowledge or goods overseas.

There is potential for government and industry to address these weaknesses and threats, for example where feasible, through stimulating domestic demand through policy, building pipelines, and taking advantage of offshore wind build out. Measures are currently being implemented through both the Hydrogen Action Plan and the UK Hydrogen Strategy (see for example Scottish Government (2022c), Department for Business, Energy and Industrial Strategy (2022) and Department for Energy Security and Net Zero (2021)).

Key strengths are the availability of high-quality labour, and existing expertise in the oil and gas sector and supply chain. Niche manufacturers in the oil and gas sector (e.g. of compressors, valves, pipelines, storage tanks) would be able to diversify relatively easily into the hydrogen sector. Many specialist services from the oil and gas and chemical industries are also applicable to the hydrogen sector and are areas of strength in Scotland.

There are expected to be large demands for hydrogen fuels in north-western Europe (IEA, 2021). Some countries (particularly Germany) have started seeking international contracts for state-subsidised purchase of hydrogen fuels. Scottish hydrogen producers could compete for these contracts, albeit Scottish producers are unlikely to be the most cost competitive. Scottish hydrogen costs are likely to be impacted by the inherently high costs of transportation for hydrogen fuels, the current lack of pipeline infrastructure in Scotland for hydrogen transportation, and Scotland's relatively high electricity costs.

8.2 Introduction to the sector

Scotland's clean hydrogen sector is not yet operational at scale. A number of pilot projects and proposals for project development are in place (Scottish Enterprise,2023). Many of these pilot projects have received extensive government funding and support over the years. These include green hydrogen projects that make use of Scotland's extensive renewable electricity generation resources, as well as a long-running pilot and feasibility programme in Aberdeenshire for a blue hydrogen project that would make use of gas fields in the Scottish part of the North Sea for storing captured carbon dioxide (Storegga *et al.*, 2023).

Currently, 99.3% of global hydrogen production if produced by using unabated fossil fuels, resulting in an excess of 90 million tonnes of hydrogen (IEA, 2022). The role of hydrogen in driving decarbonisation is widely anticipated (IEA, 2022; Climate Change Committee, 2020). It can be used as a fossil free fuel and efficiently converted into electric energy through fuel cells. Furthermore, hydrogen plays a pivotal role in facilitating various other hydrogen-based fuels, encompassing ammonia, methanol, and e-fuels, a class of synthetic fuels.

The Scottish Government considers that hydrogen could be a cost-effective approach to decarbonisation where electrification is more costly and technically difficult (Scottish Government, 2022c). This suggest hydrogen would be used most extensively in decarbonising the industrial sector, in replacing existing uses of high-carbon hydrogen, in heavy long-distance transport and in long-distance and heavy shipping and aviation sectors.

The Scottish Government is targeting 5GW of hydrogen production capacity by 2030, and 25GW by 2045 (Scottish Government, 2023a). This would involve the creation of significant amounts of infrastructure, with associated investment. The scale of the economic impact of this will depend on the scale of production, the extent to which that economic value is captured domestically, and the scale at which Scotland can competitively export hydrogen fuels as a commodity. One study for the Scottish Government estimated potential GVA impacts of between £5 billion and £25 billion a year by 2045 for one set of potential hydrogen production scenarios. (Scottish Government, 2023a).

8.3 Current performance of the sector and value chain

8.3.1. Definition of the sector and value chain

The sector definition is used to identify performance data and to drive data investigation and judgements in the SWOT process. The use of an LCREE or LCREE-aligned sector definition is preferred to be able to use a foundational dataset, on a comparable basis, to describe the performance of the sector. For this reason, an adapted LCREE sector definition was used, making use of the 'Alternative Fuels' category included in LCREE (LCREE - ONS, 2023a).

Sector definition (ONS, 2021 p. 1):

- The production, distribution, storage, and commodity trade of 'alternative fuels for low carbon and renewable energy use'.
- This includes: design, development, construction, production, specialised consultancy services and installation of infrastructure for producing energy from 'alternative fuels'.
- The operation and maintenance, design, production and installation of technologies using these fuels. *Including* those for distribution and transmission. *Excluding* technologies for consumption of these fuels.
- Examples of alternative fuels include:
  - Alcohol fuels (ethanol, methanol, butanol)
  - Ammonia
  - Carbon-neutral synthetic fuels
  - Hydrogen produced by electrolysis and low carbon thermochemical processes
  - Low carbon fuels from fossil waste e.g., waste industrial gases or unrecyclable
  - Renewable fuels of non-biological origin e.g., power to liquid

Exclusions**:** Hydrogen produced by thermochemical processes without carbon capture usage and storage ('grey hydrogen'), compressed natural gas and LPG. Biofuels. End uses of fuels and necessary machinery (e.g., hydrogen boilers, alternative fuel vehicles). Energy generation/extraction, wider carbon capture and storage (CCS) infrastructure.

This sector definition was discussed and verified as part of the stakeholder engagement. Much of the complexity of the definition arises from the variety of fuels covered. This was seen to be a benefit, since these fuels are often discussed together with the use of pure hydrogen as a decarbonisation route, for example as 'hydrogen carriers' or as 'power-to-X' technologies. Stakeholders highlighted that the technology or infrastructure that companies were developing or were likely to develop in future would likely be specific to one of these alternative fuels, since they require different specialisations, processes or handling. Despite this specialisation, these alternative fuels are anticipated to function as an integrated 'ecosystem.' By this we mean that hydrogen could serve as a foundational material or process step for many of alternative fuels. This interdependence suggests that these fuels, while individually distinct, will work in harmony to achieve a comprehensive and synergistic approach to decarbonisation.

There are other points worth highlighting in relation to the sector definition:

- It does not include grey hydrogen, which refers to the production of hydrogen from natural gas. This means that existing hydrogen production (of which there is some at the Grangemouth facility) is not captured in the definition. This makes sense from the point of view of maintaining a net-zero and climate-adaptation (NZCA) economy specific definition, which was the objective in this study.
- It does not include end-uses directly such as hydrogen-fuelled vehicles or boilers. We took this decision in order to keep scale of the sector considered manageable. The methodology could be carried out separately for these sectors, to understand more about their potential performance.
- It does not include biofuels. Biofuels are also an alternative lower carbon fuel, with associated economic activity and carbon benefits. This activity is defined elsewhere in the LCREE dataset.
- 'Commodity trade' is added specifically to the definition for the purposes of this study. Understanding the opportunities for the export of the fuel itself was a distinct objective for this sector's analysis, as well as understanding the opportunity for exports from the goods and services produced in the supply chain.

For the offshore wind and onshore wind sectors, an adapted version of the Wind Europe (2020) categorisation of the wind energy industry's supply chain according to the life cycle of a power plant is used: project development, manufacturing, installation, operation & maintenance, and end-of-life. A 'specialised consultancy' services category is added. See appendix 11.4.1 where this breakdown is explained in more detail.

For comparability and consistency with the other sectors analysed, the hydrogen sector is also analysed according to the same value chain breakdown. The LCREE by industry SIC coding component of the LCREE data is used to allocate activity (turnover only in this case) on a proportionate level to different value chain stages. Note that the by industry turnover data is available only on a UK basis, so it is assumed that the value chain breakdown is the same in Scotland as at the UK level, and the Scottish whole sector value is applied with the UK value chain proportions. Because LCREE data for the hydrogen sector reports low level of employment in Scotland, with significant uncertainty in the values, hydrogen sector employment is not considered at the value chain breakdown level. Data was also averaged across recent available data years, to address data gaps and instances where data was suppressed for confidentiality.

As with other sectors, most LCREE SIC industry coded data categories could be mapped onto one of the selected value chain stages, except for specialised consultancy services, which although concentrated in the project development stage are present throughout the value chain and are thus analysed separately. However, a much larger proportion of activity in the hydrogen sector does not map to any of the value chain categories identified for the purposes of this report. This is reflected in the large proportion of data allocated to the 'other sector'.

8.3.2. Turnover, employment, and GVA

As discussed above in section 6.3.1, the LCREE Alternative Fuels data set was identified as being appropriate for use for the hydrogen sector. According to LCREE (ONS, 2023a), the clean hydrogen sector estimated a central value of £20mn for Scottish turnover and approximately 100 FTE employed in the sector in Scotland, in 2021. Most of the data points for the Alternative Fuels sector in Scotland since 2016 have been supressed for confidentiality reasons in the LCREE results, making it difficult to draw trend conclusions. In 2021, turnover in Scotland accounted for approximately one quarter of total UK turnover – a higher proportion than on a population basis and higher than the LCREE average.

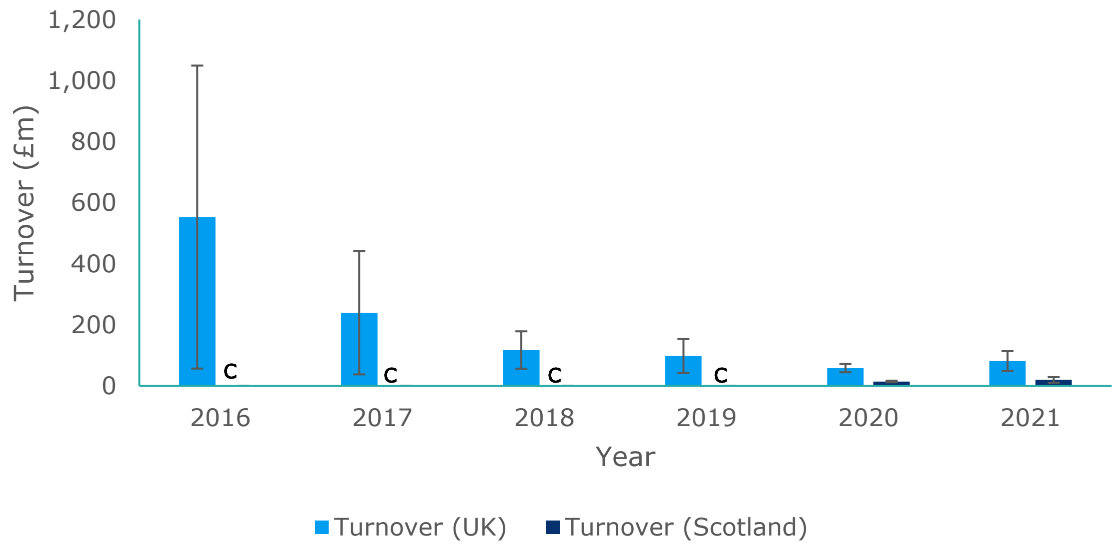

Figure 13 Clean hydrogen sector turnover in Scotland and the UK, 2016-2021. Source - LCREE 'Alternative Fuels' (ONS, 2023a). Values marked as 'c' are where the Scottish estimate has been suppressed for confidentiality reasons in the LCREE data.

Figure 13 shows LCREE (ONS, 2023a) turnover data for clean hydrogen. It shows a significant decline in clean hydrogen turnover from 2016 to 2021.

As most of the data points for turnover in Scotland are supressed for confidentiality reasons, the estimates of UK turnover values are also presented in the chart above. Figure 13 shows that estimates for turnover in England has varied somewhat in the period, implying that the estimated turnover for the remainder of the UK (most of which is likely to be in Scotland) has also varied. The changes in UK turnover that are suggested in the figure above are unlikely to be a significant trend – no underlying reason why the size of the sector might have contracted significantly since 2016 has been identified by this analysis. The overall numbers are small (note vertical axis scale), and the uncertainty is great (note the size of error bars), and so the suggestion from this analysis, is that no trend should be read into the figures, and simply it should be concluded that the hydrogen sector is not operational at scale. This is illustrated by Figure 13 as explained above, Table 13 and Figure 14. The figure below illustrates the number of FTEs in Scotland, which were fewer than 100 in 2021.

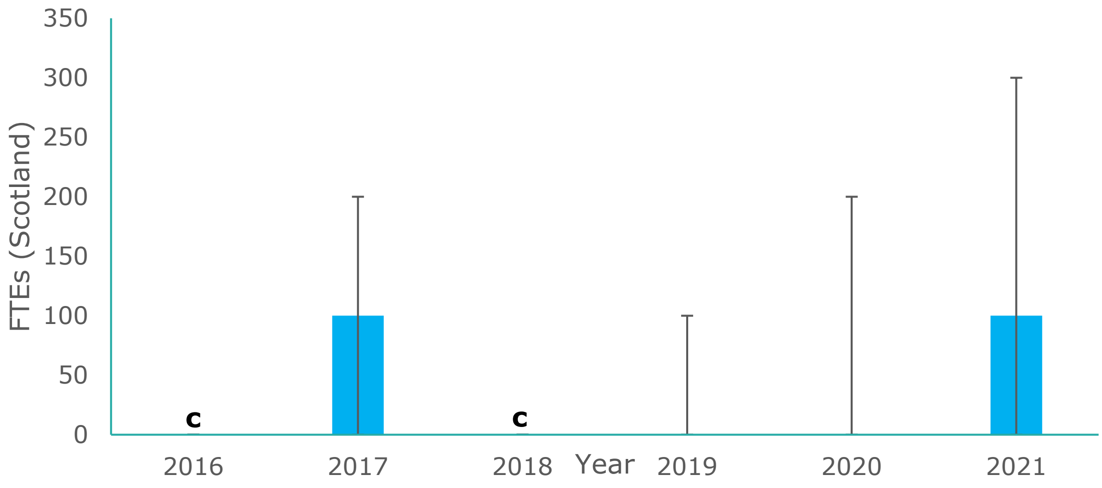

Figure 14: Clean hydrogen sector employment in Scotland, 2016-2021. Source - LCREE 'Alternative Fuels' (ONS, 2023a). Values marked as 'c' are where the Scottish estimate has been suppressed for confidentiality reasons in the LCREE data.

Figure 14 shows LCREE (ONS, 2023a) FTE data for the clean hydrogen sector in Scotland. It shows that 2017 FTE is roughly the same as 2021 FTE. Some of the data has been supressed for confidentiality reasons.

£20million of annual turnover and 100 FTE for the clean hydrogen sector in Scotland makes it currently a micro part of the Scottish Economy, see Table 16. The nascent state of the industry means that it is not possible to estimate indirect or induced levels of economic impact. Other analysis for the Scottish Government (EY, 2023) has also noted that low carbon hydrogen production is not yet operational in Scotland, and that therefore the economic impact is currently negligible.

Table 16: Direct, and Direct, indirect and induced turnover and employment in the hydrogen sector for 2020 and 2021 - illustrating the lack of available data.

	Direct	Direct, indirect, and induced
Turnover (2021)	£20mn[1]	NA
Turnover (2016-21 range)	NA	NA
Employment (2021)	<100 FTE[1]	NA
Employment (2016-21 range)	NA	NA
Gross value added / output (turnover) ratio (2020)	NA	NA

Note: The results on turnover and FTE are approximations and should therefore be interpreted as the best available estimates rather than precise numbers.
Source: [1] = LCREE figures for Scotland (ONS, 2023a).

As discussed in appendix 11.1.2 there are limitations to the LCREE dataset, but it remains the best available current data source. There are large confidence intervals to the data points, and high levels of uncertainty, particularly for Scotland-specific data points.

8.3.3. Value chain breakdown

Using the same methodology used elsewhere in the report (see 11 for explanation), estimates of activity were allocated across the value chain breakdown (Table 17):

Table 17: Value chain breakdown for turnover in the hydrogen sector, 2021. Source - LCREE (ONS, 2023a).

Value Chain Stage	Turnover	FTE
Project Development	NA*	NA
Manufacturing	£2.2mn	NA
Installation	£2.8mn	NA
Operation & Maintenance	NA	NA
Specialised Consulting Services	£6.2mn	NA
End-of-life	NA*	NA
Other/unknown	£8.8mn	NA
Total	**£20mn**	**<100 FTE**

* = Likely contained within Specialised Consulting Services.

Given the lack of available data on current activity in the supply chain in Scotland, further mapping and analysis of future/projected supply chain was carried out, building on other existing work (Arup, 2022; Wood and Optimat, 2022).

We developed the following diagram to show various resources, goods, products and services that are extracted, traded, manufactured and so on throughout a future hypothetical developed green hydrogen value chain (Figure *15*). Coloured blocks show economic activity considered to be included in the hydrogen sector for the purposes of this study. Grey blocks show activity that is not included in the sector definition. Colour coding has been used to map the sector to the value chain definitions used elsewhere in this report (project development, manufacturing, installation, operation & maintenance, and end-of-life).

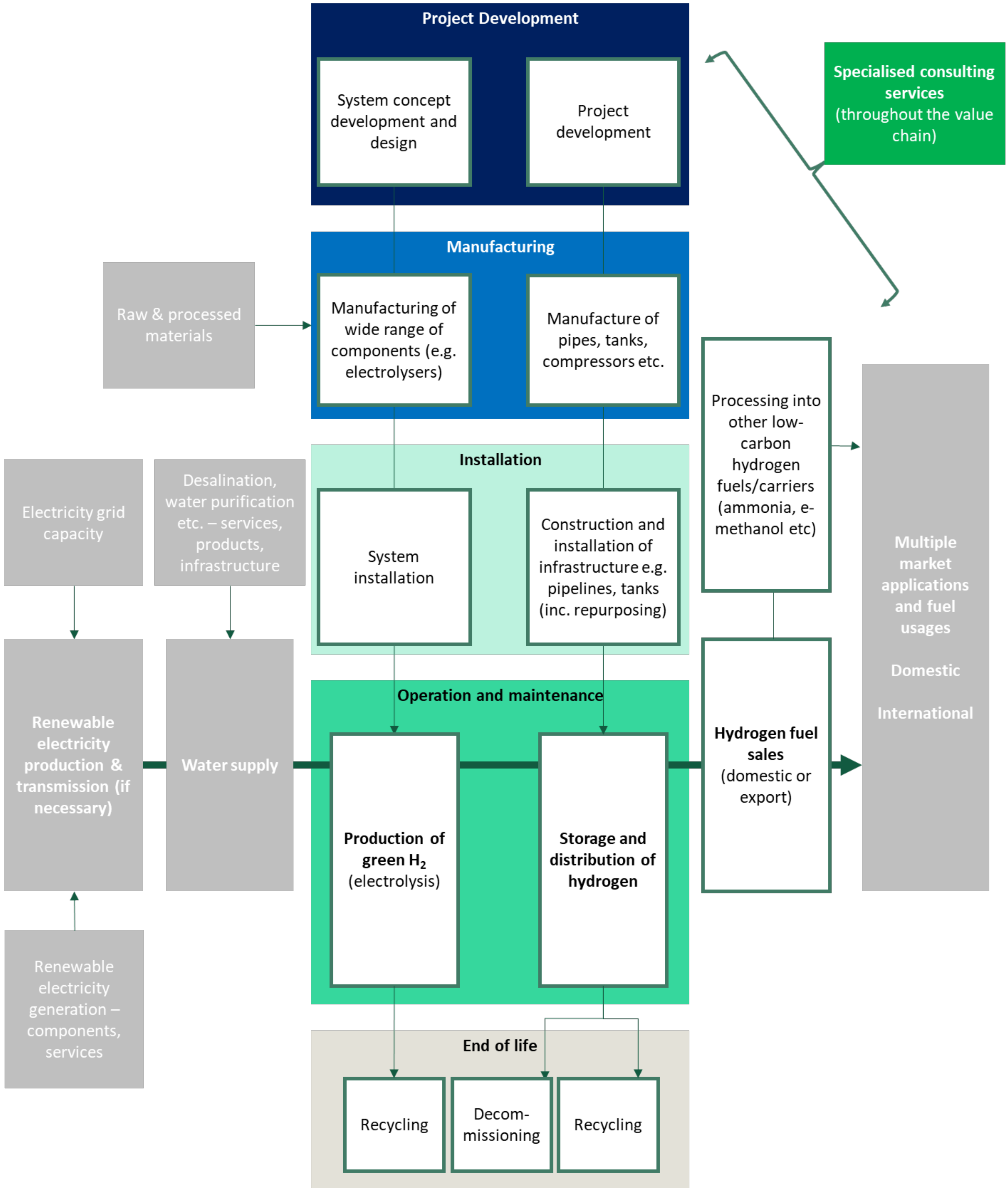

Figure 15: Expanded hydrogen value chain. Source - Ramboll.

The expanded hydrogen value chain is depicted in Figure 15. It takes off in project development including system concept development and design and project development, then moves on to manufacturing including manufacturing of a wide range of components (eg electrolysers) and pipes, tanks, compressors etc. The manufacturing will require inputs such as raw and processed materials, the sourcing of these is however not included in this report. The next step in the value chain is the installation, both of systems and construction and installation of infrastructure such as pipelines etc. The next step is operation and maintenance including production of green hydrogen and storage and distribution of hydrogen. This step requires inputs in the form of renewable electricity and water. Measures to bring these inputs to the electrolysers are also needed. The hydrogen can be sold as hydrogen fuel for domestic use or exported. The hydrogen can also be processed into other hydrogen-based fuels such as ammonia. These will have multiple market applications and can be sold domestically or internationally. The last step of the value chain is the end of life where we find recycling of electrolysers and decommissioning and recycling of storage and distribution infrastructure.

This analysis highlights that a mature green hydrogen sector will likely be complex, with multiple companies and company-types trading multiple goods, products, and services. These value chain products are diverse, and unlikely to lend themselves to deep vertical integration. It is much more likely that there will be wide amounts of firm specialisation.

The hydrogen sector should be considered highly modular, with the manufacture focussing on components. For example, a developed hydrogen fuelling station might include components from a wide variety of companies, and could include storage, compression and onsite electricity generation. Many components (including electrolysers) are scalable, and are already manufactured at different sizes, which can be combined in a system array. This makes this sector less like a specialised infrastructure sector than the wind sector, where project installation is subject to detailed local specific design[17] and a large amount of civil engineering works (i.e. installation). However, it is also not like a highly commodified sector (e.g. vehicles) where products are made for 'off the shelf' purchase by customers. It is somewhere in-between, much like the solar sector, where components are commodified, but there is a significant, specialised design role for amalgamating these components at scale into a system designed for a specific local use case and site conditions. This modular basis for the infrastructure type has major consequences for how export opportunities should be understood in the sector – with the manufacturing and specialised consulting services aspects of the supply chain the most internationally traded. This is explored further in appendix 11.4.1.

