Smart strategies for the transition in coal intensive regions

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A strategic approach to Research & Innovation in the field of energy in Wales

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TRACER website: www.tracer-h2020.eu

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Executive summary

This report provides an overview of the Research and Innovation (R&I) approaches to the energy and environment sectors in Wales. It draws on strategic policy documents and previous work conducted within the TRACER project, namely the mobilisation of stakeholders in an Entrepreneurial Discovery Process, as per the Smart Specialisation framework. The aim of the report is to develop R&I visions for just transition for the next decades, providing recommendations in the fields of energy, environment, governance, regional development, and innovation policy and funding more generally.

Key objectives and priority areas for investment are detailed. These include the promising energy sectors of hydrogen, wind and marine energy, and the development of technologies related to e.g. carbon capture and the storage of energy. The promotion of decarbonisation and renewable energy in the Wales energy mix is particularly emphasised. Recommendations related to areas of need and opportunity are made based on the previous TRACER work, related to political, regulatory and financial incentive frameworks, infrastructural and sectoral investments, and labour market, skills and community.

The governance support framework and R&I strategies and plans for the transition have been characterised by OECD as fragmented. Horizontal and vertical collaboration and cross-departmental/sectoral efforts have been recommended, as well as the continued development of an integrated R&I strategy for Wales. This is particularly important in the context of relative uncertainty post-Brexit, especially with regard to future funding. Efforts to increase coordination are already underway. Since publication of the OECD report, and following an election in 2021, a new climate change ministry was announced within Welsh Government, bringing together the portfolios for environment and energy (along with housing, planning and transport). Further, a new integrated innovation strategy is currently under development.

Finally, emphasis is placed on broader conceptualisations of research and innovation that consider the social aspect of the transition, with behavioural change needing to be promoted.

1 Introduction

The European Union's Cohesion Policy current research and innovation policy framework is based on the concept of Smart Specialisation. It involves the process of identification of a region's areas of uniqueness and strength and the design and implementation of a strategy (RIS3 or Research and Innovation Smart Specialisation Strategy) that can materialise an ideal regional development pathway. The Smart Specialisation policy framework was announced as an ex-ante conditionality for the access to European Structural and Investment Funds (ESIF), meaning that in its near-mandatory adoption it spurred a widespread innovation governance experiment across EU regions.

The framework introduced several new governance mechanisms based on innovation theories, with the most salient being:

- Entrepreneurial Discovery Process (EDP), centred on stakeholder mobilisation toward the identification of areas of weakness and (potential) strength for the region that can promote its competitive advantage. It is mostly based on a quadruple helix model of innovation, meaning that the EDP seeks to involve stakeholders from government, industry, higher education/research institutions and civil society (e.g., non-governmental organisations).
- Industrial modernisation and related diversification, focusing on the knowledge combination between different, though related, areas or sectors, allowing for 'cross-pollination', innovation, and the creation of new areas to occur. Synergies are enabled based on the exchange of skills and/or resources. The upgrading of industry and value chains is therefore sought here.

- New policy thinking, emphasising evidence-based policy and the role of universities and research institutions in contributing toward development and effective policymaking. It also highlighted a process-oriented approach to policy, focusing on the continuous monitoring and adjustment of the strategy depending on new developments, innovations, and emerging challenges.
- Common vision, building on the stakeholder mobilisation to promote a general commitment to the strategy's values and its implementation. The co-creation of the strategy has the potential to promote collective place leadership and a more decentralised mode of territorial governance.

This policy framework thus seeks place- and evidence-based regional revitalisation, specifically aiming to achieve this through the promotion and alignment of research and innovation with regional needs. More recently, a sustainable and inclusive component has been promoted within the Smart Specialisation framework, in the form of Smart Specialisation Strategies for Sustainable and Inclusive Growth (S4). This highlights the framework as being challenge- or mission-oriented, and the relevance of its use in the context of a region's decarbonisation or just transition. In broader terms, the decarbonisation or just transition agenda is set at both the supra-national and national levels, with ambitious targets and objectives set for the next decades (e.g., net zero carbon by 2050). The Smart Specialisation framework is viewed as the place-based approach needed to realise these targets at more local and regional levels, with it being argued to contribute to a better management and organisation of the changes that can arise from the restructuring of the economy and society towards low-carbon alternatives.

The TRACER project thus makes use of the Smart Specialisation framework – as the broader research and innovation (R&I) policy framework across Europe – to analyse and contribute to regional strategy-making for the decarbonisation and just transition. This report focuses on the case of Wales, and considers several strategies and plans linked to R&I, regional development, energy, and environment. It is organised as follows:

Chapter 2 provides an overview of the R&I context in Wales, including a regional profile, the energy and environment outlook and a description of the region's energy technology landscape.

Chapter 3 details the objectives, expected outcomes and key guiding principles of the existing Welsh strategies and plans for R&I in the energy and environment sectors.

Chapter 4 discusses the broader R&I support framework for energy and environment, describing the governance structure in place in the Welsh context for these strategies and plans, the existing and potential public and private funding opportunities, the key priority areas in which investment should be focused, and the evaluation and monitoring mechanisms employed to assure outcomes.

Finally, *Chapter 5* provides a concluding note, summarising the main challenges and recommendations for R&I in the energy and environment sectors in Wales.

1.1 Overview of the process

This report builds on previous work conducted within the TRACER project, namely on Work Package 5 which focused on the implementation of an Entrepreneurial Discovery Process with stakeholders in Wales, as per the Smart Specialisation framework. This stakeholder mobilisation process was carried out in collaboration with Welsh Government with the aim of identifying R&I priorities in energy and environment for the just transition. A mapping of stakeholder priorities thus took place in the form of interviews and a stakeholder workshop, with a report (deliverable 5.3) setting out a vision and future-oriented priorities for Wales.

Section 4.3 further discusses some of the priorities identified based on this stakeholder mobilisation.

Furthermore, this report considers several strategies and plans linked to R&I, regional development, energy, and environment. At the UK level, an Integrated National Energy and Climate Plan (NECP) was completed in January 2020, including R&I, energy and environment targets and objectives for the next decades. At the Wales level, 'Prosperity for All: A Climate Conscious Wales'[1] sets out the country's climate adaptation programme over five years (2020-2025). The Prosperity for All strategy also includes a collection of specific policies and proposals for a low carbon Wales.[2] Additionally, a Net Zero Wales plan for the reduction of emissions was published in October 2021, establishing Wales' second carbon budget for 2021-25, and seeking to build the foundations for following carbon budgets that can meet the net zero target by 2050. These and other strategies and plans are referenced throughout this report.

The research and drafting of this report are based on multiple policy documents and sources because there is currently no unified R&I strategy for energy and environment in Wales. Nonetheless, an integrated Innovation Strategy (Logic Model) is currently being developed by Welsh Government, focusing on the key priority objectives set out in the 2015 Well-being of Future Generations (Wales) Act (see Chapter 3), including the building of a prosperous and resilient Wales based on sustainability principles. This Innovation Strategy is as of November 2021 in a stage of seeking broader input from stakeholders in Wales.

2 Setting the context

Wales is a nation and a devolved administration within the United Kingdom, with specified powers to enact primary and secondary legislation. It accounts for less than one-tenth (9%) of the total area of the UK, covering roughly 20,800 square km in area. Three national parks cover 20% of the country's land mass. The country is generally mountainous, and has over 2,700 km of diverse coastline.

With 3.1 million inhabitants, Wales holds less than 5% of the UK's population. Cardiff, the capital city of Wales, located on the South East coast, has the biggest population of around 363,000 and is also the Welsh centre of economic, cultural and educational activities. There are eight universities in Wales. Currently, key industries in Wales include:

- Advanced Materials and Manufacturing,
- the Creative Industries,
- Financial and Professional Services and Fintech,
- Energy and Environment,
- Food and Drink,
- Life Sciences,
- Tech and Tourism.

Wales has a complex and varied geology with a wealth of natural minerals. Although it has been strongly associated with the coal industry, it has also been the world's leading supplier of slate and of copper. The combination of a temperate climate and physical geography and geology have given rise to many different types of landscape and biomes rich in biodiversity. Welsh resources and their use are explained in Table 1.

Although, Wales has a long history in coal-mining it has largely transitioned to other sectors. Nowadays only limited opencast coal-mining continues. As a net exporter of electricity, Wales is also successively lowering dependence on fossil fuels. In 2019, Wales generated an

[1] https://gov.wales/prosperity-all-climate-conscious-wales
[2] https://gov.wales/prosperity-all-low-carbon-wales

estimated 27.9 TWh of electricity, while consuming approximately 14.7 TWh.[3] Around 27% (7.5 TWh) of this energy was generated from renewable sources – wind, solar or others. Energy generated from fossil fuels mostly relied on gas, while coal and diesel played marginal roles.

Table 1: Natural resources in Wales

RESOURCE	SPECIFICATION	USE
WATER	- one of Wales' most abundant resources - mountainous terrain and ample rainfall - many man-made reservoirs - source of many significant rivers	- export to England - generating power through hydroelectric schemes - some of the reservoirs - popular resorts for outdoor activities such as sailing, kayaking, cycling, fishing and bird-watching - fisheries
WIND	- abundant resource	- offshore wind farms (*Gwynt y Môr* - the fifth largest such wind farm in the world) - inland wind farms
COAL	- coal deposits	- vast quantities of coal mined in Wales in the past - nowadays foreign coal available at low prices is used - anthracite used for steel production, not power station fuel
METAL ORES	- ironstone outcrops - lead, silver and to a lesser extent zinc - manganese, titanium and other minerals - gold - copper	- although important from pre-Roman times, none of the minerals are mined on a commercial scale today
STONE	- slate industry	- still quarried but at a reduced capacity - some former pits/mines turned into tourist attractions
OIL AND GAS	- oil and gas (including shale gas) deposits	- some potential for onshore production of oil and gas - shale gas may be obtained by fracking and there is methane in unmined coal seams that may be extractable - potential source of gas is the underground controlled combustion of coal seams to produce syngas, a mixture of hydrogen, methane and carbon monoxide
NATURAL ENVIRONMENT	- variety of landscape forms, - unusual biomes and areas	- protected areas because of their natural environmental value
SEA AND COAST	- numerous sandy beaches - coastline rich in sea-cliffs - relatively high tidal range in many areas	- tourism industry - sand-dunes highly valued for their wild-life diversity including the presence of some rare plant and animal species - tidal range has potential for significant energy generation

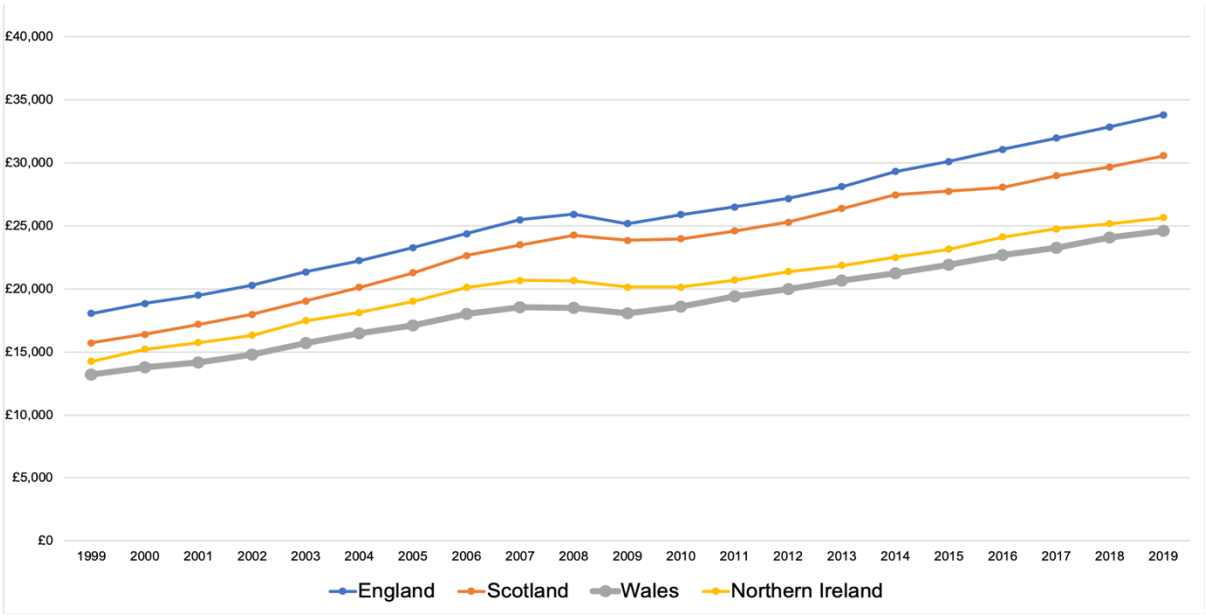
Source: Authors' elaboration based on multiple sources.