It also suggests that companies in some parts of the value chain need not specialise in hydrogen. The Assessment of Electrolysers report identified 246 existing companies in Scotland whose SIC codes suggested an adjacency opportunity, to diversify into the hydrogen sector from existing sectors that they are servicing (Arup, 2022). Similarly, Scottish Enterprise has registered hundreds of Scottish companies with an interest in monitoring the

[17] Turbine design is however in the wind industry becoming increasingly standardised.

hydrogen sector with a view to entering it in future. This also suggests that a hydrogen sector could emerge quite rapidly as companies diversify their existing provision of goods and services, adapting them for the hydrogen sector supply chain.

Finally, this analysis calls into question whether a coherent hydrogen sector will emerge in an economic sense. It is likely, that at the very least some parts of the hydrogen sector will overlap significantly with renewable electricity generation, others with specialised manufacturing (of e.g. compressors), others with the management and distribution of other gases (including fossil fuel gases during the transition) and so on.

It is therefore recommended to keep the definition and supply chain map for the hydrogen sector under review in future if this work is repeated. It is also recommended that future analysis also considers the full breadth of companies who operate both inside and outside the hydrogen sector. Much of this analysis will need to be qualitative, while the LCREE Alternative Fuels dataset is likely to remain the best way to quantitatively measure the sector, albeit with significant caveats. These points are discussed further in section 9.6.

8.4 Strengths, weaknesses, opportunities, and threats of the sector and value chain

8.4.1. SWOT overview and key insights

Multiple weaknesses and threats explain the current lack of activity in the hydrogen sector in Scotland. Most notable are the lack of domestic demand; domestic policy incentives that are still under development; and high input (electricity) and transportation costs. Despite these weaknesses/threats, there is potential for government and industry to influence them, and thereby achieve the growth in the sector that is anticipated in all forecasts (Scottish Government, 2020c; Energy Systems Catapult, 2022; Climate Change Committee, 2020; etc.). The sector can utilise opportunities and strengths arising from Scotland's highly skilled workforce and from existing expertise, companies and skills in the oil and gas sector (Table 18).

Table 18: SWOT analysis overview for clean hydrogen sector.

Strengths	Weaknesses
• There is transferrable expertise, reputation and activity from the oil and gas industry (skills/labour) • Long-standing backdrop of a variety of pilot projects and research (R&D) • Anecdotally, there is evidence of existing firms working internationally on early-stage hydrogen projects from Scotland (global market share)	• Very limited existing activity that can be classed as in the hydrogen sector from datasets (performance) • Limited existing manufacturing of key components of electrolyser systems (global market share)
Opportunities	**Threats**
• Scotland's oil and gas industry has niche manufacturing and specialist services firms that are already exporting, and can diversify to H2 (global market share/productivity) • Significant potential demand in neighbouring geographies (international demand) • Development of infrastructure (pipelines) to reduce transport costs (transport costs)	• Lack of domestic demand for hydrogen (offtakers) that can provide the income to make at-scale projects viable (domestic policy environment) • Commercial scale projects are now being developed in other geographies (productivity) • Macroeconomic environment – relatively high-cost economy, trade relationships – mean high productivity necessary to compete internationally (macroeconomic) • Scottish hydrogen fuel production may not achieve international price competitiveness (input costs, especially energy)

8.4.2. SWOT insights per category

Conduct: R&D expenditure, investment intensity, and productivity

R&D expenditure is an important factor for the hydrogen sector since it is an immature sector. Although all aspects of the technology-set are proven in pilot settings or other sectors, there is a great deal of opportunity for further technology development, efficiency improvements of components (e.g. newer electrolyser technologies), cost reductions and improvements in commercial-scale project delivery.

Based on our analysis, it is possible that much of current activity in the sector could be classified as commercial R&D, since many of the currently operational projects are pilots or non-commercial projects[18]. These current projects are supported by a long-standing set of pilot scale projects that have taken place in Scotland, trialling various forms of hydrogen technology implementation[19]. There is also extensive long-standing academic expertise, for

[18] Scottish Enterprise maintain an interactive hydrogen sector map, which includes current and planned projects (Scottish Enterprise, 2023)
[19] The Acorn Project (Storegga *et al.*, 2023), H100 in Fife (SGN, 2023), and the Aberdeen H_2 Hub (Aberdeen City Council and BP 2023) are examples of pilot projects.

example in the Hydrogen Accelerator (University of St Andrews and University of Strathclyde, 2023), and in the Energy Transition Partnership (Energy Transition Partnership, 2023).

Despite these existing R&D strengths, public sector R&D spending does not compare well for the UK, placing Scotland at a disadvantage. In 2021, the UK allocated only 2.8% of its total public energy R&D spending to hydrogen, reflecting a relative decline from the previous two years. This places Scotland at a disadvantage when compared to other countries with similar strengths, as well as the average investment in hydrogen R&D across the EU. Notably, Norway, Denmark, the Netherlands, and Germany all invested more than 10% of their total public energy R&D spending in hydrogen in the same year. (IEA, 2023).

In terms of commercial sector R&D, we found that projects in other geographies were now moving into commercial scales of delivery, particularly in the US and within EU countries. Stakeholders were concerned that the research and development carried out in the process of implementing a commercial scale of delivery for the first time in other geographies would lead to companies in those other geographies establishing ways of working, techniques, expertise and reputation that would give them a competitive advantage. Since greater R&D expenditure would be occurring elsewhere through commercialisation, this presents a possible risk to Scotland in that it risks losing the advantages gained so far in its academic and pilot-stage research and development.

While R&D represents a positive attribute within Scotland's hydrogen sector, its impact is deemed modest at best when viewed in comparison to the research efforts undertaken by other countries. Moreover, the future strength of R&D hinges on the continuation and successful commercialisation of ongoing research initiatives.

Structure and conditions: Input and cost factors

Stakeholders interviewed for this analysis identified the availability of transferrable skills in the Scottish labour market as a key opportunity for Scotland's clean hydrogen sector. Engineering skills in the oil and gas and chemical sectors were particularly identified, including process engineering, compressed gas pipe operations and maintenance, safety protocols, project development expertise, and energy engineering consultancy. Stakeholders suggested that access to these skills could form the basis of competitive advantage in Scotland. However, these skills are not unique to Scotland's oil and gas sector and are present in other oil and gas producing geographies. Further investigation of specific expertise used to support services exported from the oil and gas sector in Scotland, would allow the identification of potential areas for comparative advantage for Scotland's hydrogen sector, if these skills are applicable and transferrable. Labour quality is therefore identified as an opportunity for the hydrogen sector.

The production of hydrogen is energy intensive. Electrolytic hydrogen requires large amounts of electricity, with energy losses in both electrolysis and in use. Similarly, blue hydrogen production has natural gas as a key cost factor. Scottish electricity prices are currently internationally high, for example the UK had the highest industrial electricity prices amongst all IEA countries in 2021[20] (DESNZ, 2023b). This makes grid-based green hydrogen projects in Scotland non-cost competitive against schemes in other countries. However, in the short-term the lack of demand is a bigger barrier to project development, and subsidies are mitigating the effect of energy costs in other geographies. Longer term, there is potential to reduce electricity costs for hydrogen projects, either through the extensive build out of new offshore wind projects, or through developing 'behind-the-meter?' hydrogen projects that avoid the costs of grid connections. Energy costs are identified as being of very high importance, since they are expected to make up a high proportion of green hydrogen production costs. They are identified as a threat.

Transport costs are inherently high for hydrogen against some of its competitor sectors. Hydrogen has a much lower volumetric density than natural gas, making it more expensive to transport. It also needs careful, specialist handling, because of the small size of the molecule. Long-distance transportation of hydrogen is only cost-effective in pipelines. There are an estimated 2,000km of hydrogen pipeline operational in Europe (IEA, 2022). However, there are not hydrogen pipelines operational in Scotland that could link Scotland to its major potential markets. Although there are potentially opportunities to reuse natural gas infrastructure in future, this will in some cases require reductions in natural gas consumption. Current projects would likely need to use tube trailers, and this is costly since, a tube trailer cannot carry a large amount of hydrogen, even when liquified. Transport costs are therefore identified as a significant threat of high importance (see also Csernik-Tihn et al, 2023).

Structure and conditions: market conditions

A lack of domestic demand is identified as a key threat to the sector, of high importance. Although there are no technical barriers to commercialisation, lack of current demand for clean hydrogen means that there is currently no domestic large-scale market for this sector's final product. In the transport sector, for example, hydrogen fuel cell vehicles have not been able to compete on cost with either electric vehicles or with incumbent petrol/diesel vehicles. In the industrial sectors, potential users of hydrogen are unwilling to pay additional higher costs for hydrogen as a replacement fuel for natural gas (or to invest in the capital costs to transition their systems), and there are not in place sufficient subsidies or regulations to overcome this. Stakeholders identified this lack of demand, a lack of certainty about who the 'offtakers' would be for clean hydrogen fuels produced, as a fundamental barrier to the development of significant, commercial scale hydrogen production projects.

As the table below shows, all forecasts see significant growth in hydrogen production and demand in Scotland, in order to help achieve net-zero targets through decarbonisation of those sectors where hydrogen is likely to be a cost-effective route to decarbonisation. As

[20] The IEA includes in its membership most OECD countries, so the UK has high electricity costs in comparison to EU countries and other major economies including the US, Japan and Korea. For the past 8 years, the UK has maintained industrial electricity prices that surpass 25% of the median price in IEA countries. (DESNZ, 2023b)

the table also illustrates, the magnitude of hydrogen growth is uncertain, and from a demand point of view, is dependent on how many use cases hydrogen is successful in achieving competitiveness with high-carbon fuels and other decarbonisation options (mainly electrification).

Table 19: Scenario forecasts for growth in hydrogen production and demand

	2030	**2045**
6th Carbon Budget, (Climate Change Committee, 2020)	22.5TWh of hydrogen production UK-wide	188.2TWh of hydrogen production UK-wide
Draft Energy Strategy and Just Transition Plan (Scottish Government, 2023a)	5GW of renewable and low carbon hydrogen production in Scotland	25GW of renewable and low carbon hydrogen production in Scotland
Scottish whole energy system scenarios (Thirkill et al., 2022) (BOP scenario)	15TWh of hydrogen demand in Scotland 9TWh of hydrogen production in Scotland	25Twh of hydrogen demand in Scotland 68TWh of hydrogen production in Scotland

The demand for hydrogen is witnessing a global surge, with countries worldwide recognising its potential as a key solution in decarbonising various sectors. The expected low-emission hydrogen consumption in northwest Europe is estimated to reach about 7 Mt hydrogen per year in 2030, see Figure *16*. Germany is at the forefront, but not alone in its pursuit. The Netherlands and the United Kingdom are also expected to be large consumers followed by France. Other countries such as Switzerland and Austria are also actively working towards increasing their hydrogen consumption. These countries have set targets, implemented strategies, and are engaged in research and development projects to drive demand and accelerate the adoption of low-emission hydrogen across various sectors. (IEA, 2022)

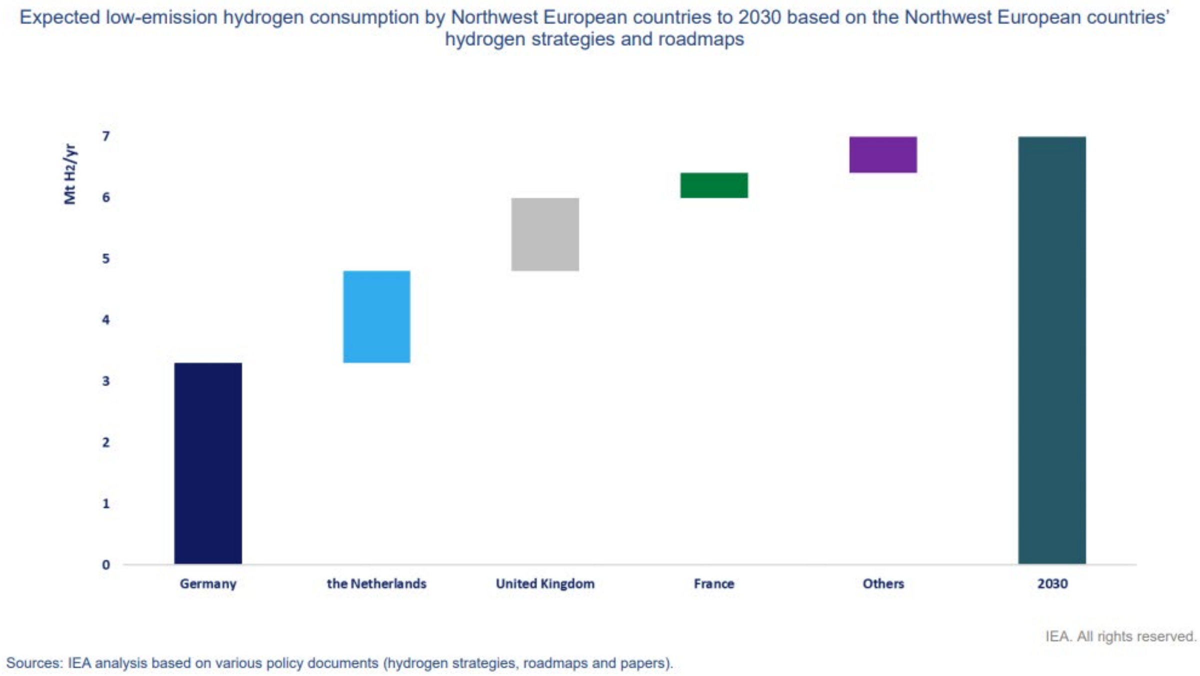

Figure 16: Low-emission hydrogen demand in Northwest Europe could reach close to 7 Mt/yr by 2030. Source IEA, 2022.

Figure 16 shows demand estimates for hydrogen for different European countries in 2030. The estimates come from the IEA, and estimates that Germany will have the largest demand of the selected countries, followed by the Netherlands and then the United Kingdom.

Importing hydrogen is increasingly important to meet demand and ensure a diverse supply. While countries develop their own production capabilities, demand often exceeds capacity. Importing hydrogen bridges this gap and ensures a reliable supply. Collaborative efforts between countries, like importing low-emission hydrogen, foster international cooperation and trade. Importing hydrogen provides access to renewable energy-rich regions, leveraging regional strengths for decarbonisation. Strategic partnerships and cross-border collaborations will play a vital role in meeting global demand for clean energy. (IEA, 2022)

Domestic policy environment

While there are ambitious government targets for hydrogen production within both the Scottish and UK administrations, these objectives are supported by insufficient and incomplete policy incentives. Stakeholders said that they provided weaker financial support than in competitor geographies (particularly the US and EU). In the US, the Inflation Reduction Act puts in place significant tax-credit based subsidies for hydrogen production, providing up to US$3/kg (EY, 2022). In the EU, there is a complex ecosystem of policy support available (EU Commission, 2023), covering extensive grant and subsidy schemes, discounted finance through a hydrogen bank, and a developing EU emissions trading scheme that places a carbon price on industrial, aviation and shipping emissions. These policies are augmented in several EU member states, including the Netherlands and Germany. However, there are domestic policy initiatives in the UK. For example the Low Carbon Hydrogen Agreement, which is a contract that forms the foundation of the hydrogen production business plan (DESNZ, 2023d). This plan will offer financial backing to hydrogen producers, bridging the cost difference between low carbon hydrogen and high carbon fuels. Its purpose is to encourage investment in low carbon hydrogen production and utilisation, with the ultimate goal of achieving the UK government's target of up to 10GW of low carbon hydrogen production capacity by 2030 (DESNZ, 2023d).

For hydrogen projects to achieve commercial scale, policy makers will need to ensure that hydrogen is cost-competitive with unabated natural gas usage, for example through carbon taxation approaches, and through sector-specific policies in the sectors where hydrogen fuels are likely to be a cost-effective approach to decarbonisation (e.g. in the industrial, aviation and shipping sectors).

Since the sector is immature, and there is a need for revenue-generating subsidies or policies to make the sector cost-competitive, the domestic policy environment is considered of very high importance to the hydrogen sector. This factor is identified as a weakness that mainly should be addressed at the UK level.

Macroeconomic environment

The macroeconomic environment is consistent across all sectors and is classified here using the indicators exchange and interest rates, cost level, and economic growth forecast. Scotland's current macroeconomic environment is relatively weak, with a weak exchange rate, high interest rate, high-cost level, and slow economic growth prospects. See section 9.1 for more details.

9 Themes relevant for all sectors

9.1 Challenging macroeconomic environment impacts all sectors and companies

9.1.1. Highest interest rate in 15 years may discourage investments

During 2009-2021 interest rates were very low. Since 2022, the Bank of England has raised interest rates to bring down high inflation. Currently, the interest rate is higher than it has been in the last 15 years (at 5.25% in August 2023) impacting borrowing in the UK, including Scotland (Bank of England, 2023).

Higher interest rates make borrowing more expensive, raise the cost of capital, and make investments more expensive. Service and goods providers also tend to respond to higher interest rates by cutting production. This generally leads to reduced economic activity, which slows down the economy, and produces a generally unfavourable economic macroeconomic environment.

High cost of capital affects sectors with high capital expenditures (Capex) more negatively than other sectors. This is the case for many NZCA sectors requiring large infrastructure investments to reach government targets and meet market demand. However, given the strong political will to expand NZCA sectors and the strong market demand, there is potentially more option for NZCA sectors to find financing or handle higher borrowing costs than traditional sectors.

9.1.2. The economic downturn reduces economic activity and may discourage investments in the short run

The average annual GDP growth rate of UK and Scotland has been 1.62% and 1.32% respectively since 1999. The UK has generally experienced slightly higher growth rates than Scotland.

After a sharp drop in GDP in 2020 (due to the Covid-19 pandemic) and a quick recovery in 2021, projections for economic growth are again negative for 2023 and to slowly pick up again in the coming years, see Figure *17* and ONS (2023b). Reasons for the downturn include the Russian war in Ukraine, high energy prices, high inflation combatted by high interest rates, and lingering supply chain problems since the Covid slowdown. Slow economic growth reduces the general economic activity, may reduce the risk appetite among investors, and reduce the availability of financing, all leading to a reduction in market-driven investments.

Despite general slow economic performance in the UK and across Europe, the Scottish onshore, offshore, and hydrogen sectors are largely driven by government set ambitions, policy, and regulation which can reduce the negative impact of market trends. As the business cycle is relatively short-term, economic growth is expected to return within a few years, meaning that any economic downturn should only impact economic activity and investments over the next few years.

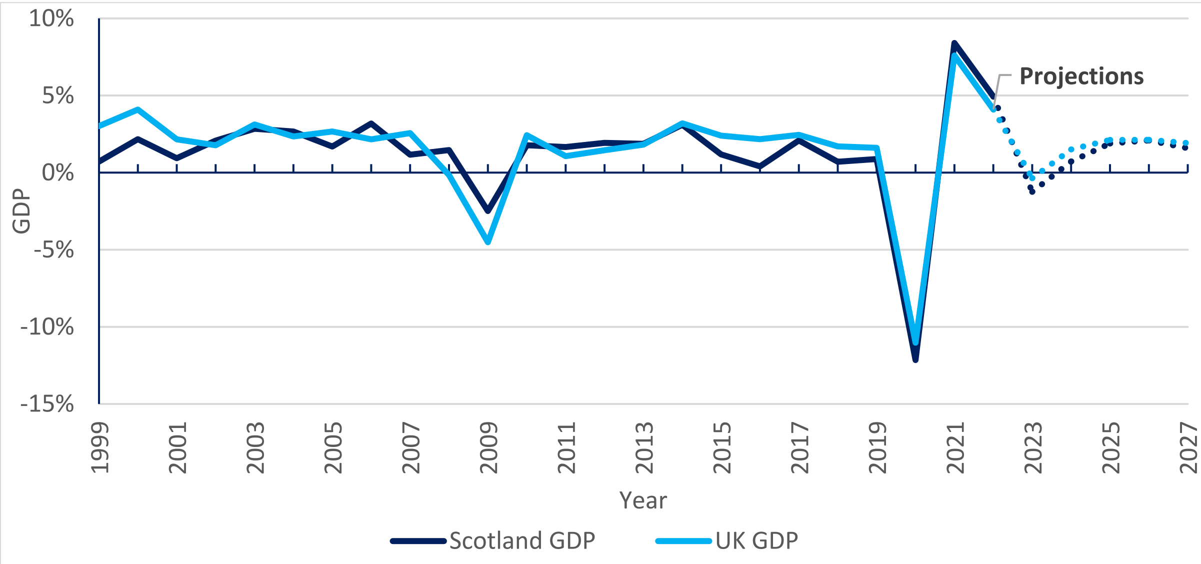

Figure 17: Annual historic and forecasted GDP growth (Scotland and the UK), 1999-2027. Source: Historic: Scottish Government, 2023; ONS, 2023b. Forecast: Forecast Source: Office for Budget Responsibiliy,2022; National Institute of Economic and Social Research – NIESR 2022; Scottish Fiscal Commission, 2022.

This figure shows Scottish and UK GDP from 1999 through to present day and adds projections through to 2027. It shows that GDP growth for Scotland has tended to mirror the UK's GDP growth closely, and that both data trends have tended to hover between 0% and 5%, with notable exceptions due to the 2008/09 financial crisis (a dip of up to 5%) and COVID-19 (where GDP growth dropped to approximately -11% before rebounding to over 7%). Future projections predict a drop in GDP growth to 0%, before a levelling off of at approximately 2%.

9.1.3. The weaker exchange rate can benefit exports, at least in the short term

A currency's strength is measured in relation to other foreign currencies. In the past 8-9 years the exchange rate of the British pound against the US dollar has decreased and remained relatively constant against the Euro, see Figure *18* and ONS (2023c). This indicates that the British pound has become slightly weaker in the last decade.

A lower valued currency makes a country's imports more expensive and its exports less expensive. Hence, a lower valued currency will benefit Scotland in realising export opportunities, but it will at the same time make imports needed for domestic build of NZ&CA sectors more expensive, making the NZ&CA transition more costly.

Whether the weaker exchange rate is an opportunity, or a threat depends on the perspective of the analyst. With an export-oriented perspective the current weaker exchange rate is an opportunity. However, it is difficult to predict how the exchange rate will develop in the future.

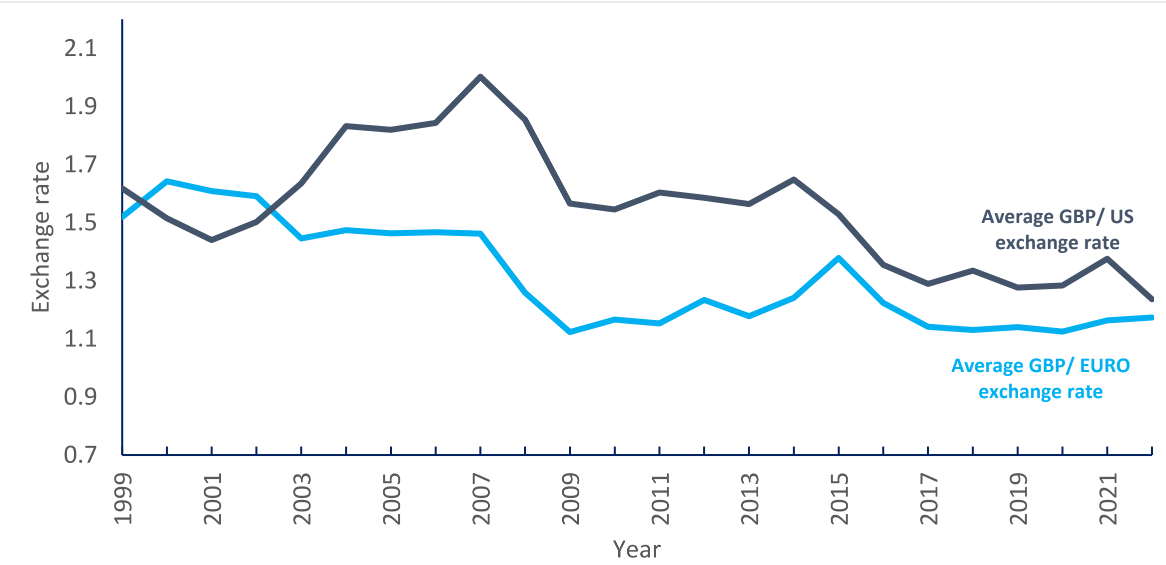

Figure 18: GBP/USD and GBP/Euro exchange rates, 1999-2022. Source: ONS, 2023c

Note: The value on the y-axis measures the relative level of the currencies. A value of 1 for GBP/Euro means that one GBP equals one Euro. A value of 2 means that it 1 GBP is worth 2 Euro, and a value of 0.5 means that one is worth 0.5 Euro.

This figure compares the average GBP / US and GBP / EURO exchange rates since 1999. It shows that the average GBP / US exchange rate has, with the exception of 2000-2002, remained consistently above the GBP / EURO exchange rate, although both have remained between 1.0 and 2.0 across the period.

9.1.4. Scotland is a high-cost country, which is a comparative disadvantage for exporting companies

The UK, including Scotland, has a relatively high domestic price level for goods and services. In April 2023, 11 countries from the OECD had higher price levels than the UK, see Figure 19. However, some of the countries Scotland is likely to compete with on international NZCA markets, like Denmark, Finland, Norway, and United States, have a higher cost level than the UK.

The higher the cost level, the more expensive it will be to produce goods and services in the country unless they are produced in a more efficient way. This poses a general barrier and threat to exporting companies. Therefore, to realise export opportunities, Scotland will need to differentiate via specialisation (i.e., expertise, technological advances, productivity, incumbent experience) to justify the higher costs.

The cost-disadvantage together with the lack of historic manufacturing of turbines in Scotland is likely one reason why Scotland does not have a domestic manufacturer. This will likely continue to form a barrier for turbine manufacturing companies to establish in Scotland.

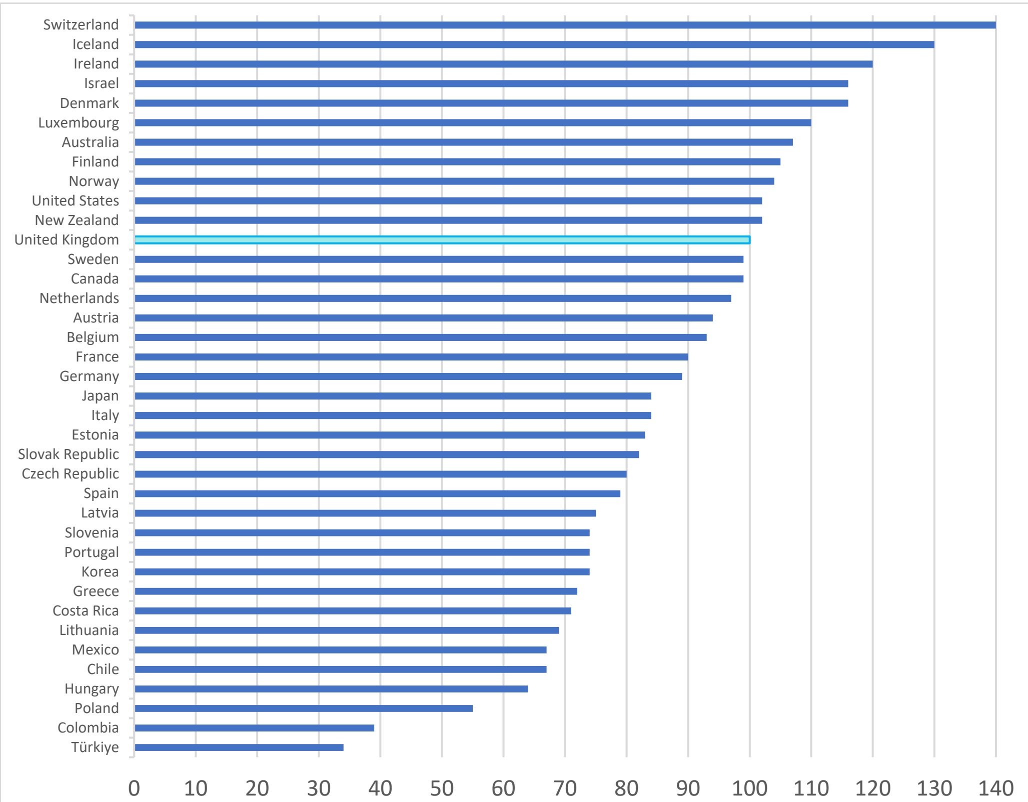

Figure 19: Comparative price levels (PPP) of the UK and OECD countries, April 2023. Source: OECD, 2023

Note: Purchasing power parities (PPPs) is a concept in economics used to compare the domestic price levels of countries despite the countries having different currencies. The PPP is expressed in relation to another country's price level. In the graph, we use the price level in the UK as the norm value (100), and a value higher than 100 means that the price level in the country is higher than in the UK, and vice versa.

This figure assesses the comparative price levels (assessed using purchasing power parity or PPP) of the UK and OECD countries in April 2023. It shows, with the UK's PPP set at 100, that the UK's PPP is competitive, ranking below only Switzerland, Iceland, Ireland, Israel, Denmark, Luxembourg, Australia, Finland, Norway, the US, New Zealand amongst OECD nations.

9.2 Brexit and new trade policy is still uncertain and forms a barrier for trade

Brexit is likely to keep providing regulatory uncertainties and possibly competitive disadvantages for Scottish companies trading with the EU. Since the referendum in 2018 several risks related to Brexit have been voiced, for example risks related to higher trade barriers (Lowe, 2023), lack of market access (McKinsey, 2019) disruptions in internationally integrated supply chains (McKinsey, 2019), regulatory harmonization (Campbell, 2019), investment, and funding for example in research and development (Rowsell, 2022; David, 2023). Some of these risks have been alleviated in recent UK-EU negotiations, while others remain uncertain. One stakeholder we spoke to raised the risk of reduced access to EU investment and funding as a disadvantage for UK companies compared to EU companies.

Brexit, and other international trade policy such as the US Inflation Reduction Act which favours domestic activity in the US, are external factors impacting all NZ&CA sectors Scotland. However, they will impact sectors and value chain stages that are dependent on EU and international trade more than others. We consider Brexit and trade policy in general to be important and to pose a threat for trading companies. Although important, we have not analysed Brexit implications for the analysed NZ&CA sectors in depth.

9.3 Future lack of skilled labour may limit the net zero transition

According to PwC's latest Green Jobs Barometer, Scotland has the most green jobs in the UK (PwC, 2022b). Adverts for jobs with a positive impact on the environment more than doubled in Scotland over the course of 2022, to make up 3.3% of all job adverts in Scotland, well-ahead of the UK average of 2.2%. Demand for such jobs is driven by the energy sector, with the Scottish northeast boasting the largest pool of highly transferable energy-related skills in the UK (PwC, 2022b). UK offshore wind employment alone is expected to increase by over 220% by 2030 (Offshore Wind Energy Council, 2023), part of a global need for more than half a million wind technicians by 2026 (GWEC, 2022).

There is a risk, however, that this demand may outpace supply of labour, and numerous sources highlight the potential for a green skills gap affecting the renewable energy industries. PwC estimates a green skills gap of c.200,000 workers in the UK (PwC, 2022a), stating that approximately 117,000 of the 400,000-strong demand for green jobs are required to join the sector by 2030 and that the UK could be many tens of thousands off the pace to reach a net zero energy workforce by 2050. While stating that "there are no [current] perceived skills gaps in the wind, tidal, nuclear or solar industries as these are well-established in the UK", Green Alliance (Alvis *et al.*, 2022, page 13) suggest that every major sector in the UK needs to close a significant skills gap to enable them to reach net zero, and Weir *et al*. (2023) highlight that a talent shortage is a key concern for the hydrogen economy.

Skills Development Scotland's Sectoral Skills Assessment (Skills Development Scotland, 2022) highlights additional demographic uncertainty surrounding Scotland's future labour market. Scotland's population is anticipated to decrease by 1.5% while it also gets older over the next 25 years, and Brexit has heightened uncertainty about the supply of migrant labour from the EU and further afield – particularly concerning given that EU citizens accounted for 7% of Scotland's energy sector employees, higher than the average for all sectors in the region (Skills Development Scotland, 2022). Between August and September 44.5% of Scottish businesses reported worker shortages (Fraser of Allander Institute in SDS, 2022), and 42.4% reported difficulties recruiting employees (Joseph Rowntree Foundation in Skills Development Scotland, 2022).

Given the demographic challenges faced by Scotland, and that an estimated 20% of the current workforce will have left due to retirement by 2030, it may be beneficial to transfer existing skills from non-green sectors or roles, and retrain staff for the green economy as well as attracting new green entrant employees (Alvis *et al*., 2022). The UK Government acknowledges the scale of the challenge. In 2020, it published the Energy White Paper (BEIS, 2020b) and created the associated Green Jobs Taskforce (UK Government, 2020), and in 2022 announced the launch of a cross-industry digital passport for offshore energy to enable easier transition between sectors (Buljan, 2022). Further investment could support industry collaboration, utilise UK know-how, and facilitate R&D and on-the-ground training initiatives to achieve the scale-up required across green jobs' supply chains (Barnes, 2021). Recommendations provided by Green Alliance range from industry-recommendations for a UK-wide body and framework to match supply and demand regionally, to institution-level green jobs training courses and public campaigns to increase awareness of the benefits of green jobs (Alvis *et al*., 2022).

The evidence indicates that although Scotland has a strength in its high-skilled green jobs, demographic challenges and large demand for these jobs mean that there is a risk of a skills gap affecting many NZ&CA sectors in the future.

9.4 Scotland can utilise its experience and skilled labour in the oil and gas sector

Oil and gas is a core sector of the Scottish economy, responsible for a total GVA of £16bn, or 9% of total Scottish GDP in 2019, supporting 57,000 direct and indirect jobs (EY, 2023). While the sector will remain a significant source of economic activity and employment for years to come, it is forecasted that there will be a marked and continued decline in production in the Scottish North Sea. Numerous sources have called for the need to ensure a just transition and policy intervention minimising negative impacts and managing the decline in oil and gas (e.g., BEIS, 2020; Alvis *et al*., 2022; PWC, 2022a, 2022b; Skills Development Scotland, 2022; EY, 2023).

This sector has created a wealth of knowledge and skills across multiple disciplines that are transferrable across multiple NZ&CA economy sectors. In terms of offshore wind for instance, the Global Underwater Hub survey (ClimateXChange, 2023) shows the primary and secondary sectors of nearly 1000 UK supply chain companies in underwater sectors. While for the majority of companies surveyed (834) report that their primary sector is oil and gas, 495 companies report their secondary sector as offshore wind. Stakeholders we have interviewed suggested that Scotland could have advantages in terms of repurposing existing oil and gas infrastructure and equipment for offshore wind and other marine sectors (for instance platforms and vessels in the installation and operation and maintenance phases). However, the extent to which this is feasible is yet to be determined, particularly for newer larger technologies such as floating wind. Stakeholders also mentioned that higher profitability and wages in the oil and gas sector compared to NZ&CA sectors such as onshore and offshore wind may disincentivise companies and employees from transferring from the oil and gas sectors to NZ&CA sectors, at least in the short term.

According to interviewed stakeholders, the existing oil and gas value chain has some core existing manufacturing strengths that are highly transferrable to the hydrogen sector, for example in compressors, valves, pipelines, and storage tanks. There are also several service areas requiring high-level expertise that are transferrable from the oil and gas sector to hydrogen and possibly other NZ&CA sectors, for example engineering consultancy, process engineering, safety protocols, operation and maintenance of pipelines.

Nonetheless, it is important to remember that the oil and gas industry remains a significant contributor to the Scottish economy, and the transition of jobs and skills from the sector cannot be viewed as a short-term panacea to future green jobs gaps (K2 Management, 2022). Instead, jobs transfers should be viewed as a contributing enabler to the growth of net zero sector supply chains, utilised alongside targeted investments to enable the achievement of the UK's renewable energy targets.

9.5 Many companies are active in several NZCA sectors, as well as in existing oil and gas activity

Our research has shown that many companies operate across several NZ&CA sector definitions (e.g., onshore wind, offshore wind, and hydrogen). For example, project development or construction companies may be involved in the value chains of onshore and offshore wind, or in the value chain of offshore wind, oil, and gas sectors.

A few specific examples are engineering firms (e.g., Wood Group), some of the project developers (Scottish Power), installation companies in the construction sector (e.g., RJ McLeod). See more stylised and illustrative (not based on real companies) examples are given below.

Stylised company examples:

Construction or civil engineering company. Subcontracted for site preparation, installation for onshore wind farm, developing port infrastructure for offshore value chain.

Power generation firm. Project development in onshore and offshore wind generation. Involved as a partner in an integrated hydrogen production facility with onsite renewable generation.

Engineering consultancy. Carrying out feasibility study for a hydrogen refuelling hub in north African country. Supporting offshore wind developer in Scotland with site design. Providing maintenance inspections service to oil and gas companies.

The structure, conditions and external factors influencing these companies can often be more similar in the same value chain stage across different sectors, than they are within the sector. The competitiveness challenges are mostly the same for installation companies in any of the three sectors (they operate in a domestic market with high barriers to international competition).

Our conclusion is therefore that shifting focus from traditional economic sector definitions to NZ&CA definitions is not enough to understand the NZ&CA economy. Instead, research into specific NZ&CA sectors would benefit from a cross-sectoral focus to provide the full picture. The NZ&CA economy is in fact a matrix with new technology-defined NZ&CA sectors (columns) and more traditional economic sectors (or value chain stages) where companies can operate both horizontally across sectors, and vertically within sectors, depending on their individual strengths, weaknesses, opportunities, and threats (Table 20).

Value chain stage	Onshore wind	Offshore wind	Hydrogen	Other NZCA sectors
Project development		Company A		Company A
Manufacturing	Company B	Company B		
Installation	Company C			
Operation & maintenance	Company C			
End of life				
Specialised consulting services		Company D	Company D	

Table 20 The NZ&CA economy as a matrix of NZ&CA sectors and traditional economic sectors

9.6 Domestic services can be exported by opening subsidiaries in other countries

Large parts of the value chains we studied are domestic in nature, for example project development and operation and maintenance (wind). These services are difficult to export, at least with a strict definition of exports where the goods and services are produced in Scotland and sold to other countries, meaning that jobs, economic activity, and tax revenue stay in Scotland. This strict definition is generally applied in this research unless otherwise stated.

However, Scottish companies providing these services could still serve an international market by opening subsidiaries or offices locally in other countries to provide the services there. This will not directly generate Scottish jobs, economic activity, or tax revenue[21]. However, it could lead to benefits including strengthening international relationships, increased labour mobility, and knowledge technology transfers. Such benefits could indirectly boost exports of Scottish goods and services produced in Scotland or increase efficiency in the Scottish value chains. One example of where this has taken place is in the oil and gas sector, which has historically been successful in providing high-skill services internationally and sector-relevant training for employees in other countries. This has provided an export opportunity in itself, as well as a way to build relationships and trade connections that with indirect benefits.

[21] The actual contribution to the Scottish economy would depend on various factors, for example the legal company structure.

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11 Appendix

11.1 Methodology and data

11.1.1. The Low Carbon and Renewable Energy Economy (LCREE) survey, its adoption in the literature, and its limitations

LCREE provides estimates at the UK and devolved country level for turnover, number of businesses, imports, exports, employees (FTEs), and capital investment, classified into 17 defined LCREE sectors. The survey inputs are structured according to standard industry classification (SIC) codes, and sample approximately 25,000 UK businesses, with the most recent available data 2021 (published February 2023).

LCREE is a widely used source, cited by organisations and publications such as: the Fraser of Allander Institute's (FAI) *Economic Impact of Scotland's Renewable Energy Sector* (2022); Scottish Energy Statistics Hub (Scottish Government, 2023); Scotland's Energy Strategy (Scottish Government, 2023); the DESNZ, 2023a); the biennial Energy in Northern Ireland publication (NI Government, 2023); Welsh Government departments (Welsh Government, 2023); and UK Government's Environmental Goods and Services Sector reporting (ONS, 2023d).

Despite its widespread use, LCREE has limitations which must be highlighted.

- Data are collected from a representative sample of organisations in a self-reported survey. Hence, data are associated with wide confidence intervals, limiting the reliability and precision of results.
- Numerous data points are suppressed for confidentiality reasons. This limits the analysis of certain data, e.g., export data. Where possible, we have provided context on what Scottish data may be depending on the non-confidential UK or English data.
- Value chain breakdowns are available for turnover and FTEs only, and then only at the UK-level and according to SIC codes that don't exactly match our study. See section 11.1.2 for how this limitation was addressed.
- Hydrogen is not a listed sector in LCREE. We are assuming the fuel is listed under alternative fuels, an assumption validated with stakeholders.
- Potential double counting across LCREE sectors. Prior to 2014, if a business was active in three sectors it counted as a third of a business in each sector. Since the release of the 2015 estimates in 2017, a business active in each sector was counted as one business within each sector. Given many companies (and therefore employees) work across multiple LCREE sectors (as highlighted by this report), this presents a risk of double counting.

LCREE's limitations must be recognised and its results treated with a degree of caution. Nonetheless, the consistent methodology applied across numerous metrics and sectors, and its wide usage in public reports, means it serves as a useful and probably the best foundational source for the purposes of this project – **provided its data are triangulated and sense-checked against other sources where possible**.

11.1.2. Use of LCREE data in this study and triangulation with other sources

We use LCREE data as the foundational source to inform our performance indicators for each sector. In some instances, e.g., for import and export data, LCREE figures are used directly, and cross-checked with qualitative information to gain insight on the precise goods and services imported or exported. In other instances, LCREE data processed to provide greater insight, e.g., for value chain breakdowns for direct turnover and FTE.

LCREE's value chain breakdowns are based on Standard Industrial Classification (SIC) codes and have been mapped to the value chain breakdowns adopted in this report as shown in Table 21. LCREE provide value chain breakdowns at a UK level only, for turnover and FTEs. Within the value chain data, there are also data points within each year which are "suppressed for confidentiality reasons". To determine the direct performance make-up of the Scottish onshore wind value chain and cover confidential data points, LCREE value chain data were aggregated across 2019-2021 to obtain more reliable breakdowns. Proportions for each value chain stage were then applied to total Scottish turnover and FTE figures, with the value chain breakdown across the UK assumed to be representative of that within Scotland (a hypothesis validated with stakeholders). Where possible, other sources have been used to validate value chain breakdowns – for example Vivid Economics (2018) for GVA/FTE values for onshore wind (Table 9), and Scottish Industries Directories (2023) and Xodus in Scottish Renewables (2021) for number of businesses involved across the offshore wind supply chain (see Figure *25*).

Table 21: Mapping of Standard Industrial Classification (SIC) codes used in the Low Carbon and Renewable Energy Economy (LCREE) survey (ONS, 2023a), as they relate to the value chain breakdowns adopted for the renewable energy sectors in this report.

Value chain stages	Direct, indirect and induced activities
Project Development	No designated LCREE data stage. Discussed with stakeholders and concluded that project development activities are likely to be included within those classified as specialised consulting services (noted in the report).
Manufacturing	Manufacturing
Installation	Construction; Transportation and storage
Operation and maintenance	Electricity, gas, steam and air conditioning supply
Specialised consulting services	Professional, scientific and technical activities; administrative and support service activities
End-of-life	No designated LCREE data stage. Discussed with stakeholders and concluded that, as with project development activities, end-of-life activities are likely to be included within those classified as specialised consulting services (noted in the report).

Other	Agriculture, forestry and fishing; mining and quarrying; water supply (sewerage, waste management and remediation activities); wholesale and retail trade (repair of motor vehicles and motorcycles); information and communication; real estate activities; education; other activities

Where available, other quantitative data are used to triangulate LCREE performance metrics, and these data are referenced throughout the report accordingly. One notable example is the FAI's *Economic Impact of Scotland's Renewable Energy Sector* – data from this study are added to LCREE's direct turnover and FTE figures. The last update of the FAI study (which combines LCREE data with a model for the Scottish economy) provides indirect and induced turnover and FTE data, but the latest year with data is 2020. To provide estimates for 2021, it was assumed that the proportions of indirect and induced data to direct data remained largely consistent between 2020 and 2021; as such, the proportions of indirect and induced 2020 turnover and FTE data to their direct 2020 figures were applied to the updated 2021 direct LCREE figure. The FAI's study is also used to provide GVA and GVA/FTE figures for each sector, as these metrics were not provided in the LCREE database.