2.1 Regional profile and specialisation: Wales

Wales has transformed from a predominantly agricultural country to an industrial economy, and to services, information, and research. In 2019, GDP in Wales was over £77 billion, an increase of £2 billion in comparison to 2018, and over £20 billion since the 2009. Welsh GDP per capita, which was £24,586 in 2019, ranks last among UK countries, ca. 75% of the average GDP per capita of the UK. Nevertheless, similarly to the general trend for all UK countries in the last decades, there is an upward trend, last interrupted at the end of the 2000s (Figure 1).

[3] https://gov.wales/sites/default/files/publications/2021-01/energy-generation-in-wales-2019.pdf

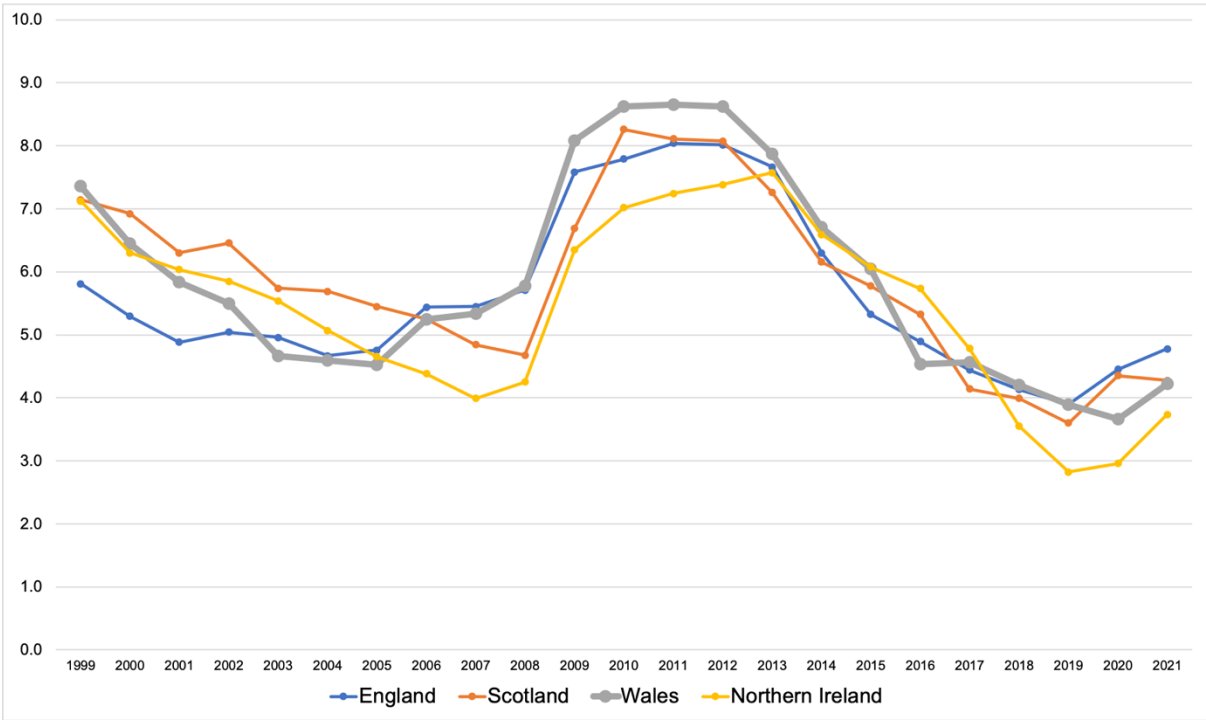
Figure 1: GDP per capita in UK 1999-2019, by country



Source: https://www.statista.com

Although the labour market in Wales was the most affected by the 2008 crisis among UK countries, it has demonstrated a recovery. In 2019, the unemployment rate of 3.9% was very close to the UK average. It further decreased in 2020 to 3.7%, ranking Wales the second lowest in the UK, ahead of only Northern Ireland. This was also the lowest unemployment rate for Wales in the 21st century. Figure 2 (below) illustrates changes in unemployment rate between 1999–2021 in Wales and other UK countries.

Figure 2: Unemployment rate (%) in UK 1999–2021, by country



Source: Authors' elaboration based on https://www.statista.com.

Overall Welsh economic performance within the last few years shows a steady growth trend (Table 2).

Table 2: Selected Welsh economic performance indicators, 2016-2021[4]

	2015	2016	2017	2018	2019	2020	2021
GDP[5]	£67 863	£70 667	£72 607	£75 505	£77 517	-	-
GDP per capita	£21 898	£22 700	£23 233	£24 057	£24 586	-	-
GDP per capita growth	3.2%	3.7%	2.3%	3.5%	2.2%	-	-
Unemployment rate	6.1%	4.5%	4.6%	4.2%	3.9%	3.7%	4.2%[6]
Change in unemployment rate	-0.7	-1.5	0.0	-0.4	-0.3	-0.2	0.6

Source: Authors' elaboration based on https://www.statista.com.

According to the Regional Innovation Scoreboard 2021, Wales is a strong innovator, and its innovation performance has increased over time (2014-2021) by 21.2%. The table below (Table 3) shows the normalised scores per indicator and relative results compared to the UK and the EU. It also includes the Regional Innovation Index (RII) in 2021 compared to that of the UK and the EU in 2021, the RII in 2021 compared to that of the EU in 2014, and performance change over time between 2014-2021.

Table 3: Regional Innovation performance overview. Regional profile of Wales

	Data	Normalised score	Relative to UK	Relative to EU
Tertiary education	41.2	0.616	76	107
Lifelong learning	15.7	0.585	106	145
International scientific co-publications	1,733	0.675	96	120
Most-cited scientific publications	11.9	0.670	80	123
Above average digital skills	47.5	0.899	96	171
R&D expenditures public sector	0.41	0.269	78	56
R&D expenditures business sector	0.59	0.212	50	41
Non R&D Innovation expenditures	*	1.000	*	*
Innovation expenditures per person employed	2.9	0.775	*	*
Employed ICT specialists	*	0.361	49	72
Product innovators	*	0.491	*	*
Business process innovators	*	0.186	*	*
Innovative SMEs collaborating	301.3	0.919	*	*
Public-private co-publications	2.67	0.617	106	124
PCT patent applications	2.43	0.547	96	88
Trademark applications	1.25	0.177	51	39
Design applications	11.2	0.322	71	56
Employment knowledge-intensive activities	*	0.379	59	64
Employment innovative enterprises	*	0.759	*	*
Sales of innovative products	9.4	0.797	*	*
Air emissions by fine particulates	--	0.699	104	142
Average score	--	0.569	--	--
Country EIS-RIS correction factor	--	1.081	--	--
Regional Innovation Index 2021	--	0.615	--	--
RII 2021 (same year)	--	--	94.1	114.5
RII 2021 (c.f. to EU 2014)	--	--	--	131.5
Regional Innovation Index 2014	--	0.516	--	--
RII 2014 (same year)	--	--	88.6	110.3
RII – change between 2014-2021	--	21.2	--	--

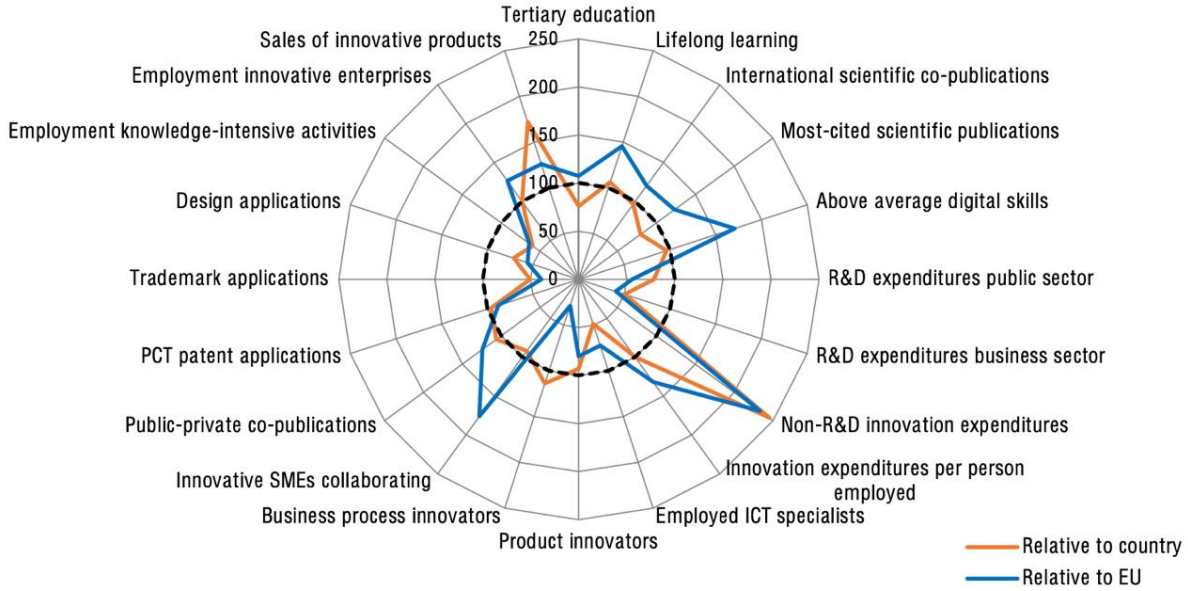
**Relative-to-EU scores are not shown as these would allow recalculating confidential regional CIS data.*

Source: Regional Innovation Scoreboard: Regional profiles United Kingdom.

[4] Where available
[5] In million GBP
[6] Based on data until September 2021

Wales' innovation-related strengths and weaknesses in comparison to the broader UK and EU context can be seen in Figure 3. The radar chart compares Wales to the UK (orange line) and the EU (blue line), showing Wales' relative strengths (e.g. non-R&D innovation expenditures[7]) and weaknesses (e.g. business process innovators).

Figure 3: Relative strengths and weaknesses of Wales.



Source: Regional Innovation Scoreboard: Regional profiles United Kingdom.

Although Wales spends comparatively less on R&D, there is some evidence that R&D expenditure has increased across its constituent parts (business, higher education, and government expenditure) over time, with overall R&D expenditure standing at £794m in 2019.