Sector-specific quantitative data sources are also used, where possible, throughout the report to validate LCREE findings and increase the reliability of results. For onshore wind, key quantitative sources used included Vivid Economics' *Quantifying benefits of onshore wind to the UK* (2019) (used primarily for its GVA figures), BVG Associates' *Economic benefits from onshore wind farms* (2017) (used for its assessment of local, Scottish, and UK content of eight surveyed wind farms), and BVG Associates' *The Power of Onshore Wind* (2018) (used for its 2030 estimations of domestic content). For offshore wind, ORE Catapult's *Guide to an offshore wind farm* (2023) provided information on the domestic and foreign content of wind farms, and both Scottish Industry Directories (2023) and Scottish Renewables (2021) provided valuable insights into the performance of the sector and are subsequently in the graphs and tables used throughout this report and associated Excel data tables.

For the SWOT analysis for each sector, while LCREE survey data are taken into consideration, those sections of the report are based on both quantitative and qualitative findings, informed by a more thorough literature review and stakeholder interviews.

11.1.3. Data recommendations for the LCREE survey

While recognising the challenges associated with such large-scale data reporting, we suggest the following recommendations to improve the usability of the LCREE survey.

- Turnover and FTE value chain breakdowns were found to be very useful to assess the performance of the sectors analysed in this report. However, the accuracy of our estimates is lowered by the lack of Scotland-specific data for this metric. Breaking down these metrics into each nation of the UK would improve these estimates.
- As the end-of-life value chain stage will become more significant in the coming years and decades, we recommend the inclusion of an "end-of-life" value chain stage in

the LCREE data. It is unclear exactly which SIC codes this stage would map to, however. Producing a dedicated "project development" stage would also benefit users.

- For nascent sectors such as hydrogen (assumed to be listed under "alternative fuels" in this report), the "~" symbol denoting, <£500,000 limits the precision of results. We propose, if the precision of data allow, a lower minimum value to allow the more accurate quantification of the performance of newer emergent technologies.
- A limitation of LCREE noted by stakeholders was the lack of data for indirect and induced figures. Efforts to address this, or to more clearly state the fact that LCREE addresses direct performance figures only, would be beneficial to the user.

11.1.4. Stakeholder interviews

This project involved sustained and constructive dialogue with Scottish Government's Net Zero Economy team, as well as with Scottish Government analysts and representatives from each of the three sector teams. Ramboll expertise covering each sector was also consistently used, but numerous stakeholder interviews were also carried out[22]. Additional stakeholders consulted and links to their respective websites are listed below, alongside the topics covered in discussions:

- Scottish Renewables
  - Topics covered included the confirmation of initial onshore wind hypotheses and reliability of sources. A further discussion with the supply chain team to discuss supply chain breakdowns, key challenges, and opportunities for Scottish companies across the three sectors' supply chains.
- BVG Associates
  - Current movements in the onshore wind sector (sector deal updates, key players); limitations / opportunities at each stage of the value chain.
- South of Scotland Enterprise
  - Discussed, over two meetings, potential barriers to achieving the 2030 targets for the wind industry (particularly competition for skills).
- Scottish Enterprise
  - Research Service team provided valuable further data sources covering all three sectors. Further interviews covered existing activity in the hydrogen sector in Scotland, and the export of hydrogen.
- Net Zero Technology Centre
  - Transferability of oil and gas expertise from oil and gas to offshore wind and hydrogen; floating wind opportunities.
- Energy Technology Partnership
  - Knowledge exchange (hydrogen focus).
- St Andrews University Hydrogen Accelerator

[22] While efforts were made to engage with as many stakeholders as possible, the total number of interviews was limited by the project's lifespan. A longer timeframe would enable more stakeholder engagement for future studies.

  - Challenges of commercialisation of hydrogen and scale-up.
- Scottish Hydrogen Fuel Cell Association
  - Supply chain strengths and international comparisons for hydrogen in Scotland, and the export of hydrogen and hydrogen-based fuels.
- NECCUS
  - International comparisons for Scottish hydrogen and skills.

11.1.5. SWOT analysis – visualisation of results

We assess each indicator along two dimensions: importance and magnitude, as outlined in chapter 3.3. The result of that assessment can be visualised in bubble graphs containing information on importance on the vertical axis and magnitude on the horizontal axis for each of the indicator, see the illustrative example (Figure 20). In the following sections, we present detailed results for the SWOT-analysis of each sector in the form of such bubble graphs. Strengths are labelled in green, opportunities in blue, threats in orange, and weaknesses in grey.

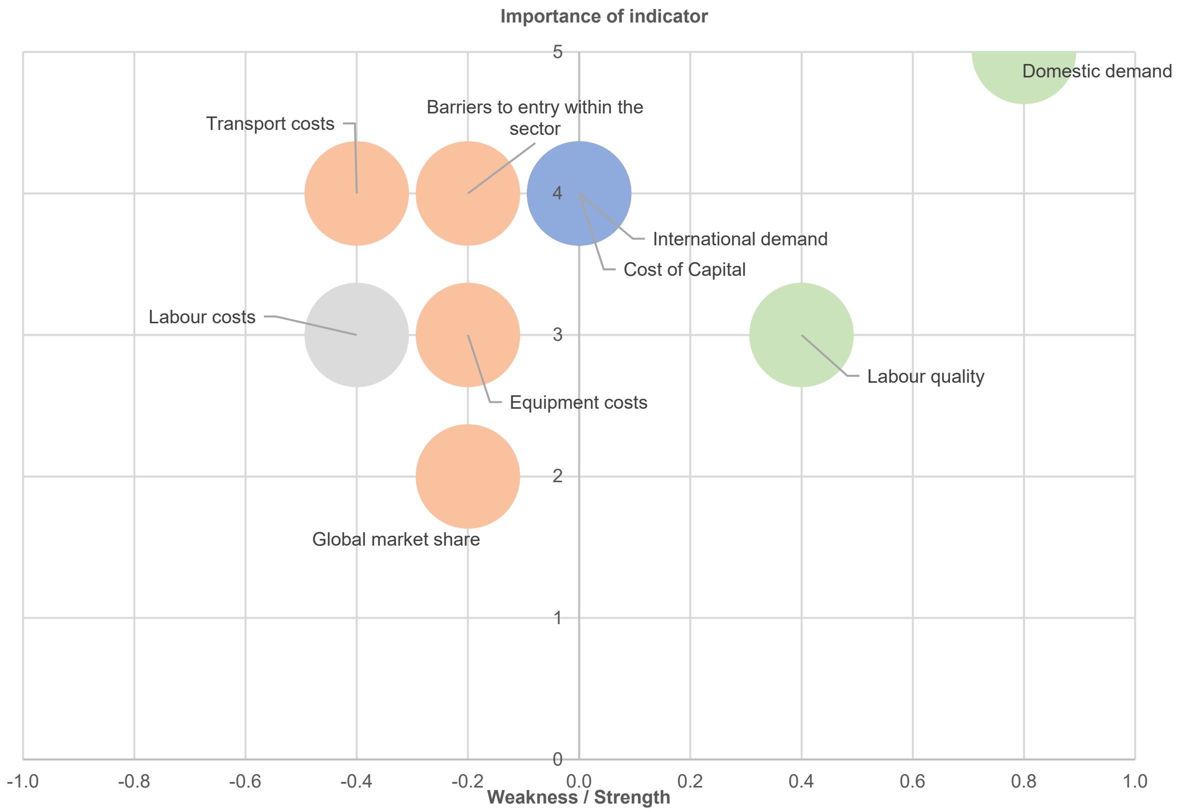

Figure 20: SWOT analysis figure for the structure and condition indicators scoped in for the onshore wind sector analysis, including market conditions, labour, and non-labour costs.

The figure shows that strengths include labour quality and domestic demand, opportunities include domestic demand and cost of capital, while threats include transport costs, barriers to entry, equipment costs and global market share, and weaknesses include labour costs.

11.2 The onshore wind sector

11.2.1. Performance – value chain breakdowns

Further detail covering the value chain for the performance of the onshore wind sector is listed in the following sections.

Project Development

- **Definition**: All stages of project development, including feasibility screening, planning and permitting.
  - BVG (2017) definition - the processes up to the point of financial close or placing firm orders to proceed with wind farm construction, and project management costs incurred by SPR.
  - Wind Energy Ireland – parties and tasks at onshore wind planning and permitting stage include: community consultation and liaison; land options; planning permission; grid connection application process; wind speed monitoring (Heneghan, 2023).
- **Qualitative insights on the value chain stage in Scotland:**
  - **Geographic market**: as is the case with most countries' markets, the Scottish onshore wind sector's project development stage is a primarily localised and domestic market. This is due to the importance of localised expertise, which can be site-specific depending on the unique needs of the prospective wind farm's policy environment, habitats / species, etc. Nonetheless, the international market carries relevance for certain project development services.
  - **Exports/imports**: despite the importance of local expertise, export opportunities do exist for onshore wind in the forms of wind farm design, wind resource modelling, construction management, and financial due diligence. BVG (2017) found Scottish suppliers made up approximately 74% of development expenditure (DEVEX) on Scottish wind farms analysed, 12% of which was local to the wind farm area. In total, UK suppliers made up 94% if total DEVEX on Scottish wind farms (Table 10).
  - **Prospects of the value chain stage**: unlikely to change in the near future, provided continuing support. Onshore wind is an established industry, with the planning stage well-defined and unlikely to shift from being primarily site-specific with added consultancy service export opportunities. Nonetheless, as highlighted by BVG in their scoping of the Onshore Wind Sector Deal (2023) government, authorities, and agencies will need to consider the capacity and capability required to deal with an increased volume of consent applications, as well as play an active role in building and maintaining public support for an

expanded onshore wind fleet in Scotland to ensure the continued approval of planning applications.

Manufacturing

- **Definition**: manufacturing of turbines and other components, including balance of plant.
  - BVG (2017) definition - the activity by wind turbine manufacturers and their suppliers, covering nacelle component manufacture and assembly and blade and tower manufacture. It includes transport, installation and commissioning. It excludes the turbine service agreement.
- **Qualitative insights on the value chain stage in Scotland:**
- **Geographic market**: the majority of the capital cost of a modern onshore wind farm is from the turbine itself (upwards of the two thirds of the cost – Deloitte, 2014). As Scotland (indeed the UK as a whole) lacks a large domestic onshore wind turbine manufacturer, the manufacturing market is more international than other value chain stages for the Scottish onshore wind market. Some manufacture does take place in the UK (Vestas have had a manufacturing presence on the Isle of Wight for 20 years and Siemens Gamesa have had a blade manufacturing plant in Hull since 2016), but the costs associated with local manufacture and domination of the market by foreign suppliers limit domestic content (SPICe Spotlight, 2023).
- **Exports/imports**: export of some turbine components is possible, but this is a value chain stage where Scotland is particularly reliant on imports. BVG (2017) found Scottish suppliers made up only 25% of Scottish CAPEX – a figure which also captured installation. Local firms' contribution was just 2.3% and the UK as a whole only contributed 34% to total CAPEX of Scottish wind farms analysed. At the turbine manufacturing level specifically, Scottish firms supplied only 1.9% of turbine content (local firms' contribution to turbines was just 0.6%, UK firms 3.5%).
- **Prospects of the value chain stage**: unlikely to change in the near future, given the lack of a large domestic onshore wind turbine manufacturer and what is quite a concentrated market. About three quarters of the global market is supplied by ten manufacturers. In Europe, the largest are Vestas (Denmark) and Siemens Gamesa (Spain/Germany). Of the rest, seven are Chinese and one is American. While some of these companies do operate in the UK (e.g., Vestas on the Isle of Wight and Siemens Gamesa in Hull), and there is scope for their UK presence to increase, BVG (2018) estimate that the scale of increase in UK turbine content is relatively modest – at just 10% by 2030, provided the UK can manufacture and supply turbine components, such as towers, blades or bearings, to large overseas turbine manufacturers for use in UK projects.

Installation

- **Definition:** includes civil works, and logistics related to the installation of onshore wind turbines.
    - *BVG (2017) definition - civil works = the activity by civil contractors and their suppliers; covering roads and drainage, crane pads, turbine foundation, meteorological mast foundations, cable trenches and buildings for electrical switch gear, SCADA equipment and its installation, and a maintenance and spare part facility. Electrical works = the activity by electrical contractors and their suppliers, covering cables, electrical switch gear, protection and control system, maintenance facilities and grid connection.*
- **Qualitative insights on the value chain stage in Scotland:**
    - **Geographic market:** Scotland/UK focused, due to the high transport costs associated with machinery and local expertise required.
    - **Exports/imports:** limited opportunity for exports in installation, due to the unique requirements of each onshore wind installation site. Some potential for export of consultancy services such as construction management although notable overlap with project development regarding installation services. BVG (2017) found that civil works was a primarily domestic value chain in the onshore wind sites they analysed. 66% of civil works content was provided by Scottish firms (5.3% of which was local), while 79% of total expenditure was provided by UK firms. Electrical works were found to be less domestic – 18% of electrical works content was supplied by local firms (of which 1.8% was local), compared to 43% supplied by UK firms.
    - **Prospects of the value chain stage:** installation is a potential bottleneck for the expansion of onshore wind in Scotland, due to the need to install 3400 turbines between now and 2030 – the equivalent of a new turbine every day between 2025 and 2030 (Scottish Government, 2022). As highlighted in the Onshore Wind Sector Deal Scoping Report (BVG and Scottish Renewables, 2023), some key issues currently impact the speed at which Scotland can install its planned turbines, including:
        - the lack of available grid connection capacity in Scotland;
        - the present transmission network use of system (TNUoS), which currently places Scottish projects at a comparative disadvantage compared to the rest of the UK;
        - issues surrounding the legal framework around the moving of abnormal loads;
        - the issue of "oversail", where land access rights are required when turbine components pass over the land at the side of the road;

- other considerations related to increasing turbine sizes, such as the availability of suitable cranes;
- legislation is also required to ease the current difficulties surrounding installation of turbines, particularly as wind turbines become larger as the desire for "more impactful" projects increases. Nonetheless, installation will continue to provide strong growth while domestic demand for onshore wind remains high in Scotland.

  - *Note – many of the issues highlighted above originate in the project development phase, but they are considered under installation for the purposes of this report.

Operation & Maintenance

- **Definition:** operation and maintenance (O&M) undertaken during the life cycle of a wind farm, including labour, equipment, and spares operations and maintenance.
  - BVG (2017) definition - Transmission OMS = activity during the lifetime operation of the wind farm, covering grid connection and transmission costs. Wind farm operations, maintenance and service (OMS) = activity during the lifetime operation of the wind farm, including land rental costs, business rates, operations and maintenance costs relating to the wind farm, community benefit funds and environmental costs (Table 10).
- **Qualitative insights on the value chain stage in Scotland:**
  - **Geographic market:** within Scotland, the onshore wind industry is characterised by primarily domestic players, calling upon relatively local resources for operation and maintenance of their turbines (Scottish Renewables stakeholder interview).
  - **Exports/imports:** limited opportunity for export, due to the typical locality of the value chain stage. BVG (2017) reported that 85% of the O&M of Scottish wind turbines surveyed was provided by UK firms, of which 67% were Scottish firms and 25.1% were local to the site. This figure includes decommissioning.
  - **Prospects of the value chain stage:** with the Scottish onshore wind fleet ageing, it is unsurprising that O&M is noted as the most productive (by turnover and GVA, both individually and per FTE) value chain stage according to numerous sources. Sudden breakdown of turbine equipment leads to downtime and a significant loss of production, and analysis by Accenture (2017) found that predictive maintenance represented just 10-30% of overall maintenance activity, highlighting the urgency of most O&M activities and the potential economic opportunities of increasing the overall proportion of predictive maintenance. As the Scottish onshore wind fleet continues to grow as well as age, operations and maintenance is anticipated to remain key to

the sector and will likely expand further its large share of turnover, job provisioning, and productivity. The Scottish O&M is unlikely to transition to an international market, however economic opportunities do exist for onshore wind farm operators, from contracting, procurement and workforce automation to spare-parts supply and benchmarking[23].

Specialised Consultancy Services

- **Definition:** consultancy services across the value chain of onshore wind projects, including asset management, business advice, economic impact advice, due diligence, engineering services, forecasting, investor relations, LCOE, life extension, market analysis, modelling, technical reviews and technology roadmap consulting (see BVG Associates).
- **Qualitative insights on the value chain stage in Scotland:**
    - **Geographic market:** some specialised consultancy services remain localised due to the need for local expertise (e.g., environmental impact assessments). Nonetheless, Scottish onshore wind consultancy services across the value chain of onshore wind projects serve an international market.
    - **Exports/imports:** the value chain stage with one of the highest potentials for export, particularly regarding project planning and end-of-life consultancy services. Consultancy services exported by Scottish companies include expertise in wind farm design, wind resource modelling, construction management and financial due diligence.
    - **Prospects of the value chain stage:** although Scottish offshore wind expertise is more sought after internationally than its onshore wind expertise, specialised consultancy services remains the value chain stage with the one of the highest export potentials for Scotland. These services are primarily linked to wind farm project development, however as the Scottish onshore wind fleet begins to enter the end of its life, there will be further opportunity for the export of specialised consultancy services surrounding repowering / decommissioning. In Europe alone, demand for electricity will more than double by 2050, with wind energy meeting 50% of this demand. Onshore wind is expected to outweigh all other electricity generation types in Europe in 2050, illustrating the strong demand for Scottish Wind Expertise (Fraile *et al.,* 2021).

End-of-Life

- **Definition:** includes repowering (full and partial), life extension, recycling and decommissioning see RenewableUK *et al.*, 2023)

[23] ORE Catapult noted in 2016 (ORE Catapult, 2016) that most benchmarking for onshore wind was undertaken at individual portfolio levels, with very little benchmarking across competing portfolio asset managers, be they owner/operators or service providers.

- **Full repowering –** removal, dismantling, and replacement of the existing turbine infrastructure with new turbines. The layout and number of turbines is most likely changed, with new foundations likely to support larger turbines. Existing infrastructure is re-used where possible, but new connection infrastructure may be needed. Tends to result in increased installed capacity and energy generation.
- **Partial repowering –** includes replanting and refurbishment. Turbines may be replaced, but existing foundations, towers and layout may be kept. Blade lengths may be altered depending on planning conditions. Site output may be increased. May also include improvements such as the renewal or replacement of generation equipment, blades repairs, tower repainting, upgrades to the electrical infrastructure upgrades, operational controls, or communications systems. In all situations, the site and design life of the towers and foundations may be critical in determining the most appropriate course for furthering a site's operating life.
- **Life extension –** involves the operation of an existing asset on an existing site continuing to operate efficiently and safely beyond its initial time-limited planning permission. Assumes the continuing maintenance, repair, and replacement of components of an existing asset within the original planning approved design envelope (potential overlap with operation and maintenance).
- **Recycling and circular economy –** whist 85-90% of a wind turbine can be recycled, long-term solutions still need to be found for turbine blade recycling. The industry is committed to zero-waste turbines and will continue to grow the opportunities for developing and managing projects during and once constructed.

- **Qualitative insights on the value chain stage in Scotland:**
  - **Geographic market:** opportunities for repowering, life extension, recycling, and decommissioning projects within Scotland, and extending lessons learned and expertise to international projects and opportunities.
  - **Exports/imports:** high future export potential for the manufacturing of technical components for onshore wind production as well as professional services around the industry, including design and engineering consulting.
  - **Prospects of the value chain stage:** by 2040, nearly two-thirds of the UK's current onshore capacity will reach the end of its consented lifetime (BVG and Scottish Renewables, 2023). Scottish companies can gain a first-mover advantage and develop a market-leading position thanks to Scotland's relatively old onshore wind farm fleet, particularly if legislation is introduced to support the reuse/recycling of turbine parts (particularly blades, although it must be noted that the passing of legislation in this regard may be outside

Scottish Government's jurisdiction). Another potential opportunity lies in enabling cost-efficient redeployment of wind turbines in developing countries to facilitate their own renewable targets. 74% of people surveyed in Scotland by RenewableUK supported the replacement of old turbines with new ones, once they reach the end of their lifespan. Additionally, 67% of people support installing modern, taller turbines in order to generate more power (Norris, 2021).

- "Repowering is a win-win-win game. The oldest wind farms are usually on the best wind sites but have the least efficient turbines. Repowering them makes the best use of the sites. You can triple the output with 25% fewer turbines. And local communities welcome it, not least when they've already seen the economic benefits of having a wind farm." – Wind Europe CEO Giles Dickson (Wind Europe, 2022b).

11.2.2. Further detail – strengths, weaknesses, opportunities, threats (SWOT) analysis

The following section provides further detail on the process of the SWOT analysis for onshore wind, including all SWOT graphs. All indicators are described in detail in the following sections, excluding macroeconomic indicators, which are considered the same across all sectors and are assessed in section 9.1.

All indicators (Figure 21):

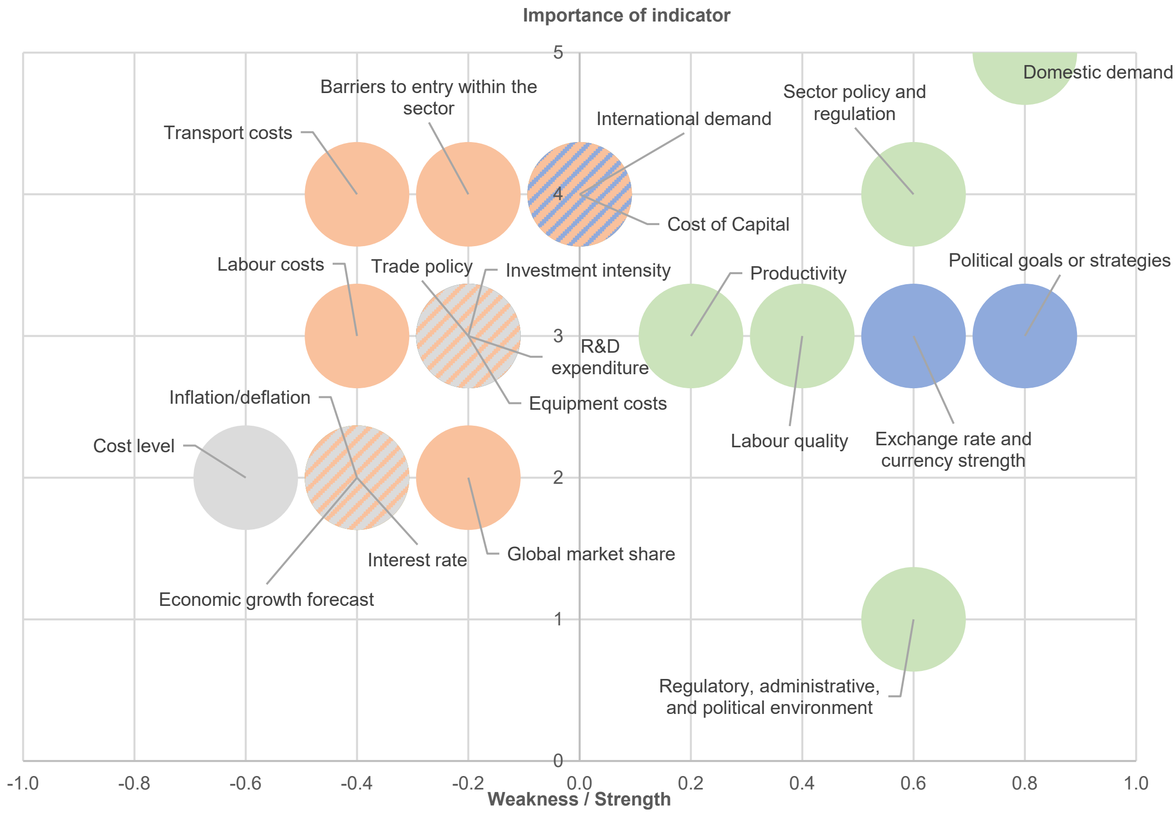

Figure 21: SWOT analysis for all indicators scoped in for the onshore wind sector analysis.

Conduct indicators (Figure 22):

The figure shows that productivity in Scottish onshore wind could be a strength in the sector, while R&D expenditures may require attention (Figure *22*).

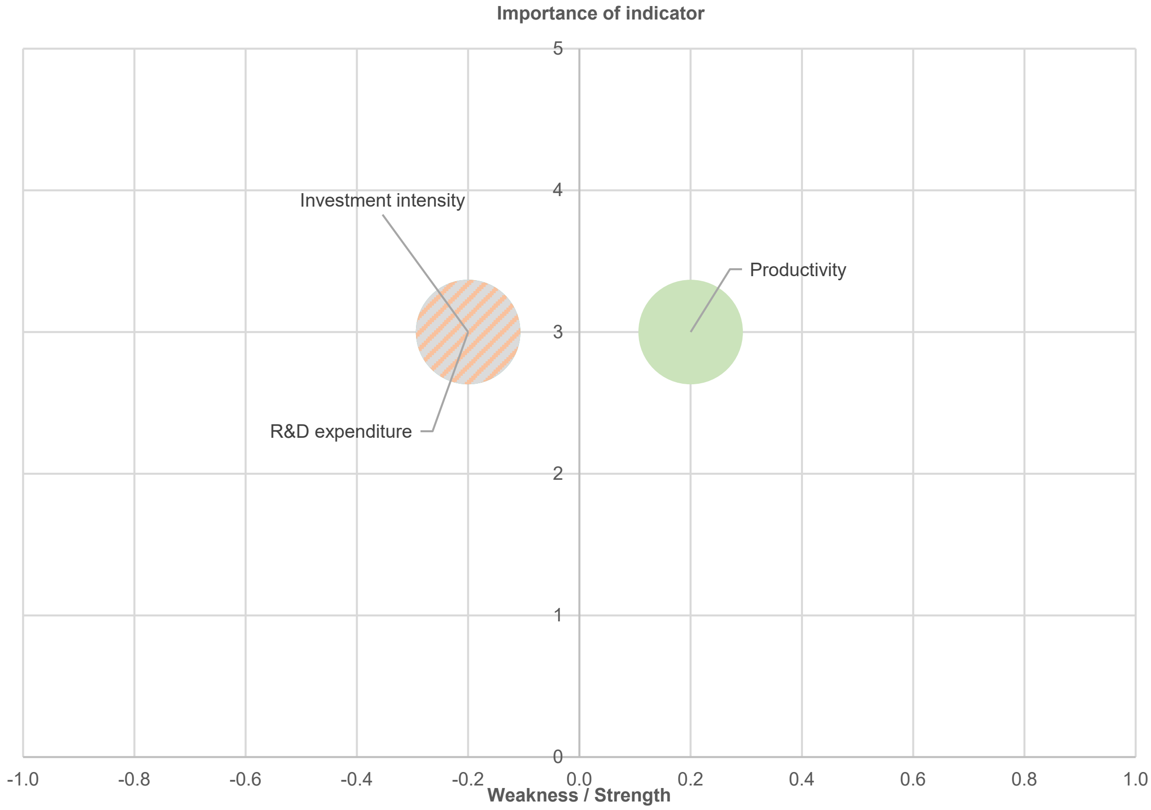

Figure 22: SWOT analysis figure for the conduct indicators scoped in for the onshore wind sector analysis.

The figure shows that productivity is a strength and internal investment and R&D expenditure are weaknesses or threats.

- **R&D expenditure**: Scotland's R&D expenditure is characterised by strong Higher Education R&D (HERD) and relatively weaker Business Enterprise R&D (BERD) (Scottish Government, 2020b). The relative established nature of Scotland's onshore wind industry works against it in this regard, as funding is concentrated towards more nascent technologies and offshore wind, characterising it as a threat. However, BERD in Scotland has increased in recent years, and private sector investment into onshore wind is also expected from companies not currently working in the sector.
- **Investment intensity**: assessed as medium importance, however importance of this indicator is highly dependent on the value chain stage. Some parts of the value chain will require ongoing investment (cranes, equipment, O&M processes, etc.), which other areas (e.g., consulting) are less dependent on investment intensity. Considered a mild threat due to potential investment shifting to onshore, and the need for targeted investment to realise the opportunities presented by e.g., end-of-life, a

largely unexplored value chain stage. Should investment materialise, this indicator can become a strength.

- **Productivity**: high GVA/FTE reflecting and existing strength going forward. Varies by value chain stage with particular opportunities in installation and O&M, confirmed by stakeholders. Slightly less important for younger sector but still significant focus given cost pressures and profitability challenges.

Structure and condition indicators (Figure 23):

Market conditions present opportunities for onshore wind in Scotland, though the impact of global market share depends on the value chain stage. Costs and quality of labour in Scotland's onshore wind sector are key in this analysis and crucial to realising economic opportunities. Scotland's labour force relevant for onshore wind is skills and reasonably expensive, with some variation across the value chain. The primary non-labour costs associated with the Scottish onshore wind industry are equipment costs (related to the installation, maintenance, and end-of-life of wind turbines), transport costs, and costs of capital (Figure *23*).

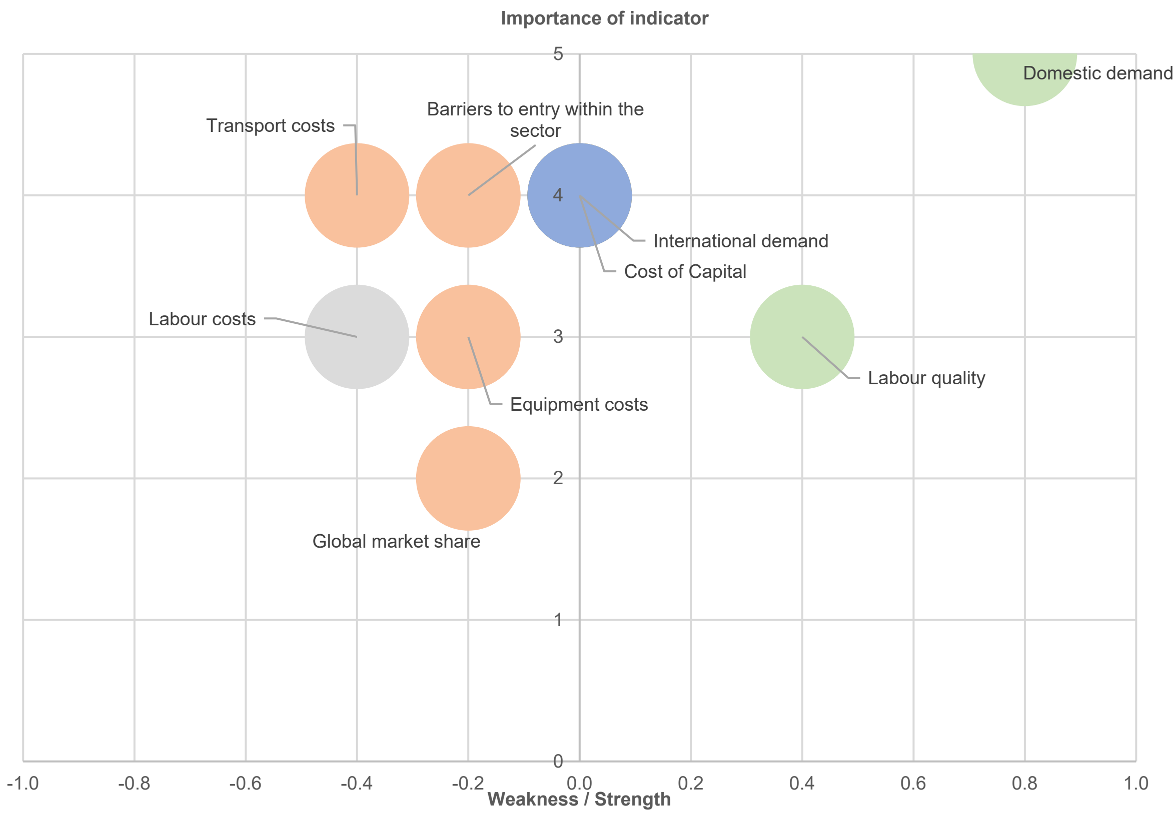

Figure 23: SWOT analysis figure for the structure / condition indicators scoped in for the onshore wind sector analysis, including market conditions, labour, and non-labour costs.

The figure shows that strengths include labour quality and domestic demand, opportunities include domestic demand and cost of capital, while threats include transport costs, barriers to entry, equipment costs and global market share, and weaknesses include labour costs.

- **Domestic demand:** high importance as reflects confidence in the sector and Scottish projects. Strong domestic demand for installed onshore wind capacity (the sector's end product) presents significant opportunity driving the sector forward. Potential constraint due to grid capacity will need to be addressed to unlock full potential however, and demand appetite will need to be maintained as offshore wind demand and installation picks up.
- **International demand:** high importance and an opportunity for onshore wind, due to the possibilities of exporting knowledge and skills related to e.g. project development, end-of-life, and other specialised consulting services. Slightly less of an opportunity than for offshore wind due to high domestic content of projects both in the UK and internationally. Slightly lower importance and scale than domestic demand given the extent and priority of delivering Scottish projects.
- **Global market share:** difficult to ascertain importance in a market which is relatively domestic. Nonetheless, scored as a slight threat due to the lack of turbine manufacturing, which limits Scotland's market share in that stage of the value chain.
- **Labour costs:** comparatively in global terms, labour costs in Scotland are high. This doesn't change substantially across value chain stages, but the relative importance of wage costs (as an input cost) does change. Some parts of value chain are more cost-dependent/cost-competitive, for instance demand for specialised consulting services being less price-sensitive given the level of expertise. Labour costs may also emerge as a key threat as the forecasted skills gap in the sector begins to become more apparent.
- **Labour quality:** labour quality captures the high availability of skilled people in Scotland relevant to the onshore wind industry. There may be challenges in accessing sufficient skilled labour, so there are some threats, and risk of displacing or moving employment to international markets. In some parts of the value chain, there is particular synergy with the offshore wind sector, and particular ability to bring across skilled employees. This enables comparative advantages, though not unique to the Scottish economy.
- **Equipment costs:** this indicator is of medium importance given the capital-intensive nature of the sector. Equipment costs are noted as a slight threat, due to the need to install larger and more powerful turbines, and a potential lack of equipment in the form of larger cranes and haulage vehicles.
- **Transport costs:** more important for onshore wind than for offshore wind, and more of a threat too. High transport costs associated with transporting turbines to sites mean that the installation of onshore wind tends to be a localised value chain stage. Protects Scottish companies for domestic projects, but limits opportunities for Scottish companies to export in project development and installation.
- **Costs of capital:** onshore wind is a capex-intensive industry, where the turbine is expensive to build and then relatively cheap to maintain (this of course varies across the value chain – specialised consulting services aren't capex intensive for example). Cost of capital is currently high due to high interest rates, but the CFD regime reduces uncertainties in future revenues reducing the investment risk and the cost of

capital. However, difficult to ascertain due to high uncertainty associated with recent readmission of onshore wind into CFD.

Domestic policy environment indicators (Figure 24):

This figure illustrates that the domestic policy environment in Scotland is favourable to the development of onshore wind, though Brexit and trade policy challenges could pose a threat (Figure 24).

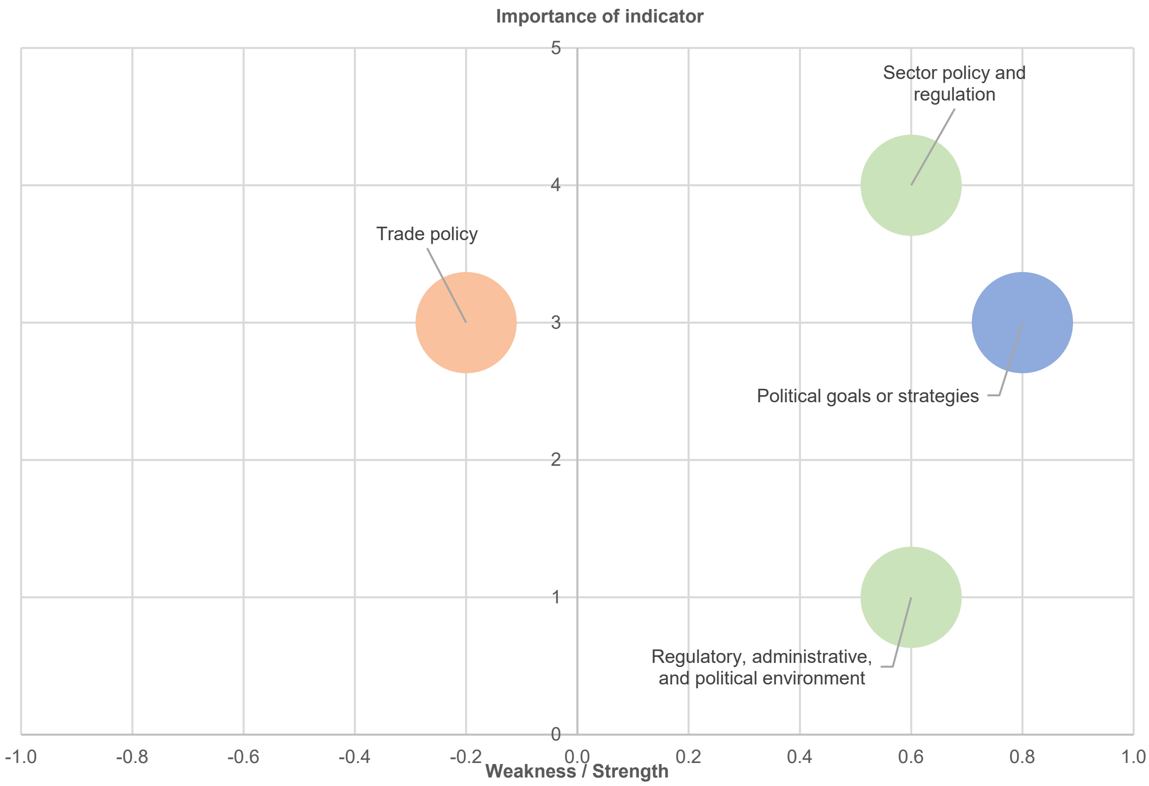

Figure 24: SWOT analysis for the domestic policy indicators scoped in for the onshore wind sector analysis. This figure shows sector policy and regulation, and regulatory, administrative, and political environment are both strengths for Scottish onshore wind, political goals or strategies represent an opportunity, while trade policy is a threat.

- **Trade policy**: medium importance due to the high domestic content of the supply chain both in the UK and internationally but requirement for import of goods and skills in the future. A weak threat given that key competitors are within the EU and Brexit has made trade more challenging (see macroeconomic slide at the end of the report for more detail).
- **Regulatory, administrative, and political environment**: low importance as not sector-specific (trade policy is also not sector-specific, but is more impactful for the sector). The UK has a high ease of doing business ranking and Scotland is generally an open and stable regulatory environment. This is a relative opportunity for businesses in Scotland, in comparison to other geographies.
- **Sector policy and regulation**: high importance and opportunity given the scale of commitments in Scotland, driving demand for projects despite challenging

macroeconomic conditions. Includes the consenting environment and associated regulation which influences project approval, as well as the CFD initiative. Unclear how the readmission of onshore wind into CFD will impact competition with offshore wind, but CFD initiative provides a competitive environment to drive down costs of projects and stimulate innovation.

- **Political goals or strategies**: relatively high importance and strong opportunity. Though this does not directly translate to competitive advantage, the scale of commitments in Scotland (and the UK) are continuing to enable demand for projects despite challenging macroeconomic conditions. Particularly key to maintain this in an environment where offshore wind is growing in importance.

11.3 The offshore wind sector

11.3.1. Performance – value chain breakdowns

Non-exhaustive estimates for the number of businesses directly involved in the offshore wind industry are provided by LCREE (ONS, 2023a), Scottish Industry Directories (2023), and Xodus in Scottish Renewables (2021). These data are illustrated in Figure *25*, including the wide error margins surrounding LCREE's estimate, but should not be relied on due to the high uncertainty surrounding both the non-exhaustive nature of the estimates and the reporting challenges surrounding whether a business classifies itself as involved in the sector or not (e.g., logistics companies). More useful conclusions from this data potentially originate from the value chain splits offered by Scottish Industry Directories and Xodus – these are cited in subsequent sections.

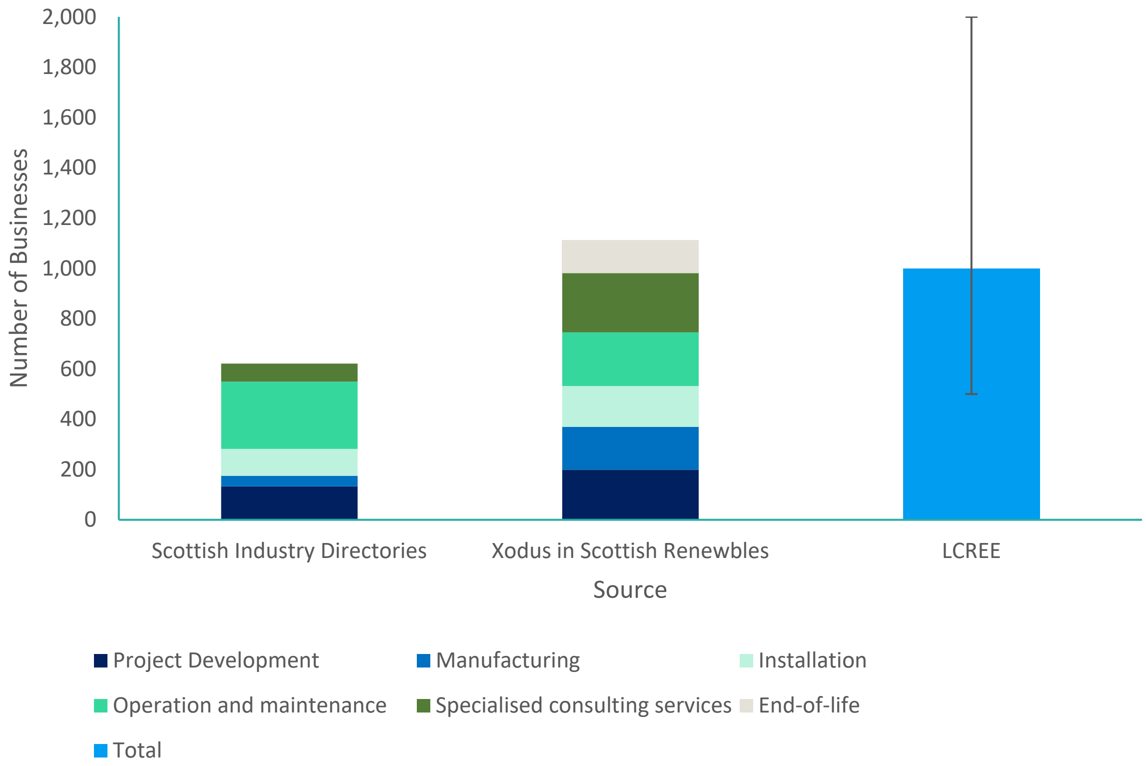

Figure 25: This figure shows estimates for the number of businesses directly involved in the offshore wind sector, as discussed in the accompanying text. Sources - LCREE (ONS, 2023a); Scottish Industry Directories (2023); Xodus in Scottish Renewables (2021).

Further detail covering the value chain for the performance of the offshore wind sector is listed in the following sections.

Project Development

- **Definition:** All stages of project development, including feasibility screening, planning and permitting.
- **Active Scottish companies:** Wind farm planning can involve a wide array of small and large companies, however, the exact breakdown is difficult to ascertain due to the lack of a dedicated "project development" activity in UK / Scottish Government Databases (LCREE). Other metrics for project development (e.g., turnover, FTE) are likely to be included under "specialised consulting services", where they are likely to contribute heavily through services such as planning, project management, environmental surveys and other project development services.
- Across the wind energy sector, major UK developers do exist, including two of the top 25 wind farm developers globally (SSE and RES Group – Bobo Woodworth, 2021). Offshore, the major British developers working in the UK include SSE. SSE state that that of 1,112 companies active across the OSW lifecycle, 199 (18%) were involved in the project development value chain stage (Xodus in Scottish Renewables, 2021). Companies may also be linked to the project development stage indirectly through sector support or sector coupling. Of 621 companies listed on Scottish Industry

Directories as being active in offshore wind, 133 (21%) were listed as involved with development and project management (Scottish Industry Directories, 2023).