Table 4: Total expenditure[8] on R&D 2015-2020 (2019) in Wales (WAL) and United Kingdom (UK).

	2015	2016	2017	2018	2019	2020
	WAL *UK*	*WAL* *UK*	*WAL* *UK*	*WAL* *UK*	*WAL* *UK*	*WAL* *UK*
Higher education bodies R&D	246 7 670	227 7 707	240 8 144	342 8 740	323 9 067	- -
Business enterprise R&D	368 21 018	440 22 580	421 23 669	431 25 192	442 26 037	494 26 937
Government and Research Councils R&D	13 2 091	15 2 171	17 2 206	22 2 604	23 2 662	- -
Private non-profit bodies R&D	2 697	- 722	- 754	4 794	6 843	- -
TOTAL	**627** **31 477**	**628** **33 180**	**678** **34 773**	**799** **37 330**	**794** **38 609**	**-** **-**

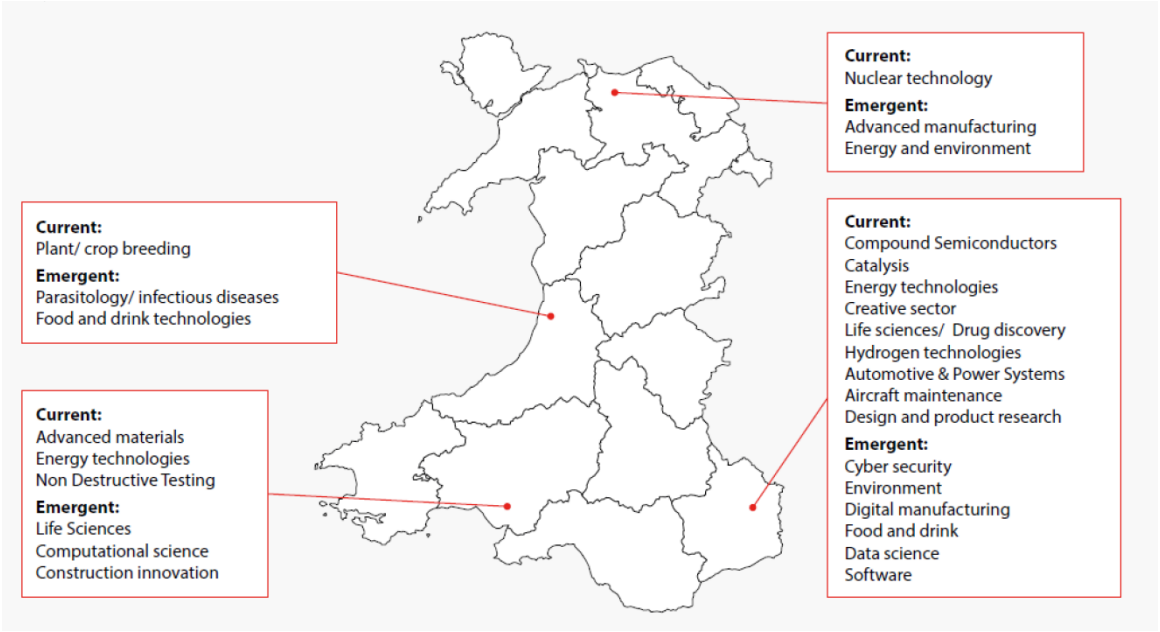
Source: https://statswales.gov.wales/

A number of 'hotspots' have been identified in university-business interactions, reflecting strengths in strategic sectors and technological disciplines (Morgan et al., 2017). These

[7] Examples of non-R&D innovation expenditures include investment in equipment and machinery and the acquisition of patents and licenses.
[8] Rounded to the nearest million GDP.

hotspots are based on university perceptions and are, in the majority of cases, found across a number of institutions (Figure 4).

Figure 4: 'Hot spots' of university-business collaboration.



Source: Morgan et al., 2017.

Furthermore, there are technology priorities set in City and Growth Deals across Wales (Delbridge, Henderson & Morgan, 2017):

- Cardiff Capital Region (Compound semiconductors, FinTech, Cyber Security Analytics, Artificial intelligence, Creative economy, Life sciences, Transport engineering, **Energy and environment**),
- Swansea Bay City Deal (Creative and digital, **Low carbon energy and marine**, Lifesciences, well-being, and sport),
- North Wales Growth Deal (**Low carbon and nuclear energy**, Advanced "smart" manufacturing, Digital and creative sectors),
- Mid Wales Growth Deal (High value manufacturing, Agriculture, food and drink, Defence and security, Tourism).

Low carbon energy is an area where Wales is well placed to innovate in the exploitation of its natural assets, e.g., in wind and waves. The wider challenge of decarbonisation is approached in Wales mainly through renewable energy, and through implementation of the Well-being of Future Generations (Wales) Act (Welsh Government, 2015).

2.2 Wales' energy and environment outlook

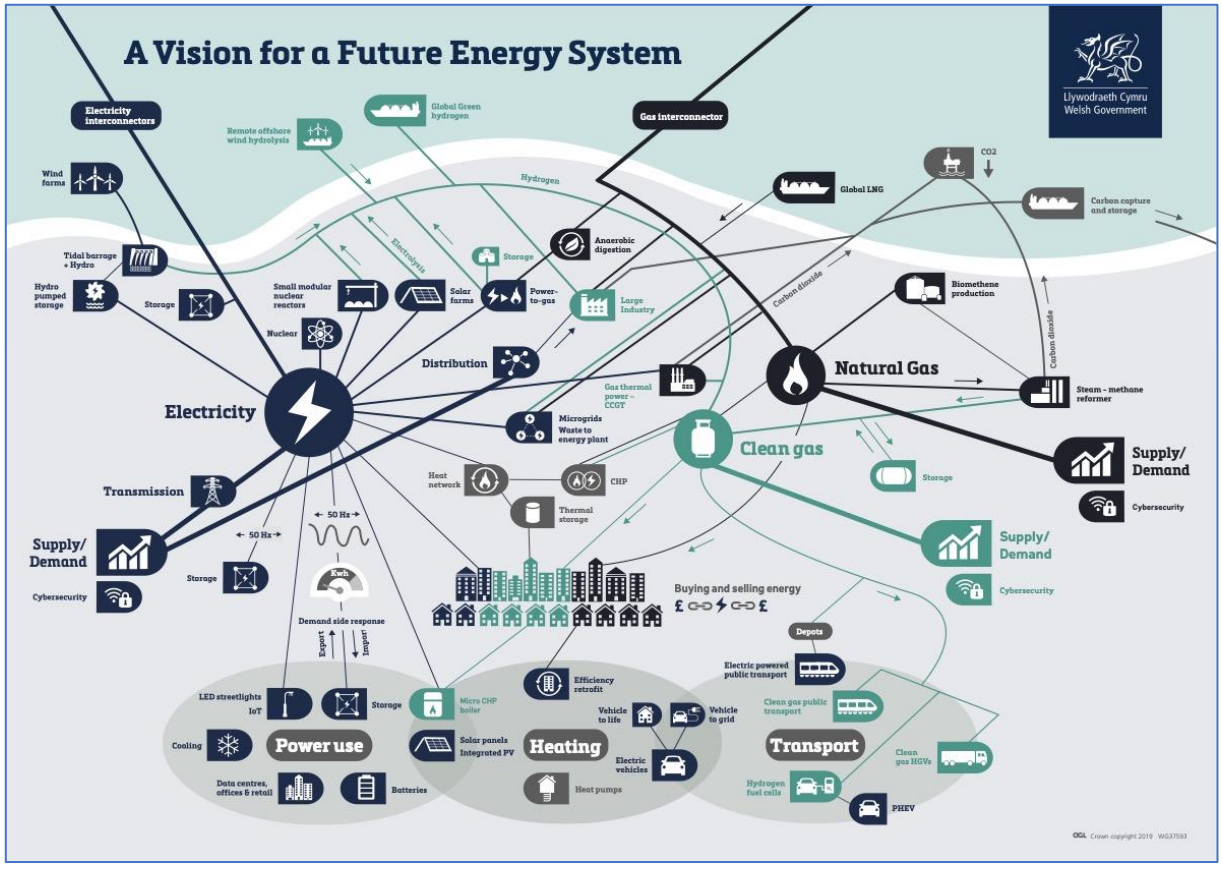
In April 2019, the Welsh Minister for Environment, Energy and Rural Affairs declared a climate emergency for Wales, and in June 2019, the Minister set out Welsh Government's ambition to bring forward a target for Wales to achieve net-zero emissions by no later than 2050. The decarbonisation measures are summarised in the policy document 'Prosperity for All: A Low Carbon Wales' (Welsh Government 2019a). Alongside this strategy, 'Prosperity for All: A Climate Conscious Wales' sets out the climate adaptation programme for Wales over the period 2020-2025 (Welsh Government, 2019b). The 'Clean Air Plan for Wales: Healthy Air, Healthy Wales' (Welsh Government 2020b) brings together work across many Government departments and public bodies to tackle air pollutants from many sources, reduce emissions from industry, agriculture and domestic heating to support air quality improvements. The 2015

Well-being of Future Generations (Wales) Act provides the guiding principles for these objectives and approaches (Welsh Government, 2015).

The Environment (Wales) Act 2016 established that Welsh Ministers must prepare and publish a plan for each budgetary period setting out policies and proposals for meeting the carbon budget. More recently, a Net Zero Wales plan for the reduction of emissions was published in October 2021, establishing Wales' second carbon budget for 2021-2025, and seeking to build the foundations for future carbon budgets to meet the net zero target by 2050 (Welsh Government, 2021b). Related to environment, the Wales Natural Resources Policy establishes the delivery of nature-based solutions as a national priority (Welsh Government, 2017a) while the Clean Air Plan for Wales includes a focus on emissions reduction (Welsh Government, 2020b).

In terms of the projected status of **energy generation technologies**, Welsh Government has an ambition to make the long-term transition to a low carbon energy system. In 2017, the Welsh Government announced a target of meeting the equivalent of 70% of Wales' electricity demand from domestic renewable electricity sources by 2030. A further target was to achieve at least 1 GW of renewable energy capacity to be locally owned by 2030, and there is an expectation for all new energy projects in Wales to have at least an element of local Welsh ownership from 2020. The 'Prosperity for All: A Low Carbon Wales' strategy includes a vision for a future energy system in Wales (see Figure 5).

Figure 5: Vision for a future energy system in Wales



Source: Welsh Government (2020) A Vision for a Future Energy System; https://gov.wales/low-carbon-energy-scheme-infographic

An even more ambitious perspective was published by the Institute of Welsh Affairs (IWA) (an independent think tank) in 2019; they described a path for Wales to become a country with 100% renewable electricity by 2035 (see Box 1).

Box 1: Institute of Welsh Affairs: A plan for Wales' renewable energy future

The IWA has published a vision for a Wales with 100% renewable electricity by 2035. This vision includes:

- More than 870,000 homes receive energy efficiency measures, a 20% energy demand reduction across the Welsh domestic stock, 9,500 annual FTE jobs in Wales, £2.2bn of gross value added created in Wales.
- 2,670 MW of solar PV, 1,800 annual full-time equivalent (FTE) jobs in Wales, £1.3bn of gross value added created in Wales.
- 2,545 MW of onshore wind, 2,000 annual FTE jobs in Wales, £520m of gross value added created in Wales.
- 1,700 MW of offshore wind, 1,300 annual FTE jobs in Wales, £430m of gross value added created in Wales.
- 4,000 MW of tidal range, tidal stream, wave and floating wind sectors, 5,200 annual FTE jobs in Wales, nearly £3bn of gross value added created in Wales.
- at least 55 MW of in-stream hydropower, 50 annual FTE jobs in Wales, £30m of gross value added created in Wales.
- 115 MW of fuelled technologies (biomass, anaerobic digestion, energy recovery), 300 annual FTE jobs in Wales, £60m of gross value added created in Wales.
- Total: 11,085 MW of renewable energy:

+ energy efficiency measures to 870,000 homes

= by 2035 supply Wales' annual territorial electricity demand

+ 20,150 jobs annually across Wales during a 15-year investment period (2020-2035)

+ £7.4bn in total Welsh GVA created.

The plan for a renewable energy future is based on 10 actions:

1. **Fund the future**: through an immediate 12-18-month low carbon economic stimulus for Wales which accelerates action on renewable energy and energy efficiency. Wales is required by the Environment (Wales) Act 2016 to reduce carbon emissions by at least 80% by 2050.
2. **Renew Wales' homes**: through improved building standards and a long-term greener homes programme.
3. **Retain the benefits in Wales**: by requiring all new renewable projects above 5MW to have between 5 and 33% community and local ownership by 2020.
4. **Use local land for local benefit**: by ensuring that planning regulations and public land are used in support of new renewable energy schemes and create maximum local benefit.
5. **Focus on delivery**: by ensuring there is sufficient capacity and expertise in key public bodies to deliver the vision in practice.
6. **Future-proof the grid**: by getting the electricity grid ready to meet Wales' energy aspirations.
7. **Get SMARTer**: by ensuring Welsh businesses, local and community organisations are supported to capitalise on and lead the shift to smarter energy technology and business transformation.
8. **Get ahead in marine**: by taking a coordinated approach between government, industry, academia and others to establish a global advantage over marine energy and floating offshore wind as niche Welsh services.
9. **Harness the potential of bioenergy**: enabling Wales to create a world class circular economy.
10. **Decarbonise transport**: through a comprehensive 'Transport Decarbonisation Plan' co-produced by key public bodies and the transport sector, backed up by a national travel survey.

Source: https://www.iwa.wales/wp-content/media/2019/03/IWA_Energy_WP6_Digital-2.pdf

Renewable sources with a substantial share in Welsh electricity generation are currently wind, solar PV and biomass. **Offshore and onshore wind** are likely to continue to play an important role in renewable energy generation in Wales. Wales currently has three offshore and six onshore wind farms including the fifth-largest offshore wind farm worldwide in Gwynt y Môr (Sea Wind). **Solar** accounted for 12% of all renewable electricity generation in Wales in 2019 and a number of zones have been identified as priority areas for large-scale solar energy developments in future (Welsh Government 2019c). On **marine and tidal energy**, two demonstration zones have been assigned in Wales to test wave and tidal stream technologies. However, further investment is required to generate revenue as a sector. Wales already has access to expert academic and research facilities on marine renewables.[9]

In terms of **fossil fuels**, the UK Government has committed to removing coal from the electricity mix by 2025, and is currently consulting on bringing this forward to 2024 (HM Government 2020). In addition, it will not provide new direct support for UK thermal coal mining or coal-fired power plants. In Wales, the last coal-fired power plant for commercial energy generation closed in March 2020. Further, Welsh Government's Coal Policy was published in March 2021 and includes a commitment to avoiding the continued extraction and consumption of fossil fuels.[10] Coal fired electricity generation is therefore not expected to contribute to Wales' energy mix in the future (Welsh Government 2020a). In addition, the proposed Clean Air Bill would ban the indoor burning of solid fuels (traditional house coal and wet wood) after 2023 (Welsh Government 2020b).

UK Government accepts that the UK as a whole will continue to rely on **natural gas** for 'some years' (HM Government 2020). It plans to consult with network operators, suppliers and consumer groups in 2021 on the future of gas, including on whether it is appropriate to end gas grid connections to new homes from 2025 in favour of clean energy alternatives. A gradual move away from fossil fuel boilers is planned through a combination of energy efficiency measures and lower carbon replacement boilers. In Wales, gas fuelled power stations accounted for almost 70% of electricity generated in 2019 (Welsh Government 2020a). However, gas generation in Wales is increasingly changing from providing a steady, baseload supply to a more flexible peaking and backup role. Wales and West Utilities has pledged to deliver a Net Zero-ready smart gas network by 2035 in a multi-vector energy system to deliver heat, power and transport demand securely and at lowest cost for customers (Welsh Government, 2021d). The company advocates a "whole system approach" to considering energy supply grids. This considers all energy demands, all energy supplies, and the networks that join them together. A whole energy system includes renewable generation such as wind power, tidal power and green gases. It also includes provision for developing technologies such as charging for Electric Vehicles and local energy storage in homes. The network will include storage, flexibility and needs to connect everything together in a reliable way.

Hydrogen will play an important role in the switch from gas at UK level. To facilitate the development of hydrogen activities and opportunities, Welsh Government has set out a pathway for hydrogen development in Wales during current carbon budget period (2021-2025).[11] The next stage is to develop a long-term plan to make hydrogen zero-carbon, after which hydrogen could also play a role in decarbonising the power system. Welsh Government's commitment to a net zero pathway, backed by financial support, regulation and clear hydrogen strategies and targets, could trigger unprecedented and sustained momentum in Welsh hydrogen in the medium to longer-term (Welsh Government, 2021b). Collaboration with the UK Government, the external Welsh Government Hydrogen Reference Group and

[9] https://www.morlaisenergy.com/; https://www.iwa.wales/wp-content/media/2019/03/IWA_Energy_WP6_Digital-2.pdf
[10] https://gov.wales/coal-policy-statement
[11] To this end, Welsh Government are working with UK Government (DBEIS) and have issued a joint call for evidence: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1001949/decarbonisation-readiness-call-for-evidence.pdf

other stakeholders, will be key to achieving ambitions in this area and help attract central government and private funding.[12]

In terms of **energy efficiency**, the challenges are to be addressed by working towards a resource efficiency agenda and accelerating the circular economy. Furthermore, in order to ensure that Wales is in the best possible position to realise its full energy efficiency potential and become a major exporter of energy efficiency technology and know-how, the Welsh Government has developed an energy efficiency strategy for the period up to 2026 (Welsh Government, 2016). The strategy defines targeted energy standards in Wales and five key areas of action: awareness, domestic supply chain, well- educated and skilled workforce, innovation support, and clear funding mechanisms.

2.3 Wales' current energy related R&I landscape

A range of actors is relevant to the energy technology research, technological development and innovation (RTDI) landscape in Wales. **Welsh Government** plays a key role in terms of providing a policy lead on innovation, and as a source of funding, including through domestic low carbon programmes such as SMART Living, and the EU co-funded SMART Innovation programme.

The Welsh universities are central actors leading energy-related RTDI in Wales. All Welsh universities are public universities funded by the Welsh Government through the Higher Education Funding Council for Wales (HEFCW). Wales' universities have long-standing research expertise encompassing a broad range of energy technologies, concentrated in the universities of Cardiff, Swansea, South Wales (USW) and Bangor (see Table 5 for a selection of energy-related research centres and areas of expertise within these universities). Examples include the **Sêr Cymru National Research Network for Low Carbon, Energy and Environment,** a pan-Wales research initiative based at Bangor University supporting world-leading research in low carbon energy, nature-based solutions to environmental challenges, the bio-economy and sustainable food production. Also at Bangor, the Smart Efficient Energy Centre was launched in 2019 to develop joint research between Welsh and international organisations and businesses, and investigate the options for using big data science to improve the efficiency of low carbon energy systems including nuclear, marine and offshore wind energy. The centre was forecast to become an international hub of excellence in North Wales encouraging collaboration on new ideas and innovative solutions to global energy efficiency issues. Cardiff University's Energy Research Cluster brings together scholars across the University's School of Geography and Planning research groups who are concerned with policy and societal perspectives on energy, climate change, and low-carbon transitions.

Within Wales, the European Regional Development Fund (ERDF) has supported numerous **project consortia** working on energy research. These often include Welsh university partners, e.g. SPARC II (solar/PV energy research) includes the universities of Bangor, Swansea, and Aberystwyth[13]; FLEXIS (energy systems technologies) includes the universities of Cardiff, Swansea and South Wales as strategic partners, as well as the universities of Aberystwyth and Bangor and the British Geological Survey as collaborative partners, together with local government and industrial partners[14]; while SOLCER (low carbon systems) includes the universities of Glyndwr, South Wales, Swansea and Cardiff.[15]

Wales' universities also have extensive experience of participating in world-leading **international research consortia** e.g. funded under successive EU Framework Programmes.

[12] https://gov.wales/written-statement-energy-statement
[13] https://www.swansea.ac.uk/sparc-ii/
[14] https://www.flexis.wales/about/
[15] http://www.solcer.org/what-is-solcer/

Table 5: Energy-related research centres and areas of expertise in Wales' universities (selected examples)

Bangor University	Sêr Cymru National Research Network for Low Carbon, Energy and Environment[16] Sêr Cymru Nuclear Futures Institute[17] Smart Efficient Energy Centre[18] Solar[19] Marine[20]
Cardiff University	Energy Research Cluster[21] Energy Systems Research Institute[22] Centre for Integrated Renewable Energy Generation and Supply[23] Centre for Research into Energy, Waste and the Environment[24] Electric Vehicle Centre of Excellence[25] Cardiff Catalysis Institute[26] Gas Turbine Research Centre[27]
Swansea University	SPECIFIC IKC[28] Active Buildings Centre (ABC)[29] Circular Approaches to Utilise and Retain Energy (CAPTURE)[30] Marine Energy Research Group[31] Centre for Solar Energy Research[32] Energy Safety Research Institute[33] PV and Solar Energy[34]
University of South Wales	Hydrogen Centre[35] Wales Centre of Excellence for Anaerobic Digestion[36] Centre for Automotive and Power Systems Engineering (including energy storage)[37]

A wide range of low carbon energy research across Welsh universities was brought together under the umbrella of the **Low Carbon Research Institute (LCRI)**[38]during the period 2008-2015. The LCRI was funded by the ERDF and HEFCW. The Institute provided an overview of research being undertaken across topics relating to the built environment, solar PV, hydrogen, large scale power generation and marine by the universities at Cardiff, Glyndwr, Bangor, South Wales and Swansea. Individual universities took the lead for the research topics, but many projects involved collaboration across the partners. LCRI also worked with industry and government and collaborated on projects with research partners across the UK.

The **Higher Education Funding Council for Wales** (HEFCW) provides university research programmes with resources to enable them to compete for external research funding. HEFCW

[16] https://lceernw.ac.uk/
[17] https://nuclear-futures.bangor.ac.uk/
[18] http://seec.bangor.ac.uk/
[19] https://www.bangor.ac.uk/energy/solar.php.en
[20] https://www.bangor.ac.uk/energy/marine.php.en
[21] https://www.cardiff.ac.uk/research/explore/research-units/energy-research-cluster
[22] https://www.cardiff.ac.uk/energy-systems-research-institute
[23] https://www.cardiff.ac.uk/research/explore/research-units/centre-for-integrated-renewable-energy-generation-and-supply
[24] https://www.cardiff.ac.uk/research/explore/research-units/centre-for-energy-waste-and-the-environment
[25] https://www.cardiff.ac.uk/research/explore/research-units/electric-vehicle-centre-of-excellence
[26] https://www.cardiff.ac.uk/cardiff-catalysis-institute)
[27] https://www.cu-gtrc.co.uk/
[28] https://www.specific.eu.com/
[29] https://abc-rp.com/
[30] https://www.swansea.ac.uk/engineering/research/capture/
[31] https://www.swansea.ac.uk/engineering/zcce/energy-environment/
[32] https://cser.org.uk/
[33] https://www.swansea.ac.uk/engineering/research/esri/
[34] https://www.swansea.ac.uk/research/research-highlights/steel-innovation/printed-photovoltaics/)
[35] http://www.h2wales.org.uk/pages/hydrogen-centre/hydrogen-centre.html
[36] https://www.walesadcentre.org.uk/
[37] https://www.southwales.ac.uk/research/research-groups/capse/
[38] http://www.lcri.org.uk/

also provides support for innovation and engagement activities through the Research Wales Innovation Fund (RWIF)[39].