- **Qualitative insights on the value chain stage in Scotland**
  - **Geographic market:** international. Compared to onshore wind, the project development value chain stage for offshore wind is less localised. Local expertise is high, however challenges faced with planning offshore wind farms are more common across geographies.
  - **Exports/imports:** in 2019, RenewableUK's Export Nation estimated that the 'UK exports of wind energy products and services were worth £525m a year' with 47 firms exporting to 37 countries, and 70% of contracts in the offshore sector (Norris, 2019).
  - **Prospects of the value chain stage:** in part enabled by historically strong government support through the Contracts for Difference (CFD) scheme, the UK has led the world in offshore wind deployment and until recently had more offshore wind than in any country. The recent AR5 results have dealt a blow to domestic installation ambitions (DESNZ, 2023e). However, with many other countries scaling up their own offshore wind installation, there is potential for export of Scottish offshore skills and knowledge, especially as offshore wind projects increase in their size, distance from shore and complexity. For Scotland, there is a particular opportunity to capitalise on knowledge of floating offshore wind due to its deep-water sites.
  - **Prospects of the value chain stage:** in part enabled by strong government support through the Contracts for Difference (CFD) scheme, the UK has led the world in offshore wind deployment and until recently there was more offshore wind in the UK than in any country. With many other countries likely to follow suit, there is potential for export of offshore skills and knowledge, especially as offshore wind projects increase in their size, distance from shore and complexity. For Scotland, there is a particular opportunity to capitalise on knowledge of floating offshore wind due to its deep-water sites.
  - Moving forward, project development is likely to attract significant demand in the coming years, despite AR5's poor results for offshore wind (DESNZ, 2023e). The ScotWind leasing round of 2022 (which revealed ambition of 28GW compared to the ~10GW expected by Scottish Government) "reflected market ambitions which exceed current planning assumptions". ScotWind projects are expected to be delivered "from the late 2020s onwards" (The Crown Estate Scotland, 2022). The British Energy Security Strategy (DESNZ, 2022b) has also set out new planning reforms to streamline the project development of new wind farms, including cutting the approval times from four years to one. Such streamlining measures provide opportunities to ease frictions in this stage.

Manufacturing

- **Definition:** manufacturing of turbines and other components, including balance of plant.
- **Active Scottish companies:** SSE state that that of 1,112 companies active across the OSW lifecycle, 171 (15%) were involved in the manufacturing value chain stage (Xodus in Scottish Renewables, 2021). No dedicated manufacturing value chain stage is listed on the Scottish Directories Industry website, but of 621 companies listed as being active in offshore wind, 42 (7%) were listed as involved with wind turbines and 84 (14%) were listed as involved in balance of plant functions (manufacturing of non-turbine elements), meaning over 20% of companies involved in offshore wind in Scotland may be involved in the manufacturing stage (Scottish Industry Directories, 2023).
- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market**: international. Offshore, the turbine makes up much less of the overall cost compared to onshore, as the necessary grid connections and installation are more costly than onshore developments.
    - As mentioned in section 11.2.1, some manufacture does take place in the UK, but the costs associated with local manufacture and domination of the market by foreign suppliers limit domestic content.
    - **Exports/imports**: there are more opportunities for Scottish companies to manufacture and export components for offshore wind than onshore wind, including subsea cables and cable protection systems, steelwork for platforms and stairways and lighting systems (RenewableUK, 2019). In particular, floating offshore wind presents an opportunity, through Scotland's experience in hosting some of the world's first floating wind farms and ability to draw on its established oil and gas sector.
    - **Prospects of the value chain stage**: there is limited opportunity for Scotland to engage in large-scale domestic manufacturing of wind turbines in the near future. About three quarters of the current global market is supplied by 10 manufacturers. Two are European (Vestas of Denmark, and Siemens Gamesa (Spain/Germany)), seven are Chinese, and one is American.
    - Nonetheless, the UK Government has announced plans to double UK content of offshore wind farm turbines from 5% to 10%, and there are some signs that "wind energy related manufacturing" maybe increasing in Scotland. Plans have recently been announced to build electricity cable production plants in Ayrshire and Easter Ross (Spice Spotlight, 2023). ORE Catapult (2023) also state that UK content in the "balance of plant" value chain stage is anticipated to increase from 2% to 7% of overall content.
    - Floating wind also presents an opportunity for Scotland to utilise its first-mover advantage – RenewableUK expect reductions of 65% in turbine cost by

2030, and reductions in cost from two to five times for floating wind foundations (Ebbesen, 2021)[24].

Installation

- **Definition:** includes civil works, and logistics related to the installation of offshore wind turbines.
- **Active Scottish companies:** SSE state that that of 1,112 companies active across the OSW lifecycle, 162 (15%) were involved in the transport and installation value chain stage (Xodus in Scottish Renewables, 2021). Of 621 companies listed on Scottish Industry Directories as being active in offshore wind, 107 (17%) were listed as involved with installation and commissioning (Scottish Industry Directories, 2023).
- **Qualitative insights on the value chain stage in Scotland:**
    - **Geographic market**: international. As with other value chain stages, the installation stage of offshore wind operates at a more international scale than for onshore wind, due to the similar challenges faced by different offshore environments.
    - **Exports/imports**: more export opportunities exist for UK (and Scottish) companies for installation of offshore wind than onshore. For example, RenewableUK (2019) highlight the Norfolk-based company Seajacks, awarded a contract in 2019 to transport and install more than a hundred giant turbines in Taiwan using its specialist vehicles. Scottish knowledge surrounding floating wind is also particularly valuable, due to the nation's first-mover expertise. Nonetheless, installation makes up just 5% of total content in both current and 2030 scenarios outlined by ORE Catapult (2023).
    - **Prospects of the value chain stage**: significant demand on this value chain stage expected. While installation times of turbines decreased by approximately 70% between 2000 and 2017 despite increasing distances to shore (Lacal-Arantegui et al., 2018), the rate of wind turbine installation needs to be tripled for the UK to hit its 2030 target (Moore, 2022). Scotland will need to capitalise on its expertise on adjacent sectors such as oil and gas and onshore wind to meet the skills challenges of meeting this target, while aiming to increase domestic content.

Operation & maintenance (O&M)

- **Definition:** O&M undertaken during the life cycle of a wind farm, including labour, equipment and spares operations and maintenance.
- **Active Scottish Companies:** SSE state that that of 1,112 companies active across the OSW lifecycle, 213 (19%) were involved in the operation and maintenance value

[24] It should be noted that there exists the potential for a "first-mover disadvantage", whereby Scotland invests significantly in relatively untested technology which others then follow suit on at a fraction of the price.

chain stage (Xodus in Scottish Renewables, 2021). Of 621 companies listed on Scottish Industry Directories as being active in offshore wind, 183 (29%) were listed as involved with installation and commissioning (Scottish Industry Directories, 2023).

- The Crown Estate noted that in 2022, 10 major players dominated the ownership of operating and under-construction wind farms, totalling 70.5% of the market. Of this, 12.4% was owned by SSE and 2.5% by Greencoat UK Wind (The Crown Estate, 2023a). However, with subcontracting and activity by third-party local providers high in O&M (Phillips *et al.,* 2013), this is less impactful than for other value chain stages.
- **Qualitative insights on the value chain stage in Scotland**:
    - **Geographic market**: local/national – exhibited in part by the high (33%) UK content in current O&M as listed by OREC. O&M is typically carried out by local companies or contractors due to proximity to the site.
    - **Exports/imports**: limited opportunity for export, due to the typical locality of the value chain stage. However, this also protects local companies and reduces Scottish reliance on imports for O&M.
    - **Prospects of the value chain stage**: moving forward, ORE Catapult project the local content in operation and maintenance to increase only marginally (Local content in O&M is projected to move from 33% of overall spend to just 34% by 2030 – ORE Catapult, 2023). However, the large percentage of O&M costs to overall wind farm costs means that although this value chain stage is already considerably localised, efficiencies can result in major cost savings to wind farms overall.
    - This value chain stage is also set to grow in importance as the offshore wind fleet increases and ages. Already, total operational capacity in the UK stands at 13.7GW, 45% of the European offshore wind total and 24% if the global offshore wind total (The Crown Estate, 2022a). Data compiled by ORE Catapult (2021) estimated that the UK offshore wind O&M market will grow faster in relative terms than any other offshore wind sub-sector market over the next decade, becoming the UK's second-largest sub-sector market after turbine supply and providing a projected £1.3bn per year. While much of the UK's fleet is established off the coast of England, Scottish strong UK and Scottish Government pushes to further enlarge the fleet ensures that Scotland will continue to benefit from this growth.

Specialised consulting services

- **Definition**: consultancy services across the value chain of onshore wind projects, including asset management, business advice, economic impact advice, due diligence, engineering services, forecasting, investor relations, levelised cost of energy (LCOE) consulting, life extension, market analysis, modelling, technical reviews, and technology roadmap consulting.
- **Active Scottish companies**: SSE state that that of 1,112 companies active across the OSW lifecycle, 236 (21%) were involved in the sector support and sector coupling

value chain stages (173 and 63, respectively) (Xodus in Scottish Renewables, 2021). Of 621 companies listed on Scottish Industry Directories as being active in offshore wind, 72 (12%) were listed as involved with development and project management (Scottish Industry Directories, 2023).

- **Qualitative insights on the value chain stage in Scotland**:
  - **Geographic market**: international. Some specialised consultancy services are typically localised due to the need for local expertise (e.g., environmental impact assessments), but in general offshore wind consultancy operates at a more international market compared to onshore wind. Consultancy services and expertise in areas such as wind farm design, wind resource modelling, construction management and financial due diligence are in particularly high demand on the international market.
  - **Exports/imports**: the value chain stage with one of the highest potentials for export for offshore wind. In part due to its established offshore oil and gas industry and early floating wind expertise, Scottish offshore wind expertise is sought after internationally and therefore specialised consultancy services is a significant source of export potential for Scotland. For example, RenewableUK highlight that the Orkney-based European Marine Energy Centre (EMEC) has exported its knowledge to 18 countries since 2003, working on 12 offshore wind, wave and tidal projects with China, Ireland, Kenya, Serbia, South Korea and the USA in 2018 and 2019 alone (Waugh, 2023). Expertise in wind farm design, wind resource modelling, construction management and financial due diligence are in particularly high demand.
  - **Prospects of the value chain stage**: projected to retain its importance, particularly as Scotland continues to develop its floating wind capabilities and other countries seek to develop their own offshore wind expertise as they aim to 'catch up' with world leaders in the field (Waugh, 2023).

End-of-life

- **Definition:** includes repowering (full and partial), life extension, recycling and decommissioning.
- **Active Scottish companies:** SSE state that that of 1,112 companies active across the OSW lifecycle, 131 (12%) were involved in the end-of-life value chain stage (Xodus in Scottish Renewables, 2021). Of 621 companies listed on Scottish Industry Directories as being active in offshore wind, none were directly listed as being involved with the end-of-life value chain stage, although activity is likely to be captured in other categories (Scottish Industry Directories, 2023).
- **Qualitative insights on the value chain stage in Scotland:**
  - **Geographic market:** International. Globally, over 3.5GW of offshore wind capacity will reach its end of operational life by 2035 if no other action is taken (Spyroudi, 2021). With the Scottish (and UK as a whole) fleet typically

reaching this stage before the global average, domestic end-of-life skills will be in international demand.

- **Exports/imports:** effective knowledge of recycling, repowering, or decommissioning offshore wind farm components provides a potential market and opportunities for export and trade.
- **Prospects of the value chain stage:** due to the relatively young age of the Scottish (or indeed any) offshore wind fleet, limited information is available on the end-of-life value chain stage for this sector. ORE Catapult estimate that about 600 offshore wind turbines will need to be decommissioned by 2030 (Spyroudi, 2021). Expertise from the relatively older onshore Scottish wind fleet, and from the decommissioning of offshore oil and gas platforms can both be utilised to develop the most cost-effective end-of-life option. In 2014 oil and gas decommissioning in the UK was estimated to be between £30-£40 billion (Scottish Government, 2014). The ORE Catapult cites a "real opportunity in decommissioning offshore wind farms" creating a circular economy and long-term employment.
- Analysis from ORE Catapult has looked into the most economical solution for the end-of-life stage for offshore wind turbines (Spyroudi, 2021). They suggest that partial repowering (with a 10MW turbine upgrade in a 210MW offshore wind farm site) has the highest NPV of £221m, extending the wind farm's life for a further 25 years and its electricity generation by 34,575GWh. Life extension was noted as the second most economically attractive option, while total and partial decommissioning were not found to offer any wind farm revenue return to the developer. Nonetheless, end-of-life remains an understudied value chain stage for offshore wind, representing just 2-7% of total undiscounted lifetime spend and 12% of total capital cost (Spyroudi, 2021; ORE Catapult, 2023). End-of-life is projected to increase in relevance drastically in the coming decades as the Scottish fleet is installed and ages.

11.3.2. Further detail – strengths, weaknesses, opportunities, threats (SWOT) analysis

The following section provides further detail on the process of the SWOT analysis for offshore wind, including all SWOT graphs. All indicators are described in detail in the following sections, with the exception of macroeconomic indicators, which are considered the same across all sectors and are assessed in section 9.1.

All indicators (Figure 26):

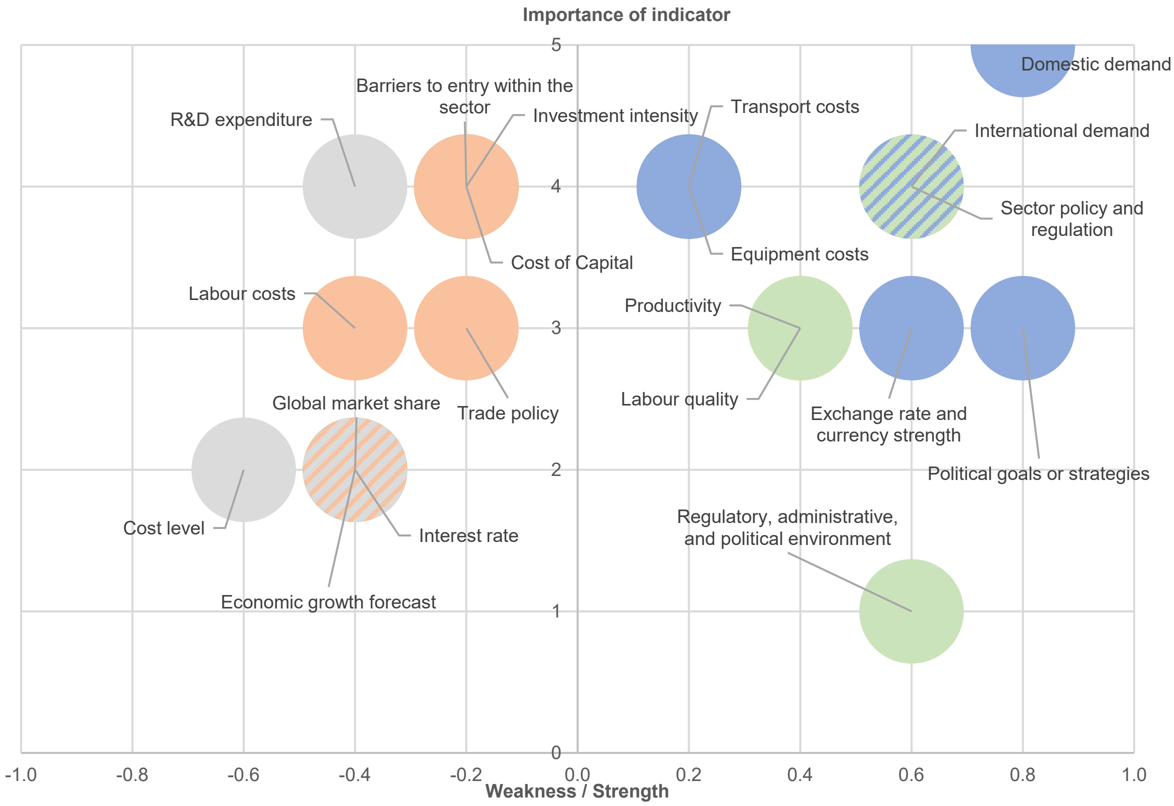

Figure 26: SWOT analysis for all indicators scoped in for the offshore wind sector analysis.

This figure illustrated all indicators assessed for offshore wind in Scotland. Strengths include labour quality, productivity, and regulatory, administrative and political environment. Opportunities include political goals or strategies and transport costs. Threats include barriers to entry within the sector and trade policy. Weaknesses include R&D expenditure and cost level.

Conduct indicators (Figure 27):

This figure shows that productivity in Scottish offshore wind could be an opportunity in the sector, while R&D expenditures may require attention (Figure *27*).

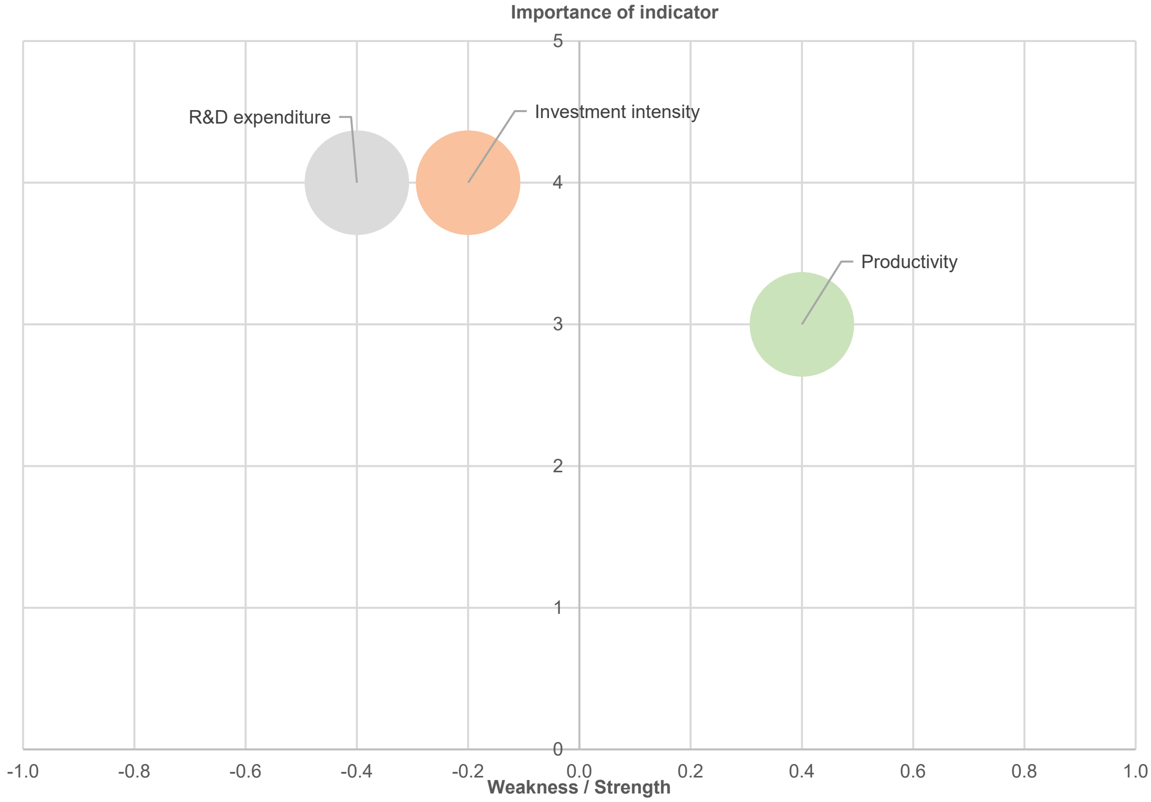

Figure 27: SWOT analysis figure for the conduct indicators scoped in for the offshore wind sector analysis.

This figure shows productivity as a strength for offshore wind, investment intensity as a threat, and R&D expenditure as a weakness.

- **R&D expenditure**: Anecdotal findings from stakeholder interviews suggest that R&D expenditure is lower than is necessary to capitalise on identified opportunities in the sector (first mover advantage in floating wind, adjacencies with green hydrogen). There is evidence to show higher levels of academic R&D as opposed to private sector R&D. Stakeholders also raised that there are some company and project specific pilots of newer technologies (floating/subsea), though research has not been able to confirm or verify the scale of this. It was also noted by stakeholders that while semi-commercial pilots with high levels of R&D and innovation exist, developers are protective over their learnings. This sector-specific metric is of high importance due to the technologies being in earlier stages of development (particularly floating). This indicator should be further tested and researched.
- **Investment intensity**: highly dependent on the specifics of the value chain but a weakness in terms of getting infrastructure (e.g. ports) ready to deliver on plans. US used as a comparison who have been more aggressive with their investment.
- **Productivity**: high GVA/FTE reflecting and existing strength and opportunity going forward. Varies by value chain stage with particular opportunities in installation and

O&M, confirmed by stakeholders. Slightly less important for younger sector but still significant focus given cost pressures and profitability challenges.

Structure and condition indicators (Figure 28):

Market conditions present opportunities for offshore wind in Scotland, though the impact of global market share depends on the value chain stage (Figure *28*).

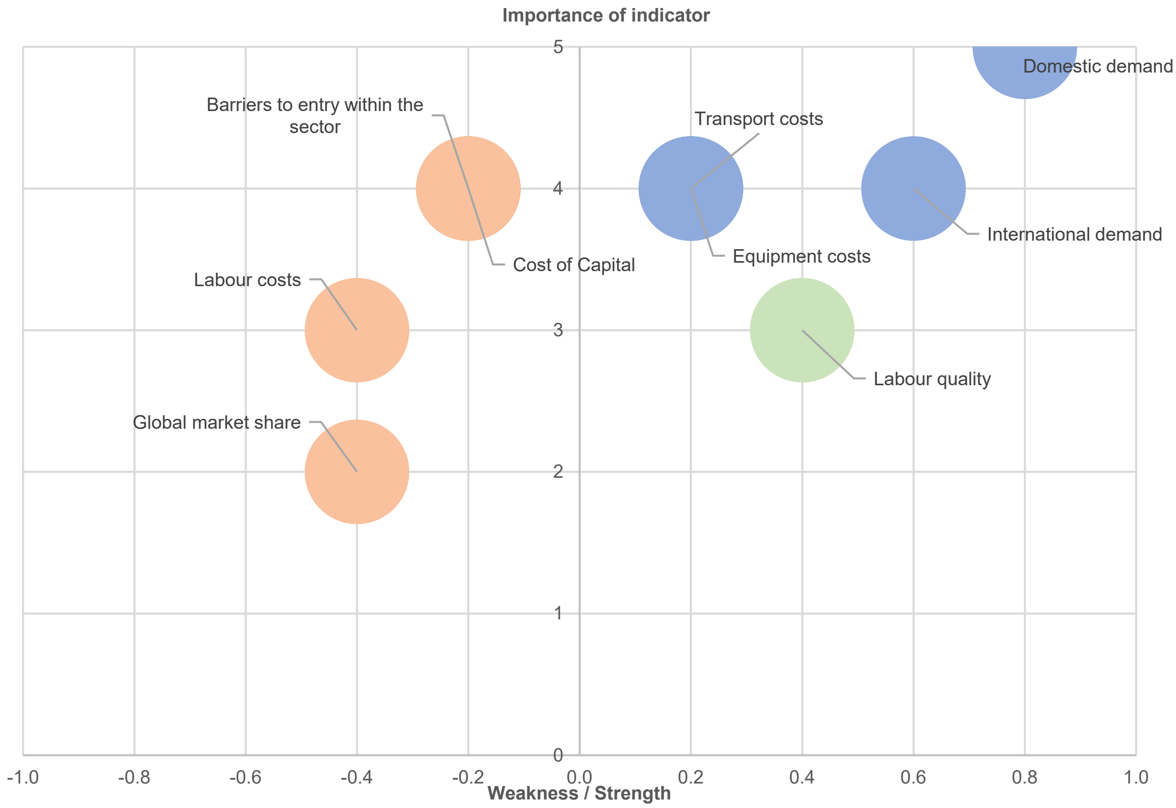

Figure 28: This figure shows the SWOT analysis figure for the structure / condition indicators scoped in for the offshore wind sector analysis, including market conditions, labour and non-labour costs.