Other public sector bodies are also active in energy-related research in Wales, for example the remit of Natural Resources Wales (*Cyfoeth Naturiol Cymru*) includes undertaking research and evidence gathering. At regional and local governance levels, the **City and Growth Deals**, as well as **local authorities**, are active in energy strategy development and providing innovation support. The Welsh regions have published strategy and vision documents that identify specialisms and themes that form an important part of the innovation landscape. At local level, actors are working in partnership to support energy innovation. For example, the **Anglesey Energy Island Programme**, established by Isle of Anglesey County Council, is a collective effort between stakeholders within the public, private and third sectors working in partnership, aiming to put Anglesey at the forefront of low carbon energy research and development, production and servicing.[40] A further example is the **Tech Valleys Initiative**, where Welsh Government is working with Ebbw Vale Enterprise Zone Board, Blaenau Gwent County Borough Council, industry and academia, to make the South Wales Valleys, and Blaenau Gwent in particular, a globally recognised centre for the development and delivery of emerging technologies and host to significant organisations in the next wave of high value manufacturing.

The private sector also plays a role in the energy-related RTDI landscape in Wales. This includes **grid operators and related energy organisations** which are enthusiastic to be involved in energy transition (e.g. Western Power Distribution, the National Grid, Welsh Water and Warm Wales) and industrial clusters such as the **South Wales Industrial Cluster**, a partnership between Welsh industry, energy suppliers, infrastructure providers, academia, the legal sector, service providers and public sector organisations, working to develop holistic industrial site decarbonisation options and create a plan to help South Wales industry achieve net zero by 2050.

Welsh Government works with **industrial partners** to develop renewable energy sectors, for example, working with industry and academia to develop the marine energy sector, where partners include RWE Renewables, Morlais, Port of Milford Haven, Minesto, Marine Power Systems, Geoscience Ireland, Floventis Energy, DST Innovations, Bombora and Blue Gem Wind. Renewable energy **industry representative bodies,** such as Marine Energy Wales and Renewable UK Cymru, also provide a coordination role and aim to drive policy in their sectors. For example, Marine Energy Wales publishes an annual 'State of the Sector' report which provides an update on sectoral research undertaken.[41]

Wider UK policy is also important to the Wales innovation landscape - the overwhelming majority of UK public funding for R&I is allocated by UK Government and UK level institutions (Tilby, 2021). UK-level innovation strategy is led by the UK **Department for Business, Energy & Industrial Strategy** (DBEIS), while **UK Research and Innovation** (UKRI) is the national funding agency investing in science and research in the UK. UKRI operates across the whole of the UK and brings together the **Research Councils** and **Innovate UK**, the UK's innovation agency. Innovate UK has established a network of world-leading technology and innovation centres across the UK. These include the **Catapult Centre for Offshore Renewable Energy** which is situated across nine locations, including Pembrokeshire in Wales.[42] ORE Catapult research is industry-led; the research strategy is influenced by consultations with key stakeholders and combined with research community engagement, particularly academic

[39] https://www.hefcw.ac.uk/en/our-responsibilities/research-innovation-and-engagement/research-and-innovation-initiatives/
[40] https://www.anglesey.gov.uk/en/Business/Energy-Island%E2%84%A2-Isle-of-Anglesey-North-Wales/What-is-Energy-Island%E2%84%A2.aspx
[41] https://www.marineenergywales.co.uk/developers/research/
[42] https://ore.catapult.org.uk/

engagement. The research hubs aim to provide a complementary offering of academic research, innovation, demonstration and representative testing to the offshore renewables sector.

In terms of the strengths, weaknesses, opportunities and threats relevant to the Welsh energy R&I landscape, a selection of these is summarised in the SWOT analysis in Table 6.

Table 6: SWOT analysis of the energy RTDI landscape in Wales

Strengths:	Weaknesses:
Excellent natural resources in relation to low carbon energy Know-how – strong position internationally Political will and commitment – strong net zero agenda and existing domestic policies supporting green transition Established cooperation between government, industry and academia Strong networks and highly collaborative environment Seven strategically located ports (including the third largest in the UK at Milford Haven), with good road and rail links to other major cities and transport hubs; cross border links Strong supply chains and manufacturing strengths in steel, metals and materials engineering Testing opportunities across a wide range of scales, from controlled tank testing for scaled prototypes to sheltered quayside zones for components, instruments and smaller devices, open water sites for individual full-scale prototypes and high energy areas for array-scale demonstration of multiple devices Proactive community sector willing to innovate Interest by grid operators and related organisations to be involved in energy transition Wales performs comparatively well in relation to STEM degrees	Structural weaknesses including low levels of R&D spend and reliance on EU Structural Funding for R&I activity R&I system lacks volume and mass Limited R&I capacity among SMEs Existing initiatives are small-scale; need to link up pilot projects with broader vision ('many successful pilots' problem) Need for a broader understanding of innovation and mission-orientated innovation to tackle societal challenges Risk aversion e.g. perception of early stage funding Lack of strong private sector innovators and high growth firms has resulted in university-led innovation becoming the primary avenue available to absorb EU RTDI funding in Wales Uneven success in access to major UK funding sources for innovation Innovation support landscape becoming more complex
Opportunities:	**Threats:**
Dissemination of results of ongoing projects Provision of demonstration zones and test-beds with natural resources available A green recovery after COVID-19: addressing the climate emergency and focusing green recovery in a more resilient, low carbon, resource efficient economy Making renewable energy part of Welsh identity: a cleaner, greener chapter in the industrial story Developing a world class centre for marine energy development Support for small scale renewables Including grid operators to take a strategic approach to grid development in Wales Rural areas offer opportunities around green industries	Vulnerability to plant closures Risk involved – not all projects can succeed, and many projects will risk being outpaced by policy or technological change Governance system/Welsh Government legislative powers - reserved powers mean that UK government has a role in whether or not important initiatives can proceed (e.g. onshore wind, tidal lagoon) Lack of certainty around future R&D funding post-EU Structural Funds Competitive nature of some potential funding streams (e.g. Horizon Europe) – significant investment of time and resources required to prepare bids, not all of which will be successful

Promising renewable energy clusters and projects (e.g. hydrogen in South Wales, offshore wind in West Wales, the South West Industrial Cluster) Regional agenda and Growth and City deals present an opportunity for innovation (wider view than 'science' and also funding) Partnerships between local authorities and others on capacity building[43] Growth of Intensive Learning Academies, including for innovation (starting in health and social care)	Uneven sectoral and social impact of COVID and longer-term structural effects of Brexit; lack of international agreements or avoidance of international declarations. Systemic transitions of sustainability and digitalisation

Sources: HEFCW, 2019; Michie, den Hoed & Fonseca, 2021; Delbridge, Henderson & Morgan, 2021; Tilby, 2021.

Welsh Government is currently developing a new integrated Innovation Strategy for Wales, building on research commissioned by the Innovation Advisory Council for Wales (Delbridge, Henderson & Morgan, 2021) and an extensive round of stakeholder engagement. The strategy will set out the direction and overarching priorities for innovation in Wales across sectors, government departments, delivery agents and Ministerial portfolios. The next stage will involve seeking broader input from all stakeholders in Wales.

3 R&I in Energy and Environment: Vision for 2030 & 2050

3.1 Objectives and outcomes

The objectives and outcomes for research and innovation (R&I) in the energy and environment sectors in Wales can be drawn from several existing strategies and plans. These strategies and plans are not just focused on these sectors, but also more broadly on technology, regional development, economy and well-being. Research and innovation supported through the implementation of these plans and strategies is thus expected to contribute to broader well-being and development goals, and to a long-term vision of sustainability for the energy and environment sectors. In addition to contributing in tangible terms to these sectors, research and innovation activity is seen as contributing to the evidence-based policy, processes and tools that can provide solutions to national challenges related to energy and the environment.

The main framing goals for the sustainable development of Wales are established in the 2015 Well-being of Future Generations (Wales) Act (Welsh Government, 2015), put in place to improve the social, economic, environmental, and cultural well-being of Wales. These are:

- A prosperous Wales;
- A resilient Wales;
- A healthier Wales;
- A more equal Wales;
- A Wales of cohesive communities;
- A Wales of vibrant culture and thriving Welsh language;
- A globally responsible Wales.

These goals contain several indicators to evaluate the current context and track future progress and outcomes, including on renewable energy and ecosystem health (see Section 4.4.2). Other, more specific objectives linked to science, research and innovation are set out in other strategies and plans. For instance, the Economic Action Plan, supporting the delivery of the

[43] For example, Infuse (Innovative Future Services), an ESF-funded programme to support local authorities in the Cardiff Capital Region to access new skills, methods and tools that improve their capacity and capability to innovate. https://ylab.wales/programmes/infuse-innovative-future-services

Prosperity for All national strategy (Welsh Government, 2017b), has the main aim to foster inclusive growth based on strong foundations, future industries, and productive regions, in order to build economic resilience. It sets out the following objectives:

- Support skills' development and high quality employment;
- Support R&I for decarbonisation, entrepreneurship and digitalisation objectives;
- Support the development of domestic value chains and their links with international ones;
- Support national competitiveness and inclusive growth in a variety of thematic (e.g., high value manufacturing, renewable energy) and foundational sectors (e.g., tourism, food, retail, healthcare).

Well-being and development in Wales are therefore framing R&I objectives for energy and environment, and inextricably tied to both sustainable social and economic goals, objectives, and metrics.

Marine energy and hydrogen are two sectors in Wales with identified potential in the coming years, serving as a niche for Welsh services in the wider UK and global economies. Continuing to develop new projects and R&I in these and other more established technologies – such as solar PV and onshore wind – is an important consideration for the future Welsh energy system, along with monitoring of performance of existing schemes to adapt in the face of new challenges (IWA, 2019).

The energy and environment outlooks described are based on objectives and targets set at both UK and Wales' levels, as policy responsibilities are split between UK and Welsh Governments. The main current goals and objectives contributing to a vision for the energy and environment sectors for Wales are set out in Table 7.

Table 7: Summary of established energy and environment-related objectives in Wales for the 2030 and 2050 target dates.