This figure shows domestic demand, international demand, transport costs and equipment costs as opportunities for Scottish offshore wind, labour quality as a strength, and barriers to entry, cost of capital, labour costs, and global market share as threats.

- **Domestic demand**: high importance as reflects confidence in the sector and Scottish projects (evidenced by Scotwind, "by far the world's largest commercial round for floating offshore wind" (Scottish Government, 2022a)). This strong domestic demand for installed offshore wind capacity (the sector's end-product) presents significant opportunities to drive the sector forward. Offshore Wind Scotland (2023) describes a pipeline of up to 42GW (almost 25GW of which being floating), and all "potentially deliverable" before 2035. This highlights ongoing demand for Scottish offshore wind for at least the next decade and likely beyond, although the poor results of September 2023's CFD AR5 require consideration (DESNZ, 2023e; Millard and Pickard, 2023).

- **International demand**: international demand also presents a significant opportunity for Scotland, particularly in floating offshore wind. Stakeholder interviews highlighted manufacture of floating technologies as an opportunity given subsea experience (cables, platforms etc.), earlier phases of development and there being "no clear winner yet". Adjacencies with green hydrogen were also raised as opportunities to explore. As opposed to onshore wind, there is greater exportability across the value chain, e.g., planning and installation, as challenges are more similar across geographies. In relation to domestic demand, international demand is of slightly less importance at this time, given the extent and priority of delivering Scottish projects.
- **Global market share:** whilst of reasonable importance, Scottish global market share in the offshore wind sector varies depending on the value chain stage. Since the higher-value areas of the offshore wind value chain are typically either non-competitive for Scotland (manufacturing) or are not internationally traded (much of installation and O&M), this indicator is considered a threat. However, given the emerging state of the market this indicator is subject to change. As the offshore wind sector grows internationally, the importance of this indicator is anticipated to increase.
- **Labour costs:** comparatively in global terms, labour costs in Scotland are high. This doesn't change substantially across value chain stages, but the relative importance of wage costs (as an input cost) does change. Some parts of value chain are more cost-dependent/cost-competitive, for instance demand for specialised consulting services being less price-sensitive given the level of expertise.
- **Labour quality:** labour quality captures the high availability of skilled people in Scotland relevant to the offshore wind industry. There are challenges in accessing sufficient skilled labour, so there are some threats, and risk of displacing or moving employment to international markets. In some parts of the value chain, there is particular synergy with the oil and gas sector, and particular ability to bring across skilled employees. This enables comparative advantages, though not unique to the Scottish economy. There is also a potential threat here as the transition away from oil and gas is not imminent, and it is possible these skills could be "locked up" in a lucrative oil and gas professions for years to come, so the scale and speed of transferability is debatable.
- 79% of jobs in this sector are deemed to be highly skilled, technical and management roles, and UK offshore wind employment alone is expected to increase by over 220% by 2030 (Offshore Wind Energy Council, 2023) – presenting an opportunity for Scotland. Scotland was also identified as having strong education sector strengths in this area, for example with the Energy Transition Partnership, and education and skills in this sector could be a valuable export area.
- **Equipment costs:** this indicator is of relatively high importance given the capital-intensive nature of the sector, though it is in early stages of maturity.
- High equipment and raw material costs are not unique to Scotland and given the legacy oil and gas sector there may be a small opportunity to realise savings by

repurposing equipment, compared with other sectors and geographies. However as with other indicators that have links to the existing oil and gas sector, there is likely a time lag in realising these advantages, as the oil and gas sector remains profitable with relevant equipment and infrastructure still in use.

- Floating wind also presents an opportunity for Scotland to utilise its first-mover advantage – RenewableUK expect reductions of 65% in turbine cost by 2030, and reductions in cost from two to five times for floating wind foundations (Ebbesen, 2021)[24].
- **Transport costs:** as with equipment costs, there may be a small opportunity to realise competitive advantage in transport costs given the infrastructure in place from the oil and gas sector. From an export perspective, the level of opportunity, threat and importance depends on the value chain stage, for instance the transport of manufactured goods and equipment versus the transport of knowledge and skills. This is particularly important regarding the challenge of scaling-up port infrastructure and access to electricity grids and pipelines to meet the challenge of ever-larger turbines and blades.
- **Costs of capital:** despite the high levels of capital expenditure required in offshore wind projects, cost of capital is reasonably low, given that the government contracts for difference scheme virtually guarantees a rate of return, with a guaranteed buyer for the electricity generated (the government/national grid). This is marked as a weak threat given the uncertainty around newer technologies (floating).
- As with other sectors some parts of the value chain are not directly exposed to these high costs of capital – for example specialised consulting. These parts of the value chain are not reliant on significant capital expenditure for their competitiveness.

Domestic policy environment indicators (Figure 29):

The domestic policy environment in Scotland is favourable to the development of offshore wind, though Brexit and trade policy challenges could pose a threat (Figure 29).

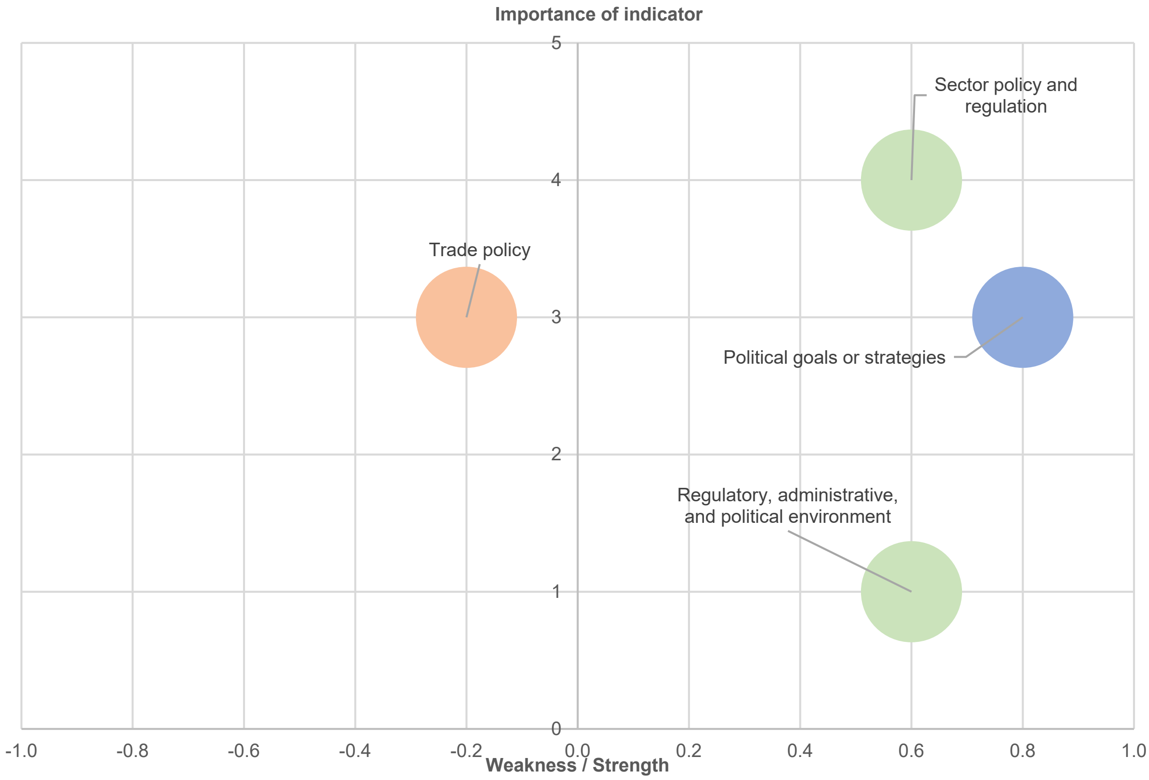

Figure 29: SWOT analysis for the domestic policy indicators scoped in for the offshore wind sector analysis. It shows that trade policy is a threat, while political goals is an opportunity, and regulatory environment and sector regulation are strengths.

This figure shows sector policy and regulation, and regulatory, administrative, and political environment as strengths for Scottish offshore wind, political goals or strategies as an opportunity, and trade policy as a threat.

- **Trade policy**: relatively high importance given the need to enable trade and grow Scotland' competitive advantage. A weak threat given that key competitors are within the EU and Brexit has made trade more challenging.
- **Regulatory, administrative, and political environment**: low importance as not sector specific. The UK has a high ease of doing business ranking and Scotland is generally an open and stable regulatory environment. This is a relative opportunity for businesses in Scotland, in comparison to other geographies.
- **Sector policy and regulation**: high importance and opportunity given the scale of commitments in Scotland, driving demand for projects despite challenging macroeconomic conditions. Includes the consenting environment and associated regulation which influences project approval and the highly successful ScotWind leasing round. Also includes the CFD initiative, which has historically provided a competitive environment to drive down costs of projects and stimulate innovation but failed to attract any offshore wind bids in its latest AR5 results (DESNZ, 2023e; Millard and Pickard, 2023). It remains to be seen how the UK and Scottish Governments will react to AR5, and indeed whether and to what extent the

perceived lack of government support cited by industry as justification for the lack of bids will impact other projects (AR5).

- **Political goals or strategies**: relatively high importance and strong opportunity. Though this doesn't directly translate to competitive advantage, the scale of commitments in Scotland (and the UK) are continuing to enable demand for projects despite challenging macroeconomic conditions. The UK Energy Security Strategy updated targets for offshore wind by 2030 means the rate of turbine installation needs to triple.

11.4 The hydrogen sector

11.4.1. Performance – value chain breakdowns

Project Development

- **Definition:** the project development encompasses a wide range of pre-construction tasks, starting from feasibility studies to system concept design and development, to obtaining permits, licences, authorisations, notifications and consents (including through the planning system).
- **Active Scottish companies:** due to the nascent stage of the hydrogen sector, there are limited companies solely dedicated to hydrogen project development services. Nevertheless, numerous companies and consultancy firms operate in related industries and sectors, equipped with the necessary expertise to contribute to various aspects of the project development phase. Consultancy firms with a presence in Scotland including Arup, Wood Group, Ramboll, Logan Energy and Xodus are known to be involved in providing project development services to hydrogen projects.
- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market:** the immature market heavily relies on government policies, and local knowledge plays a crucial role. Consequently, certain services like permit preparation and application are primarily tailored to the domestic market. However, there are also more general services, such as system concept design, that are suitable for an international market.
    - **Exports/imports:** numerous export opportunities await firms offering specialised consulting services, particularly in the field of system concept design and development. The design and implementation of hydrogen production systems require highly specialised knowledge, leading to the international utilisation of advisory services for their expertise.
    - **Prospects of the value chain stage:** this value chain stage is fully dependent on the overall development of the sector. As the sector expands, there are significant opportunities for export of specialised skills and knowledge, particularly in areas like system concept design and development. Similar to the recommendations made for the onshore wind industry, potential measures to expedite planning approvals and streamline the regulatory

process would alleviate potential frictions and ensure efficiency of this stage in the hydrogen value chain.

Manufacturing

- **Definition:** the manufacturing phase involves the production of crucial equipment and components, including electrolysers, pipes, compressors, and tanks.
- **Active Scottish companies:** Scottish Industry Directories lists 26 companies involved in the manufacture of hydrogen infrastructure. Although 13 are listed as involved in electrolysers, this is principally through the production of key components. Ames Goldsmith Ceimig for example provides precious metal catalysts (Arup, 2022), Aqualution is investigating using its experience with acid production to diversify into hydrogen production systems (Aqualution, 2023).
- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market:** currently, there is no commercial-scale local manufacturing of electrolysers in Scotland (Arup, 2022). The global market for electrolysers is primarily dominated by China and Europe, representing approximately 80% of the manufacturing capacity. (IEA, 2022b)
    - **Exports/imports:** commodified manufacture of components already exists. Generally, most aspects are small and modular and therefore readily transportable.
    - **Prospects of the value chain stage:** the manufacturing capacity for electrolysers could reach 65 GW per year by 2030. Europe and China would still lead, with around 20 GW per year of capacity each. Almost two-thirds of the capacity is for alkaline electrolyser production and a fifth for PEM electrolysers. However, the announced manufacturing capacity is insufficient to meet the electrolysis capacity in the Net Zero Scenario. This indicates a potential opportunity for new manufacturers to enter the market and bridge the gap between demand and supply. (IEA, 2022b)

Installation

- **Definition:** the installation phase encompasses various components, including system installation, construction activities, and the installation of essential infrastructure such as pipelines and tanks. Additionally, repurposing initiatives are also considered within this phase.
- **Active Scottish companies:** currently, there are few active companies within this specific segment of the hydrogen value chain in Scotland. 14 companies are listed within Scottish Industry Directories as active in the installation and commission of hydrogen infrastructure, although only 5[25] of these reach the specificity of installation and commission of hydrogen infrastructure – other activities are more peripheral. However, there are companies with valuable expertise gained from other sectors that can be readily applied to the hydrogen value chain. For instance,

[25] This includes Bilfinger Salamis UK, Hydrasun and Logan Energy.

companies experienced in working with compressors, tanks, and pipelines can leverage their knowledge and skills to contribute effectively to the development and implementation of hydrogen projects. This cross-sector transfer of experience and capabilities presents an opportunity for Scottish companies to play a crucial role in the emerging hydrogen industry by utilising their relevant expertise.

- **Qualitative insights on the value chain stage in Scotland**
  - **Geographic market:** this market is international. As the hydrogen industry continues to grow and expand worldwide, installation services are required in multiple countries and regions to support the establishment of hydrogen infrastructure. Companies specialising in installation services have the opportunity to operate in various international markets, catering to the needs of hydrogen projects across different geographies. The international nature of the hydrogen industry allows for the exchange of expertise, technology, and best practices among different countries, facilitating the global development of this emerging sector.
  - **Exports/imports:** Scottish companies have potential to export services related to the installation stage of the hydrogen value chain. As the global demand for hydrogen infrastructure grows, there is a need for specialised installation expertise in various regions. Scottish companies can leverage their knowledge and experience in installation services to offer their capabilities internationally.
  - **Prospects of the value chain stage:** as the global demand for hydrogen infrastructure continues to rise, the need for expert installation services becomes increasingly critical. The successful implementation of hydrogen projects hinges on efficient and reliable installation of production systems, infrastructure, and distribution networks.
    With the growing interest and investment in the hydrogen industry, there is a market opportunity for companies specialising in installation services. As more countries and regions embark on hydrogen initiatives, there will be a surge in demand for skilled installation professionals and companies to support the development of hydrogen infrastructure.

Operation and Maintenance

- **Definition:** the operation and maintenance phase entail the ongoing operation and maintenance of facilities for the production of clean hydrogen, along with the operation of storage (e.g. tanks or salt caverns) and distribution (e.g pipeline networks or tank trailer fleets) infrastructure. It also encompasses the ongoing maintenance of equipment and infrastructure to ensure smooth and efficient operations.
- **Active Scottish companies:** activity in this value chain stage is limited by the small number of pilot-scale projects currently operational in Scotland. There is large scope for companies providing operation and maintenance services in the oil and gas

industry to diversify into this area, since many of the services provided for natural gas infrastructure have direct equivalents in the hydrogen sector.

- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market:** the global hydrogen market transcends geographical boundaries, but transportation costs significantly impact its dynamics. Various transportation modes, including pipelines, trains, trucks, and ships, are employed to transport hydrogen, with the most cost-efficient option contingent on factors like volume and distance.
      Although Scotland lacks pipeline connections to mainland Europe, it can readily utilise shipping as an alternative means of transportation. Capitalising on its proximity to maritime routes, Scotland can facilitate the export of hydrogen to international markets. However, Scotland is likely to face strong competition from countries, for example in regions like the Middle East and Africa, using abundant and inexpensive solar energy sources to produce hydrogen.
      Furthermore, the hydrogen market is poised for substantial growth in the coming years. In order to achieve the Net Zero Scenario by 2030, hydrogen production must increase from 94 Mt in 2021 to 180 Mt. This projection emphasises the need for significant scaling and expansion within the hydrogen industry. (IEA, 2022c)
    - **Exports/imports:** as there is no activity within this part of the value chain there are currently no export opportunities.
    - **Prospects of the value chain stage:** moving forward, as hydrogen production gains momentum in Scotland and pipelines are built or repurposed, significant export opportunities are anticipated, particularly to the United Kingdom and mainland Europe. These regions represent potential key markets where the demand for hydrogen is expected to grow, creating a favourable environment for Scotland to leverage its hydrogen capabilities and establish itself as a reliable supplier of green hydrogen.

Specialised Consultancy Services

- **Definition:** specialised consultancy services play a crucial role throughout all stages of the value chain in the hydrogen industry. These services encompass a wide range of expertise, including conducting feasibility studies during the project development stage, providing operational consultancy services during construction and operation, and offering advisory support on safety-related matters. These consultancy services contribute to the efficient and effective implementation of hydrogen projects at every stage of their lifecycle.
- **Active Scottish companies:** within the hydrogen value chain, there exist consultancy firms that provide specialised services. These firms often bring valuable expertise from sectors such as the oil and gas industry, leveraging their previous experience to contribute effectively to hydrogen-related projects. Their knowledge and skills acquired in areas such as project management, engineering, safety, and regulatory

compliance can be applied to various stages of the hydrogen value chain, ensuring efficient and informed decision-making throughout the process. Examples include Wood Group, Ramboll, Atkins, DNV GL, Arup.

- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market:** different services within the hydrogen industry exhibit varying geographic market dynamics. Certain services, such as those related to application processes, tend to benefit from local expertise and knowledge due to region-specific regulations and requirements. On the other hand, services such as safety consulting have a global scope and can be applicable across different geographical markets. These services transcend borders and can be effectively provided by consultants with extensive knowledge and experience in safety standards and practices on an international scale.
    - **Exports/imports:** Scottish firms currently provide advisory services to companies in the oil and gas sector, predominantly focusing on natural gas. However, as the global market for hydrogen experiences significant growth, Scottish firms have an opportunity to expand their expertise and begin advising companies involved in the hydrogen sector. With their existing knowledge and experience in the energy industry, Scottish firms are well-positioned to offer valuable insights and guidance to companies operating in the evolving hydrogen market.
    - **Prospects of the value chain stage:** the value chain stage in the hydrogen industry presents numerous opportunities for Scottish firms. As the market continues to evolve and expand, these firms can capitalise on their expertise and adapt their advisory services to provide valuable support and guidance to companies involved in hydrogen-related activities. By leveraging their knowledge and experience, Scottish firms can play a vital role in assisting and empowering companies working with hydrogen, contributing to the growth and success of this emerging sector.

End of Life

- **Definition:** this value chain stage includes activities related with decommissioning equipment and infrastructure.
- **Active Scottish companies:** while there is much to be done and a long time before this stage of the value chain becomes relevant for Scottish companies in the hydrogen sector, their experience from other sectors can prove valuable. Companies with expertise in end-of-life activities from other industries can potentially lend their assistance and knowledge to the hydrogen sector when the need arises. By leveraging their existing skills and insights, these companies can contribute to the development and advancement of the hydrogen industry in Scotland, bridging the gap and facilitating a smoother transition to this stage of the value chain.
- **Qualitative insights on the value chain stage in Scotland**
    - **Geographic market:** the geographic market for services related to the end-of-life stage in the hydrogen value chain is primarily anticipated to be domestic,

focusing on meeting the needs within Scotland. However, there is a possibility of exporting certain products, such as electrolysers, for second-hand use in other markets. This enables Scottish companies to potentially expand their reach beyond the domestic market and contribute to the global sustainability efforts by repurposing and supplying essential hydrogen-related equipment.

- **Exports/imports:** the primary focus of the hydrogen industry in Scotland is expected to be on the domestic market, but there may be minor exporting opportunities. One notable area where exporting potential exists is in the supply of products and components that can be reused in other markets. This opens up avenues for Scottish companies to contribute to the global hydrogen ecosystem by exporting items that can be repurposed and utilised in different regions, thereby extending the reach and impact of their offerings.
- **Prospects of the value chain stage:** the prospects are very limited within the foreseeable future. The expected lifetime of a PEM electrolyser is between 50 and 80 thousand hours. (IRENA, 2020)

11.4.2. Further detail – strengths, weaknesses, opportunities, threats (SWOT) analysis

The following section provides further detail on the process of the SWOT analysis for hydrogen, including all SWOT graphs. All indicators are described in detail in the following sections, with the exception of macroeconomic indicators, which are considered the same across all sectors and are assessed in section 9.1.