Vision and objectives for 2030	Vision and objectives for 2050
UK level	
• Remove coal from electricity mix by 2025, and no more new direct support for UK thermal coal mining or coal-fired power plants; • At least one new large-scale nuclear project; • Support the deployment of Carbon Capture and Storage in four industrial clusters; • Phase out use of fossil fuels in off-grid homes, businesses and public buildings; • No new unabated gas plants to be built after 2030; • Hydrogen grid conversion trials in the 2020s; • 5 GW low-carbon hydrogen production; • End of the sale of new petrol and diesel cars in the UK.	• Hydrogen grid conversion from gas; • Patchwork large-scale conversions starting from 2030 to 2050 near industrial clusters, with some buildings in these areas switching to hydrogen; • Build a commercially viable fusion power plant by 2040; • Create the world's first net zero emissions industrial zone by 2040; • Unabated gas-fired electricity generation to end by 2035.
Wales level	
• 70% of electricity consumption from renewable energy (51% in 2019); • 1 GW of renewable energy capacity to be locally owned (83% achievement by 2019); • All renewable energy projects to have an element of local ownership from 2020; • Establish at least one renewable hydrogen production site by 2023-24, preparing for scale-up and commercial deployment from 2030; • Reducing consumption of high-carbon meat and dairy products by 20%;	• Net zero emissions; • Increase housing and energy performance standards achieve at least a 95% decarbonisation target for power sector; • Target of 180,000 hectares of new mixed woodland.

• Halving avoidable food waste by 2025 and 60% reduction by 2030; • Electric/low-carbon cars, vans and boiler replacements; • Target of 43,000 hectares of new mixed woodland; • Net zero public sector; • Clean Air Wales Bill to ban indoor burning of solid fuels (house coal and wet wood) after 2023; • Phase out of sales of oil boilers by 2028 in residential homes and by 2025-26 in commercial properties. • **Piloting smart**, **flexible and digitalised systems to help reduce demand**.	

Source: Authors' elaboration based on UK and Welsh Government strategy documents (HM Government, 2020; UKCCC, 2020; Welsh Government, 2020a; Welsh Government 2019b; Welsh Government, 2021).

An R&I strategy that supports a sustainable outlook for the energy and environment sectors in Wales must therefore focus on the development of the systems, structures, technologies, and processes for the identified areas of potential. The key objectives for R&I in these areas in Wales centre on the development of technologies, building up a strong skill base, providing collaborative R&D support for green Welsh businesses and positioning Wales as a leader in world-class R&I in the low carbon economy. Research work involves mitigating the effect of carbon-based heat and power generation (coal, gas, oil) systems, for example, through carbon capture technologies, or de-carbonising fuel supplies, whilst developing and improving the efficiency of renewable power sources such as marine and biomass-derived power. Besides technology development, R&I strategic objectives also include the analysis of impact of current and future energy use in terms of health, safety, and environmental management.

More specific objectives for R&I in energy and environment are detailed in Table 8, based on the visions for 2030 and 2050 set out in current Welsh strategies and plans (Welsh Government, 2021b; Griffiths, 2020; Carbon Trust, 2018; Marine Resources Wales & Welsh Government, 2019a; Welsh Government 2020b).

Table 8: R&I vision and opportunities for Wales in the energy and environment sectors (based on Table 7)

Sector	R&I vision and priorities
Energy	
Fossil fuels	• Sustainable substitution of this power source in the Welsh energy mix; • Upgrade the gas and electricity grid and housing stock to enable for effective heating alternatives in rural areas; • Research the use of mine water as a heating alternative based on the principles of the circular economy; • Invest in opportunities for high-efficiency electrification (e.g., EVs and heat pumps); • Substitution of fossil fuels in industrial sites in Wales (specifically the South Wales industrial cluster) with low-carbon alternatives and/or installation of efficient carbon capture and storage at scale; • Focus on the application of new fuels and propulsion technologies for the transport sector, primarily automotive and aerospace.

Nuclear	While no nuclear power stations are currently operating in Wales, and plans for future ones have been suspended, R&I opportunities remain in the nuclear sector: • Provide expert knowledge and support for decommissioning across various sites; • R&D programmes underway addressing key industry issues including human behaviour, technology, welding, waste disposal and storage, training, supply chains, production, materials and economics (e.g., Bangor, Swansea and Cardiff universities); • Investigate existing and emerging technologies, including Pressurised Water Reactor (PWR), Boiling Water Reactor (BWR), Small Modular Reactor (SMR) technology, Advanced Modular Reactor (AMR) demonstration, and medical radioisotopes.
Biomass	With bioenergy and waste use expected to grow modestly by 30% to 2050 at UK level, R&I in biomass should focus on: • Utilisation as source of renewable heat and electricity; • Research converting biomass and bio-industry wastes into biobased products with commercial applications, via biorefining and bio processing (e.g., Beacon project[44]).
Hydrogen	• Facilitate the development of hydrogen activities and opportunities in Wales, in order to set out a pathway for hydrogen development; • Invest and develop R&I to make hydrogen zero-carbon, thus contributing to decarbonising the power system; • Explore the grid conversion from gas to hydrogen and opportunities for hydrogen boilers/hybrid heat pumps.
Wind	• Investigate cumulative impacts of wind energy development on protected areas, seascape and biodiversity; • Participate in industry-wide research studies to address key strategic issues for offshore wind development; • Support universities and research bodies to undertake dedicated studies on issues that are critical to Wales, but not addressed through industry-wide initiatives (e.g. seascape issues); • Encourage data sharing via the Marine Data Exchange to develop a repository of high resolution environmental data; • Undertake R&I activities for offshore wind operations and maintenance, leveraging the local capabilities and experience of the supply chain in Wales; • Test and demonstrate innovative technologies, including new turbine models and operations and maintenance technologies.
Solar	• Research storage opportunities to allow for a consistent year-round energy flow; • Explore new uses for solar energy, namely related to charging electric vehicles, power remote sensors and a new generation of more efficient solar conversion devices.
Marine and tidal	• Take advantage of the strategically located ports which provide supply chain and deployment support for energy projects; • Investigate two large-scale demonstration zones[45] to test wave and tidal stream technologies, making it more cost-effective and competitive; • Support investments in existing expert academic and research facilities on marine renewables (e.g., Bangor and Swansea universities);

[44] https://beaconwales.org/who-we-are
[45] https://www.morlaisenergy.com/

	• Research the feasibility and efficiency of marine and tidal projects; • Research the sources and sinks of carbon across the fishing and aquaculture industries, and the potential and opportunities for decarbonisation of fishing activities, aquaculture and the fish supply chain.
Environment	With an expected increasing demand on timber and forest products, R&I in the area could focus on: • Producing new wood fibre and value-added products, e.g., cellulosic plastics from biorefineries; • Stimulate higher efficiency and productivity throughout the supply chain, from forest nurseries to wood fibre processing; • Developing remote sensing technology to monitor forests and provide more data to support decision making. More generally, R&I for the environment sector should: • Explore opportunities in land regeneration, soil behaviour, environmental design, water quality, impact of agrochemicals, climate change, and biodiversity, among others; • Research efficient carbon capture and storage structures, expected to play an important role in the manufacturing and construction sectors and in the production of hydrogen and electricity generation; • Investigate the land use implications of shifting agricultural land to carbon sequestration uses, e.g., tree planting and peatland restoration; • Working with nature and moving towards a circular economy to both increase the resilience of ecosystems, reduce pollution and improve productivity and profitability; • Prioritise evaluation of impacts on poorer and disadvantaged areas and households, namely regarding digital access, health, fuel poverty and accommodation; • Improve societal understanding of the usage of new energy systems to support broader behavioural change.

Source: Authors' elaboration based on UK and Welsh Government strategy documents, (Welsh Government, 2021b; Griffiths, 2020; Carbon Trust, 2018; Marine Resources Wales & Welsh Government, 2019a; Welsh Government 2020b).

Outcomes envisaged from these objectives include: increased R&D&I income won in Wales, improved community connectivity, increased adoption of innovation, resource efficiency, fairer distribution of investment and diversity of innovation (Welsh Government, 2021a).

3.2 Key guiding principles

The Welsh Government's Net Zero Wales Carbon Budget 2 (Welsh Government, 2021b) sets out broader R&I guiding principles until 2025. Namely, it seeks to:

- Employ a "whole-system" approach to approach the complexity of decarbonisation and the net zero carbon transition. Therefore, R&I is not focused only on technology and process improvement in this approach, but also on, e.g., business model development, behaviour change and novel financial instruments;
- Continue its commitment to support and value the high-quality research base available (e.g., through Sêr Cymru, see section 4.2) and support technology innovation to develop leadership and competitive advantage in Wales;
- Coordinate and collaborate to avoid overlaps and enable efficient complementarities (e.g., partnerships in Environment Platform Wales[46]);

[46] Environment Platform Wales brings together universities, research centres and others with the aim of translating world class research into high quality evidence for Welsh Government and Natural Resources Wales. See more information here: https://epwales.org.uk/about/

- Build on various forms of partnership, working including across the UK, to maximise opportunity and inward investment;
- Setting the net zero challenge at the heart of a new Welsh Government Innovation Strategy;
- Reduce energy and resource usage/consumption;
- Develop new support mechanisms to encourage and support innovation in industrial decarbonisation, for example in building efficiency, fuel switching, process energy, resource efficiency, carbon capture utilisation and storage;
- Promote industry and business engagement in R&I;
- Adopt a strategic approach to prioritising supply chain development activities and infrastructure investment.

Other policies and proposals within the Net Zero Wales plan (Welsh Government, 2021b) include supporting innovation in new renewable energy technology, investing in sustainable mobility, increasing woodlands areas, incentivising waste reduction, building new low carbon social homes for rent, and ensuring wide scale peatland restoration and sustainable management. Overall, research and innovation are considered essential elements to achieve significant emission reductions across all sectors and meet the net zero objective in Wales. This should be done through a place-based approach, considering the needs of each sub-region and place. Related to environment, the Wales Natural Resources Policy (Welsh Government, 2017a) establishes the delivery of nature-based solutions as a national priority. Alignment with the Well-being of Future Generations Act (Welsh Government, 2015) is also foreseen as a guiding principle for these objectives and approaches.

A pathway to net zero also implies moderate behavioural changes and innovative approaches. Delivering these to meet Welsh climate targets will only be possible if comprehensive programmes of infrastructure and skills are developed in a complementary manner over the same period. Evidence-based policy must be designed to support business models that will work in the growing markets for innovative low-carbon and cost-efficient solutions. At the same time, broader societal and behavioural change are envisioned as crucial to assist R&I in tackling the challenges in reducing emissions by the target dates.