All indicators (Figure 30):

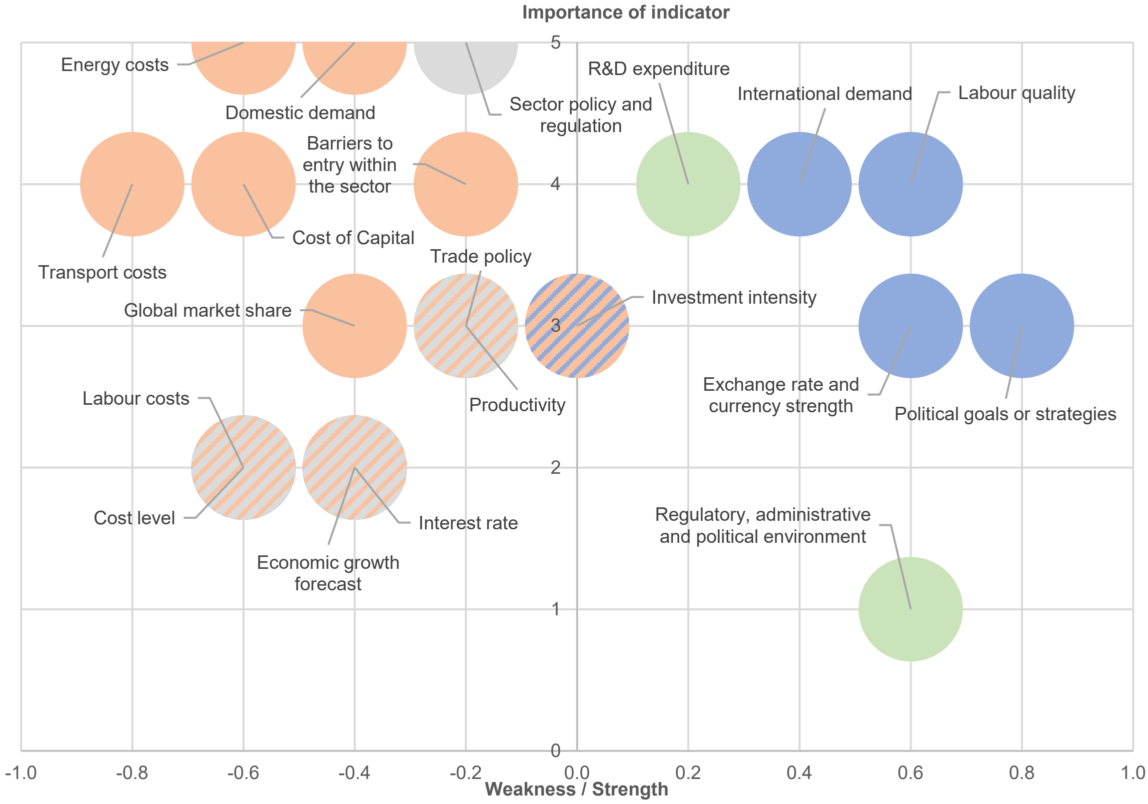

Figure 30: SWOT analysis for all indicators scoped in for the hydrogen sector analysis. The results of this analysis are discussed in the text.

This figure shows all indicators scope in for the hydrogen sector analysis. R&D expenditure and regulatory, administrative, and political environment are listed as strengths, while international demand and labour quality are included among the opportunities. Transport costs, energy costs, and domestic demand are listed among the threats, while sector policy and regulation are listed as a weakness.

Conduct indicators (Figure 31):

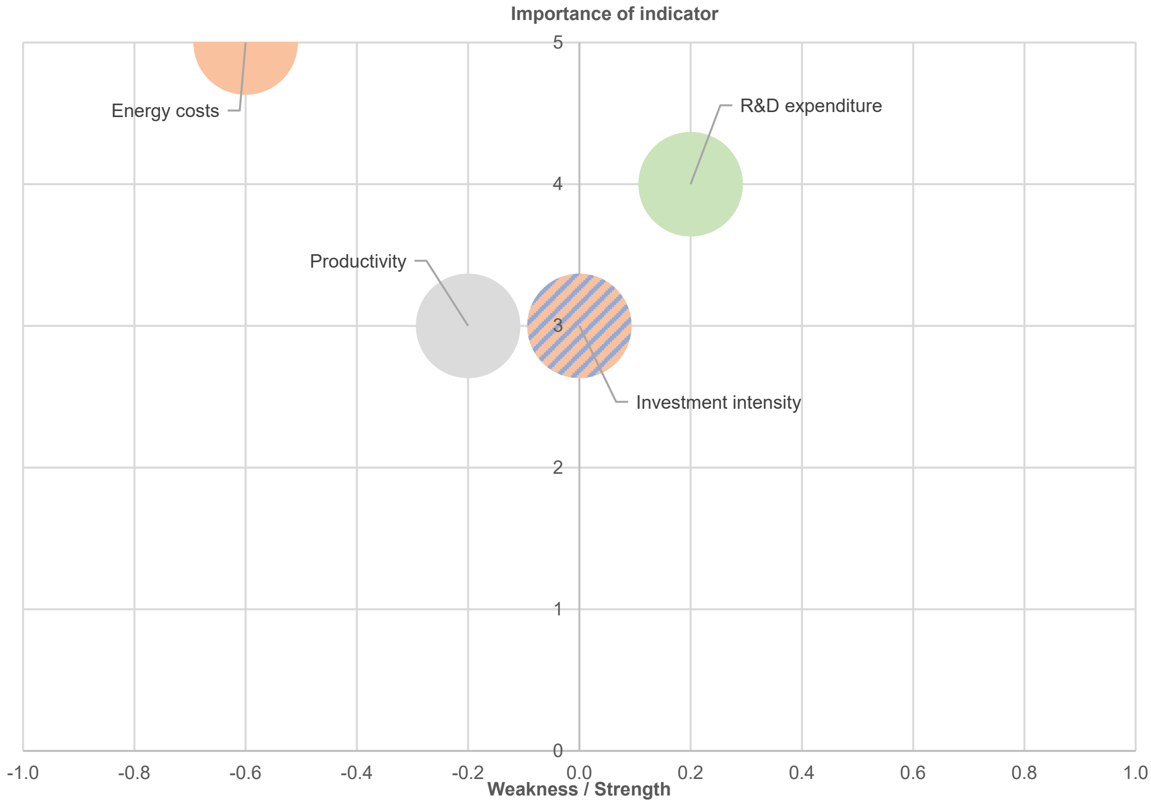

Figure 31: SWOT analysis figure for the conduct indicators scoped in for the offshore wind sector analysis.

This figure shows that energy costs are a threat, investment intensity is both a threat and a weakness, R&D expenditure is a strength, productivity is a weakness, and energy costs are a threat to Scottish hydrogen development.

- **R&D expenditure**: R&D expenditure is considered an important factor, since the sector is immature, and is a high-tech sector. Although all aspects of the technology-set are proven in pilot settings or other sectors, there is a great deal of opportunity for further technology development, efficiency improvements of components (e.g. newer electrolyser technologies), cost reductions and improvements in commercial-scale project delivery.
- **Investment intensity**: insufficient data was found in this study to conduct a SWOT analysis for this indicator.
- It should be kept in the SWOT indicators for this sector, as it could be a somewhat important indicator for the sector. The relative competitiveness of the Scottish hydrogen sector, particularly within the value chain, is likely to depend on the extent to which the constituent companies invest in their own capacity and capital.
- Some limited anecdotal evidence could point towards this currently being a weakness of the sector. For example, stakeholders raised concerns that the greater uncertainty of commercial-scale projects in a Scottish/UK setting (compared to

EU/US) meant that investment was being channelled towards other competing geographies.

- **Productivity**: generally, productivity is an important competitiveness factor for a sector. The ability of the sector to produce maximum value from its inputs, very closely represents its relative competitiveness. However, given that hydrogen is currently an immature sector, companies may still be able to take 'loss-leading' or higher-risk approaches to productivity in the hydrogen sector. This indicator is therefore rated of lower importance than it might otherwise be, at 3/5. However, as the market matures, this should be expected to change, and those companies and geographies that can achieve higher productivity more quickly, will quickly achieve incumbency advantages.
- Given the immaturity of the Scottish hydrogen sector, limited data was available to inform a judgement here. This indicator should be considered lower confidence for its placing and should be regularly reviewed. Overall, productivity is considered a mild threat, since there was qualitative evidence that companies in other geographies have had more success with expansion, suggesting that they have better productivity. Evidence is also present in the lack of major manufacturers in the hydrogen sector in the UK. However, there was qualitative evidence that there were areas of optimism for the Scottish hydrogen sector's productivity, in that there

were successful areas of activity identified within the oil and gas sector that would be able to transition/diversify successfully into the hydrogen sector.

Structure and condition indicators (Figure 32):

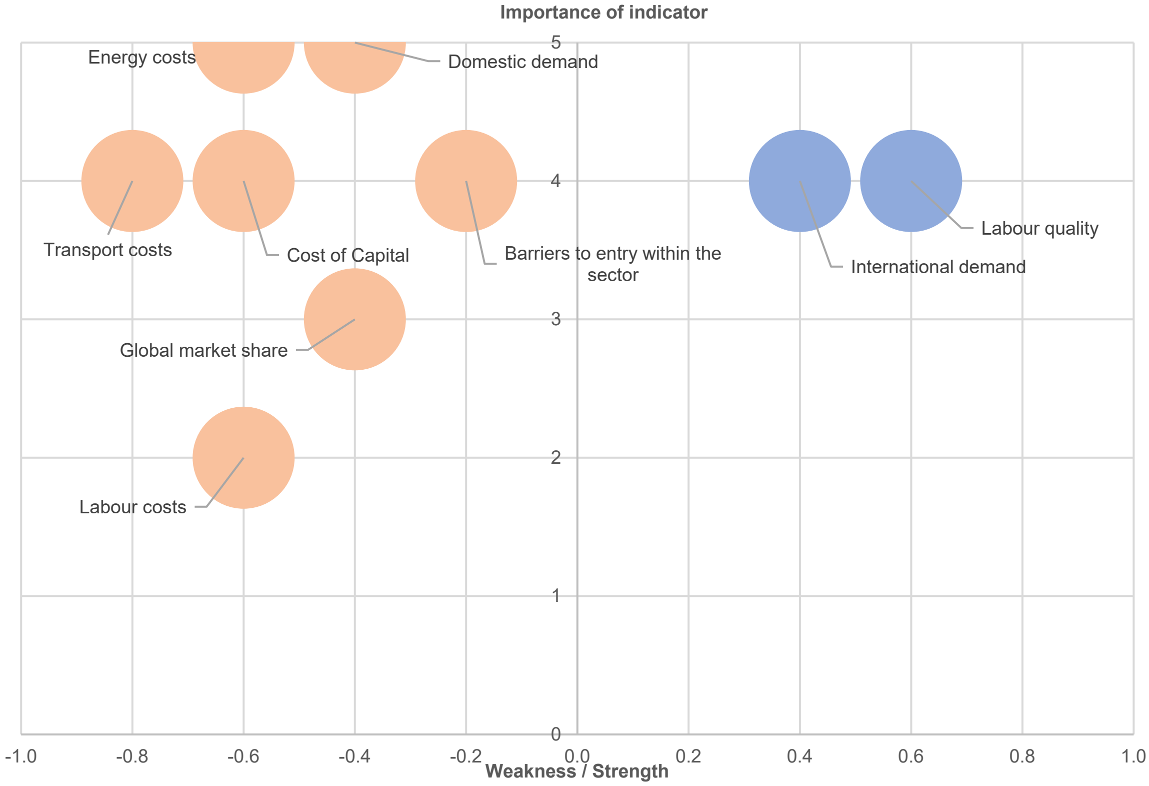

Figure 32: SWOT analysis figure for the structure / condition indicators scoped in for the hydrogen sector analysis, including market conditions, labour and non-labour costs.

This figure shows labour quality and international demand are opportunities for the Scottish hydrogen sector. Barriers to entry, domestic demand, and energy costs are listed among the perceived threats.

- **Domestic demand**: domestic demand is considered as highly important. Hydrogen is an immature sector, although there are no technical barriers to commercialisation, lack of current demand for clean hydrogen means that there is no large-scale market for this sector's final product. Demand, and particularly domestic demand (since transport costs are high), will be necessary for the sector to become fully operational. Therefore, domestic demand is of critical high importance as a factor.
- Domestic demand is considered a strong current threat. Domestic demand will have to be created, if projects in Scotland are to be developed at a commercial scale, with the value chain activity that goes with that. There are some offtakers (i.e., long-term purchasers of hydrogen) willing to pay a commercial premium for clean hydrogen against alternatives, but this severely limits the scale of current projects.
- However, a very different picture is presented when future projections for domestic demand are considered. All forecasts consider that domestic demand will grow rapidly in the next 10-15 years, requiring significant investment in production

capacity. The extent carries uncertainty, but all forecasts project major growth in hydrogen demand. These forecasts form the basis of the current limited activity, concentrated on project development, piloting, R&D, consulting.

- We should expect current domestic demand to begin to move to a less negative position soon, as key UK government policies come online in the near future (e.g., Hydrogen Production Business Model) and more industries consider paying short-term cost premiums. In some specific geographies there are also projections of reaching a comparable price (e.g., when using constrained wind resources)
- On a combined basis, it is considered a mild threat.
- **International demand**: international demand is considered high importance, for the same reasons as domestic demand. It is relatively less important (4/5 instead of 5/5). International demand is considered a weak opportunity. Currently, hydrogen is not traded internationally. However, multiple projections all project that there will be significant demand in relevant geographies in north-western Europe (especially the Germany, Netherlands, and the rest of the UK).
- **Global market share**: for other sectors, global market share is considered a high importance indicator, since it reveals a lot about the current international competitiveness of a sector, and in many sectors, incumbency is an important factor. For the hydrogen sector, since there is not currently a functional international market for the finished product, it is considered of slightly lesser importance, although key components are available internationally (e.g., electrolysers) In time, it should be expected to increase in importance as an indicator.
- There is no qualitative data available for exports from Scotland's hydrogen sector. Qualitative evidence shows that key hydrogen sector components are not made in Scotland – e.g., there is no commercial scale electrolyser manufacturer (Scot Govt, Electrolyser Assessment). However, anecdotal evidence suggests that there are both niche areas in which Scotland is already exporting in the limited international value chain market (e.g., engineering consultancies support project development), and areas where export is occurring in adjacent sectors (e.g. specialist manufacturing in the oil and gas sector) that could diversify into the hydrogen sector.
- **Labour costs:** comparatively in global terms, labour costs in Scotland are high. It is therefore rated as a threat for the hydrogen sector. However, the importance of this indicator to this sector is uncertain, and there was insufficient evidence available to this project to qualify this. For the sector overall it is unclear how important labour costs are as an input cost (e.g. into the levelised cost of hydrogen). Overall, given the immaturity of the sector and technology (likely to increase the importance of skilled labour), and the relative assumed lack of labour-intensity to hydrogen production, this is scored as of relatively low importance. However, it could be the case for key parts of the value chain (e.g. for manufacturing of components like electrolysers and their supply chain) that price sensitivity to labour is more important. This could be a valid area for further research and consideration.

- **Labour quality:** labour quality captures the high availability of skilled people in Scotland relevant to the hydrogen sector – for example in engineering professions, and in adjacent sectors such as parts of the oil and gas value chain.
- This was widely identified in qualitative engagement as being a key opportunity that the Scottish hydrogen sector could harness, and that if the sector could establish a comparative advantage, it would likely be on the basis of this aspect. It has therefore been rated as being of a high importance.
- Some nuance does need to be added around the strength of this opportunity. Qualitative evidence also pointed to high cross-sector demand for STEM graduates, and that the availability of skilled employees could create a break on the deliverability of domestic projects, and the ability, for example, to deliver on the scale of hydrogen production targeted domestically over the next 10-15 years. However, Scotland was also identified as having strong education sector strengths in this area, for example with the Energy Transition Partnership, and education and skills in this sector in its own right could be a valuable export area.
- **Energy costs:** the production of hydrogen is energy intensive. Electrolytic hydrogen requires large amounts of electricity, with energy losses in both electrolysis and in use. Similarly, blue hydrogen production has natural gas as a key cost factor. Particularly for electrolytic hydrogen, energy inputs are expected, long-term, to make up a large proportion of overall hydrogen production costs. Energy costs are therefore rated as of very high importance (5/5).
- Scottish electricity costs are currently relatively internationally high. This creates a threat. However, evidence noted opportunities to change this, or forecasted that this would change in future. Opportunities to change it included take advantage of constrained wind production, use direction connection to avoid grid costs (which make up a significant element of Scotland's high-cost electricity), or that significant renewable capacity might be built through expected offshore wind development resulting from e.g. ScotWind, resulting in significant cost reductions.
- **Transport costs:** transport costs are inherently high for hydrogen against some of its competitor sectors. Hydrogen has a much lower volumetric density than natural gas, making it more expensive to transport. It needs careful, specialist handling, as the small size of the molecule means it can escape through, for example, poorly welded pipes. These challenges can be overcome (there are 1000km of hydrogen pipelines worldwide) but they add cost. In-depth studies identify transportation costs as a significant component of delivered costs of hydrogen fuels. For these reasons transport costs are rated as high importance.
- A lack of available infrastructure means that transport costs are listed as a significant threat for hydrogen in Scotland. Qualitative evidence suggested that pipelines would be critical for Scottish hydrogen to achieve delivered cost competitiveness. The use of 'tube trucks' would only be suitable for local, small-scale levels of hydrogen production and consumption. However, opportunities were highlighted to change this factor, including, through new pipeline construction (including in the European

hydrogen backbone, and in the UK's Project Union), and the development of greater distribution and storage infrastructure.

- **Costs of capital:** the costs of capital for the hydrogen sector are marked as a threat. Hydrogen related projects are in the main still a high-risk investment, since short-term demand for hydrogen is still highly uncertain, and there are a lack of successful commercialised projects that can provide a template of established commercially-proven success. There is some nuance to this, within the value chain. There is some qualitative evidence of significant quantities of major investment decisions, and of e.g. manufacturing and hydrogen-specific developer companies globally having success in raising capital. This suggests that the high rates of projected sector growth are supporting affordable, speculative costs of capital to be secured in some parts of the value chain.
- Some parts of the value chain are not directly exposed to these high costs of capital – for example specialised consulting. These parts of the value chain are not reliant on significant capital expenditure for their competitiveness.

Domestic policy environment indicators (Figure 33):

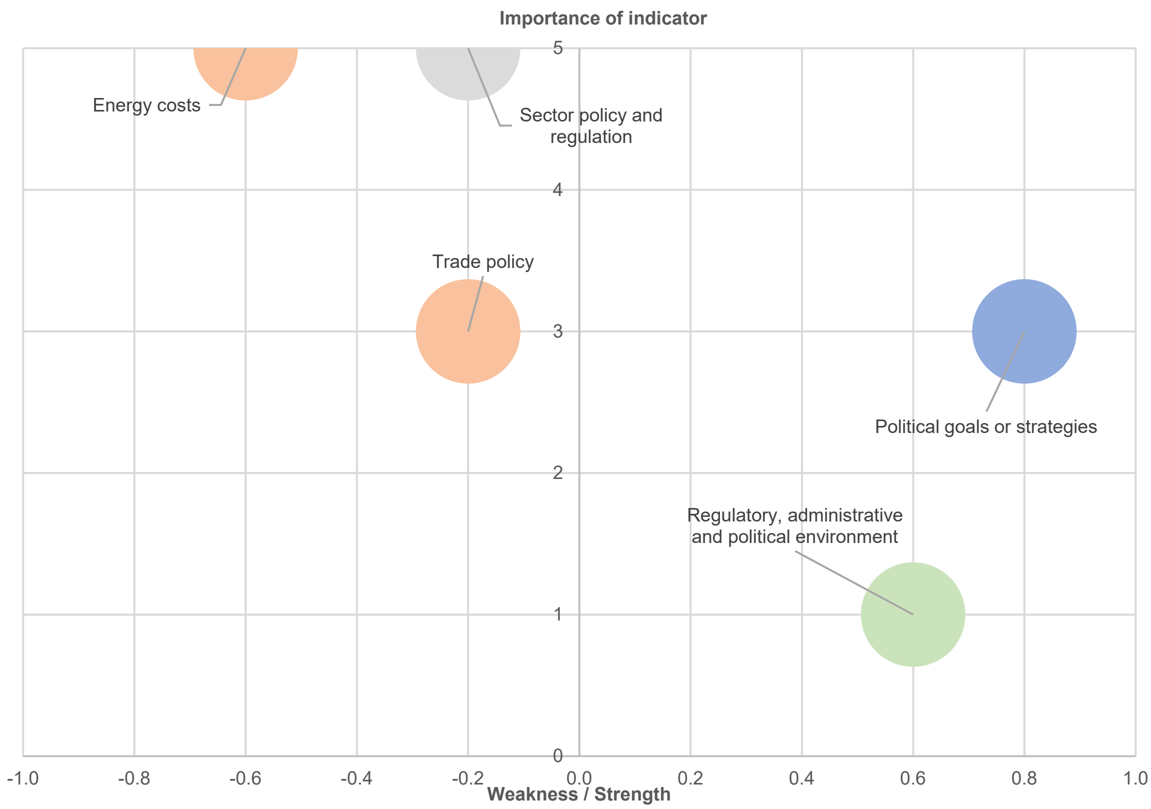

Figure 33: SWOT analysis for the domestic policy indicators scoped in for the hydrogen sector analysis.

This figure listed regulatory, administrative, and political environment as a strength, political goals or strategies as an opportunity, sector policy and regulation as a weakness, and energy costs and trade policy as threats to Scottish hydrogen development.

- **Trade policy**: relatively high importance given the emphasis on trade opportunities in this analysis. A weak threat given that key competitors are within the EU and Brexit has made trade more challenging. (See more detail in cross-cutting themes section).
- **Regulatory, administrative, and political environment**: low importance as not sector specific. The UK has a high ease of doing business ranking and Scotland is generally an open and stable regulatory environment. This is a relative opportunity for businesses in Scotland, in comparison to other geographies. (See more detail in cross-cutting themes section).
- **Sector policy and regulation**: high importance, as sector-specific and highly immature hydrogen market requires revenue-generating subsidies to create demand.
- On using other sectors as a comparator, the lack of fiscal support means that low-carbon hydrogen cannot compete with high carbon hydrogen production, nor with natural gas as a fuel substitute. Subsidies are likely required to make clean hydrogen competitive, and a carbon tax on natural gas.
- Weak threat, since although significant number of policies are in place (IEA), stakeholders said that they provided weaker financial support than in competitor geographies. However, this aspect is also a challenge in all geographies.
- **Political goals or strategies**: Relatively high importance (sector specific) and strong opportunity. Scottish and UK targets for hydrogen production is ambitious even in a NW European context (IEA).

11.5 Populated excel tables for each sector

The populated excel tables documenting the methodology applied, data collected, calculations made, and graphs created are delivered in separate excel files, one for each sector of interest.

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