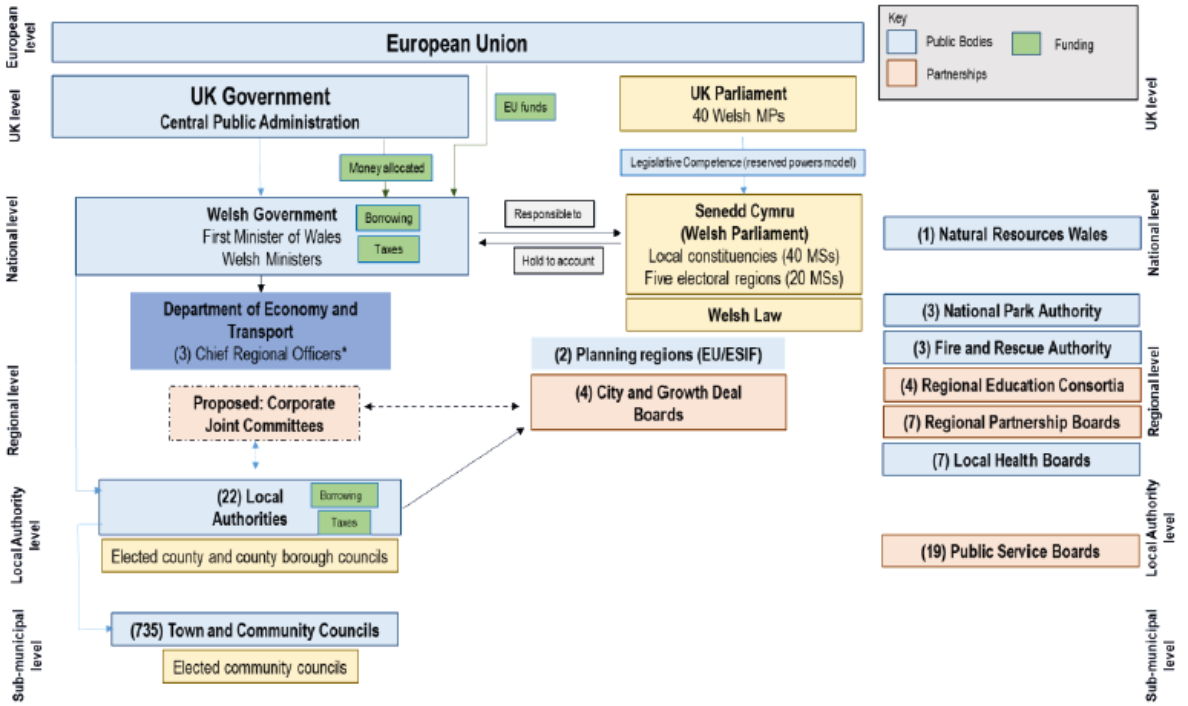
4 Support framework for R&I in Energy and Environment

4.1 Multi-level governance structure for R&I policies in Wales

4.1.1 Policy design and implementation framework

The Welsh Government is at the centre of the multi-level governance structure for R&I policy in Wales. While UK Government policy, reserved powers and financial flows inevitably have a major influence, the Welsh Government has devolved powers and governance structures for regional development and public investment. An OECD report on multi-level governance in Wales (OECD, 2020) details how the Welsh system supports public investment across multiple geographical and administrative levels, and considering a variety of public bodies, partnerships, and funding channels (Figure 6).

Figure 6: The Welsh multi-level governance system supporting public investment



Source: OECD (2020)

Note: The public investment frameworks, the regulations governing these, and the projects financed by European funds remain relevant until the financing is exhausted in 2023. The EU level has thus also remained as a silent actor in the multi-level governance system.
The position of Chief Regional Officers has been created and is attached to the Department of Economy of the Welsh Government, though acting at a regional level.

In Figure 6, some of the more notable Welsh bodies or structures for energy and environment R&I are the Department of Economy and Transport, the Local Authorities, the City and Growth Deal Boards, and Natural Resources Wales. Because this figure relates to the public investment framework in general, it does not provide a comprehensive view of the specific governance system for R&I in energy and environment. Nonetheless, it gives insight into the funding channels and multiple levels involved in R&I policy governance in Wales, and in the potential investment for R&I. Looking at relevant sectoral policies at the Welsh national and sub-national levels (excluding Welsh EU Programmes), an overview of the multi-level governance framework is provided in Table 9.

Table 9: Welsh regional development planning, implementation, and funding with contribution to energy and environment R&I

Policy planning and/or implementation	Funding strand (national or combined)	Financing sources
Welsh Government	Select department/sector policies: • Economy • Education • Energy • Housing • Innovation • Agriculture/Food • Tourism • Transport	• Welsh Government departments • EU funds

Cross-jurisdiction/functional areas	City and Growth Deals: • Cardiff Capital Region City Deal • Swansea Bay Region City Deal • North Wales Growth Deal • Mid-Wales Growth Deal • Regional Economic Frameworks (not yet in place)	• UK Government • Welsh Government • Local authorities • Other public and private sector
Local Authorities	Select local level planning documents: • Local Transport Plans • Local housing strategies • Welsh in Education strategic plans • Local Development Plans (land use)	• Welsh Government grants/transfers • Local authority budget
Public Service Boards	Well-being plans	

Source: OECD (2020)

Note: The above list of strategy documents, policies and plans contributing to regional development is not exhaustive.

Responsibility for advancing the regional development and energy and environment R&I agenda is typically spread across the government, in both the hands of the First Minister's office and of its ministers and their departments. However, the R&I support framework, strategies and plans have been characterised by OECD as fragmented. Therefore, in its efforts to realise innovation and regional development aims, the Welsh Government has been advised by the OECD (OECD, 2020) to foster horizontal and vertical coordination between operational and sectoral silos. This would avoid policy and programming fragmentation and improve policy coherence and resource efficiency across priorities, themes, and sectors. Action in innovation policy, especially, has incidence in various other policy areas, such as education and skills or energy policy. The promotion of synergies is thus recommended to achieve what are cross-cutting goals. At the same time, this could promote a more integrated regional development and innovation policy approach across already existing structures and plans, improving adherence from local stakeholders facilitating the design and delivery of policy and services. Coordinating mechanisms are suggested to promote this, such as inter-ministerial committees (e.g., in innovation or energy), investment finance teams, promotion of inclusive and diverse executive boards (e.g., in City and Growth Deals), and multi-stakeholder dialogue forums (UK Government, 2021).

Efforts to increase coordination are already underway. Since publication of the OECD report, and following an election in 2021, a new climate change ministry was announced within Welsh Government, bringing together the portfolios for environment and energy (along with housing, planning and transport).

4.1.2 Stakeholder engagement

Wales has been widely recognized for its efforts in public and stakeholder engagement in the development of its regional innovation strategies and initiatives. As far back as the early 1990s, an extensive consultation was carried out as part of the process of developing a Regional Technology Plan, to help develop consensus and improve the innovation and technology performance of the Welsh economy. Subsequent regional innovation strategies have followed a similar route.

Consultation bodies, working groups, sub-groups, and several reflection exercises are used by the Welsh Government to support the innovation policy design process. A diverse set of stakeholders is therefore brought together under these consultative mechanisms. These are usually organized in working groups around a specific topic, such as energy. They thus represent an opportunity for the Welsh Government to consult with experts and a variety of stakeholders that can contribute toward refining strategic thinking.

Consultation and engagement in regional innovation strategies and initiatives most frequently involves stakeholders from a variety of both public and private organisations, such as universities and other research organisations, industry, and third sector partners. Local authorities are also key partners in the delivery of several Welsh Government research and innovation programmes, such as the Valleys Task Force, or Targeted Regeneration Investment (TRI). More recently, local authorities have been emphasized in their role in City and Growth Deals.

As part of the Economic Action Plan, Welsh Government has created the position of Chief Regional Officers for North Wales, Mid and South West Wales, and South East Wales. These have been appointed to foster closer and more effective collaboration with regional partners and stakeholders and facilitate the delivery of economic development goals. These are liaisons between the region and the Welsh Government, thus promoting stakeholder engagement at multiple levels and influencing and informing national policy and programmes. In particular, closer working relationships are fostered with local authorities, businesses and communities, with delivery of economic development focused on a shared regional vision.

Particularly regarding research and innovation in the topics of energy and the environment, the local level is emphasized as a scale at which change and experimentation can more easily be triggered, and then be scaled-up. Local government is thus seen as being uniquely placed to increase public awareness and implement key climate and decarbonisation initiatives. The Welsh Local Government Association reiterates this (WLGA, 2021), having formed a Decarbonisation Strategy Panel comprised of representatives from local authorities, Welsh Government, trade unions and technical experts.

Stakeholders have also helped shape the size of Welsh carbon budgets 1, 2 & 3 and targets for 2020, 2030, 2040 and 2050, by submitting comments and evidence to the Climate Change Committee (CCC). The second Low Carbon Delivery plan's engagement approach (Welsh Government, 2021c) further highlights examples of stakeholders relevant to energy and environment R&I, such as academia, consumers, NGOs, community groups and industrial clusters. Annex I provides an adapted version of the table included in the engagement approach report.

4.2 Funding opportunities

The current R&I funding landscape in Wales is uncertain and in transition. Wales has a relatively low total research income – 3.5% of the UK's total research income in 2016 (Reid, 2018), compared with England's 81.4%, Scotland's 13.4% and Northern Irelands' 1.6% - placing it at an overall disadvantage in this area. Furthermore, as a previously major beneficiary of funding from the European Rural Development Fund (ERDF) for research and innovation, with Brexit, Wales must move in 2021-2022 to alternative funding sources (Welsh Government, 2021b). This includes developing new support mechanisms to allow for building upon current programmes (e.g. FLEXIS in Box 2), and creating the conditions for new private and public financing opportunities to emerge and drive the transition. Welsh Government particularly highlights the blending of public funding with private funding in matters of decarbonisation and environment R&I, with public funding and finance providing the stimulus and business and industry taking the lead on development and deployment projects (HM Government, 2021).

This section will focus on financial resources to support R&I activities in Wales. It first describes opportunities at UK level and then at Wales level, and finally highlights entities and funding sources that have promoted / can promote R&I in the areas of energy and environment.

4.2.1 UK level challenges and opportunities

UK Government policy has declared a commitment to increasing R&D spending from its current 1.7% to 2.4% of GDP by 2027, thus achieving the OECD average. This contrasts with Wales' 1% GDP investment in R&D (Tilby, 2021). Brexit has come into force in 2021, bringing with it a reduction in R&D investment in Wales from the EU.[47] At UK level, most EU R&I funding has been won under the Horizon 2020 programme. However, historically, the ERDF or Structural Funds programmes have been more important in Wales, meaning that Brexit has important implications for the country.

At the time of writing this report, the UK Government is ready to formalise Association to **Horizon Europe and other EU programmes,** including Euratom Research and Training and the European Research Council schemes. This is associated with a budget of around €500 million in 2021/22 for UK researchers and businesses, ensuring their access to these collaborative research and development programmes.[48] [49] The Wales European Funding Office (WEFO) continues to support applications to the available EU funds for Wales, but some questions remain on whether these are sufficient to substitute previous EU funding. UKRI (UK Research and Innovation) may have to spend up to £2 billion a year out of its c. £9 billion budget to pay for British participation in the international Horizon Europe programme, which was previously funded separately through the country's EU membership – thus reducing the UKRI funding of science and research.[50] These heightened contributions have been contested by both UKRI and Universities UK.[51]

UK-level programmes which have supported energy and environment R&I include:

- An **Industrial Energy Transformation Fund** of £350 million (2018-25) intended to support businesses in the development and deployment of technologies to cut high energy use and carbon emissions. This includes the **Clean Steel Fund**, with £250 million expected to be available in 2023.[52] Projects offered funding in Wales in Phase 1 (Summer 2020) were Celsa Manufacturing (£3 million financing of £8.6 million steel melting project), and BAE Systems Properties Ltd (£82,000 towards £165,000 project to undertake Front-End Engineering studies);[53]
- An **Industrial Strategy Challenge Fund**, delivered by UKRI and aiming to tackle major industrial and societal challenges. It is made up of 23 challenges, covering four themes, with one being 'clean growth'. The fund is backed by £2.6 billion of public money, with £3 billion in matched funding from the private sector.[54] It includes, for example, the **Industrial Decarbonisation Challenge** (£170 million public matched by £261 million private)[55] and the **Transforming Foundation Industries Challenge** (£66 million public matched with £83 million from private);[56]
- A **Strength in Places Fund (SIPF)**. A total of £314 million is to be allocated to help places build on existing R&I strengths to deliver benefits to local economies. All projects

[47] https://gov.wales/sites/default/files/2017-01/30683%20Securing%20Wales%C2%B9%20Future_ENGLISH_WEB.pdf
[48] https://www.gov.uk/government/publications/beis-research-and-development-rd-budget-allocations-2021-to-2022/beis-research-and-development-rd-budget-allocations-2021-to-2022#fn:15
[49] https://www.gov.uk/government/news/250-million-additional-funding-to-boost-collaboration-and-protect-ongoing-research
[50] https://www.ft.com/content/860ff4aa-fab0-4046-9196-2e151807d70e
[51] https://www.ft.com/content/6a89cafa-079a-41df-9da6-5debe66bf3df
[52] https://www.gov.uk/government/collections/industrial-energy-transformation-fund and https://www.spglobal.com/platts/en/market-insights/latest-news/metals/092221-uk-expands-ietf-funding-to-steelmakers-to-launch-clean-steel-fund
[53] https://businesswales.gov.wales/news-and-blogs/news/industrial-energy-transformation-fund
[54] https://www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/
[55] https://www.ukri.org/news/ukri-awards-171m-in-uk-decarbonisation-to-nine-projects/
[56] https://www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/clean-growth/transforming-foundation-industries-challenge/

are collaborative and are led by consortiums that include local leadership partners, research organisations and businesses. In Wales, for example, the CSconnected project benefitted from £25 million SIPF investment on semiconductor materials;[57]

- UKRI's **Industrial Decarbonisation Challenge,** which supports the development of low carbon technologies to be deployed and scaled up within the UK's six largest industrial clusters. South Wales Industrial Cluster has been awarded of £19 million;[58]
- **Knowledge Transfer Partnerships** (KTPs), a UK-wide programme led by UKRI to help businesses improve competitiveness and productivity and better use knowledge, technology, and skills. KTPs are a core component of Wales R&D and innovation and have an important role in accelerating net zero through collaboration. The Welsh Government announced in 2020 an increased funding contribution for eligible KTPs, helping to make them more accessible and cost-effective for SMEs in Wales.[59]

Additionally, the UK has launched extra R&I funding and schemes nationally, making the total UK R&D budget for 2021/22 £14.6 billion:

- A £250 million additionally R&D funding in 2021;[49]
- An increase of approximately £2 billion in **UKRI**'s annual budget to reduce the impacts of Brexit;[10]
- A new £375 million **Future Fund scheme**, co-investment between government and private investors, designed to drive investment in high growth, innovative and R&D intensive firms;[60]
- An allocation of up to £50 million in 2021/22 for the **Advanced Research and Invention Agency (ARIA)**, to focus on high risk, high reward research. The UK Government is committed to investing £800 million in ARIA over its first four years;[48]
- A **Net Zero Hydrogen Fund**, to be delivered between 2022-25 in support of commercial deployment of low carbon hydrogen production projects. This fund is currently being designed but is estimated to be worth up to £240 million;
- A **Net Zero Innovation Portfolio** providing £1 billion from 2021 across ten different priorities (e.g., offshore wind, hydrogen, nuclear, homes, carbon capture);
- **ofgem** (the Office of Gas and Electricity Markets) has also been active in this field, launching in August 2021 a Strategic Innovation Fund to fund innovative projects with the potential to accelerate the transition to net zero, with four innovation challenge areas identified (whole system integration, data and digitalisation, heat, zero emission transport).[61]

In addition, UK Government announced acceleration of £105 million for the **Cardiff City Region Deal** to fast-track projects. The **Swansea Bay City Region** deal supporting innovation and low carbon programme has also been agreed by UK and Welsh Government with a £58.7 million budget;[62]

These funding increases can bring opportunities to those who, specifically, can win competitions (Reid, 2018). Part of the R&D priorities for the UK Government include achieving net zero and delivering the Green Industrial Revolution, with an **investment of £242 million by the Department of Business, Energy and Industrial Strategy (BEIS) in net zero**

[57] http://www.discover.ukri.org/strength-in-places-fund/
[58] https://www.ukri.org/news/ukri-awards-171m-in-uk-decarbonisation-to-nine-projects/
[59] https://www.ktp-uk.org/case-study/welsh-government-extends-increased-ktp-contribution-to-february-2022/ and https://www.ktp-uk.org/case-study/knowledge-transfer-partnerships-accelerating-net-zero-through-collaboration/
[60] https://www.gov.uk/government/news/new-375-million-scheme-to-drive-investment-in-innovative-firms-of-the-future-opens-for-applications
[61] https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/network-price-controls-2021-2028-riio-2/network-price-controls-2021-2028-riio-2-riio-2-network-innovation-funding/strategic-innovation-fund-sif
[62] https://www.gov.uk/government/news/record-18-billion-a-year-for-wales-in-budget and https://businessnewswales.com/58-7m-low-carbon-growth-programme-approved/

programmes, including the Net Zero Innovation Portfolio, the Advanced Nuclear Fund and trials of new hydrogen heating technologies. This complements the wide range of net zero programmes delivered by UKRI and other organisations, including work done under the Faraday Battery[63] and Transforming Construction Challenges.[64]

These funds, including a new **Shared Prosperity Fund** (SPF) launching in 2022 to match previous EU Structural Funds investment at around £1.5 billion per year, are largely considered insufficient to replace the EU Structural Fund investment from which Wales benefitted. The funding process has received some criticism for allowing local authorities to bypass Welsh Government.[65] The UK Government is primarily responsible for the associated levers and funding to support industrial decarbonisation, which may carry its own limitations for Wales. Because of this, Welsh Government has emphasised collaboration with UK Government funding streams for decarbonisation and energy efficiency as a policy proposal under the Net Zero Wales Carbon Budget (Welsh Government, 2021b).

4.2.2 Wales level

Both public and private funding opportunities for R&I in energy and environment exist in Wales. First, regarding public funding, the Welsh Government has devolved powers to fund and conduct research and innovation, although integrated within the wider UK R&I system. Part of the strategy for R&I funding is therefore to further understand local needs and support transformation by furthering influence with UK Government funding streams. Nonetheless, several R&I funding opportunities are either led or co-led by Welsh Government:

- Welsh Government's **Whole System Business Research Innovation for Decarbonisation** (WBRID) scheme, which aims to challenge businesses to help communities and the public sector adapt to the challenge of net zero on a whole system basis;
- **Welsh Government's Energy Service** (WGES) and the associated **Wales Funding Programme**, which provide technical, commercial and procurement support to develop energy efficiency and renewable energy projects through, for example, interest free loans and grants. These have especially targeted public sector organisations. The latter has invested over £59 million since 2009;[66]
- **Smart Cymru**, a scheme that uses grant funding to support businesses and research organisations to reduce their carbon emissions commercialise new products, processes and services related to sustainable growth, and provides expert advice. It is part of an integrated Welsh Government and ERDF set of programmes, and has supported over 390 projects since 2015, awarding nearly £3.5 million in grant funding;[67]
- **SCoRE Cymru**, a grant programme by the Welsh Government which provides funding support Wales-based organisations to participate in European collaborative research and innovation programmes;[68]
- **Sêr Cymru**, a suite of schemes co-funded by the Welsh Government and the Higher Education Funding Council for Wales aiming to build research capacity in Wales, thus funding universities and research networks. The first phase of the programme[69] was announced as part of the 'Science for Wales' strategy and ran from 2012-19 with a final expenditure of £18.2 million. One of the programme's main priorities was Low Carbon, Energy and Environment. The programme was renewed with **Sêr Cymru II** with a

[63] For more information see the Faraday Institution website here: https://www.faraday.ac.uk/
[64] For more information, see: https://www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/clean-growth/transforming-construction-challenge/
[65] https://gov.wales/written-statement-regional-economic-frameworks-update
[66] https://gov.wales/energy-service-public-sector-and-community-groups and https://www.salixfinance.co.uk/loans/welsh-loans
[67] https://gov.wales/sites/default/files/publications/2021-10/working-together-to-reach-net-zero-all-wales-plan.pdf and https://businesswales.gov.wales/expertisewales/support-and-funding-businesses/smartcymru
[68] https://gov.wales/sites/default/files/publications/2021-04/score-cymru-guidance.pdf
[69] See evaluation here: https://gov.wales/evaluation-ser-cymru-1-0

budget of £56 million, again led by the Welsh Government (co-funded with EU funding), and the Welsh higher education sector;[70]

- **Economy Futures Fund**, a consolidation of previous funds that supports businesses who demonstrate commitment progressing in reducing carbon footprint and calls to action for decarbonisation, innovation, and R&D, among others.[71]

Within the Wales Economic Action Plan – supporting the delivery of the national strategy 'Prosperity for All' – funding support is also envisioned for research development for businesses which align with decarbonisation objectives. Moreover, the Net Zero Wales Carbon Budget (Welsh Government, 2021b) advances a policy proposal to heighten support for innovation and new technologies related to new renewable energy technology towards decarbonisation, the transformation of the energy system, and support the green economy. This support is directed both at businesses and academia, seeking to build collaborations in the design of net zero solutions, of which the FLEXIS consortium is an example (2).

Box 2: FLEXIS consortium

FLEXIS is a consortium involving Cardiff University, Swansea University, the University of South Wales, Neath Port Talbot Borough Council and Tata Steel UK. It was financed for five years by the European Regional Development Fund (ERDF), with the aim of building research capacity in energy systems in Welsh universities.

The consortium involved over 250 industrial collaborations and over 100 research projects are still in progress. The research and demonstration capacity of FLEXIS will be built upon through the FlexisApp, which will partly fund the development of energy technologies with a focus on industrial decarbonisation and greenhouse gas reduction. As example, Swansea university and Tata Steel are collaborating on reusing waste heat from industry, and have established the Centre of Expertise in Data and Smart Energy Systems in a partnership project with Cardiff University and artificial intelligence (AI) software company Maiple.

Source: https://www.flexis.wales/ and https://gov.wales/sites/default/files/publications/2021-10/working-together-to-reach-net-zero-all-wales-plan.pdf

Regarding private sector funding, data from the ONS[72] shows that the business sector carries out most of the spending on R&I in Wales (e.g. Box 3 on marine renewable energy investment). Private sector funding accounts for 56% of all R&D expenditure in 2019, which is nonetheless lower than the UK level of private sector R&I spending, at 67%. Nonetheless, and according to Reid (2018), it is important for Welsh Government to provide the incentives and reward structures for boosting the competitiveness of the whole Wales research and innovation ecosystem.

Box 3: R&I investment in marine renewable energy in Wales

In Wales, marine renewable energy has received a total investment of £152.4 million, signifying a £29.1 million increase since 2020. This investment comes from both supply chain investment and publicly funded Welsh research projects. Private interest and funding have been noted by Total, RWE Renewables and Shell, some of the largest energy companies that are recognising the commercial opportunities of deeper waters of the Celtic Sea, and of offshore wind. RWE specifically has invested over £3 billion in Wales in the last decade on projects related to onshore and offshore wind and hydropower stations (e.g., Gwynt y Môr offshore wind project in North Wales), generating over £8.6 million for neighbouring communities. Additionally, Minesto, a technology developer in the marine

[70] https://www.sewales-ret.co.uk/ser-cymru-ii/
[71] https://gov.wales/sites/default/files/publications/2019-02/prosperity-for-all-economic-action-plan.pdf
[72] https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukgrossdomesticexpenditureonresearchanddevelopmentregionaltables

energy sector, has invested £32 million of private equity funding and ERDF grants in its operations in Wales.

Other private sector investments are being facilitated by the promotion of collaborations with the higher education and public sector. This is the case with the ORE Catapult – a UK technology innovation and research centre for offshore renewable energy – which is supporting the growth of the Welsh supply chain related to the marine energy sector through the Marine Energy Engineering Centre of Excellence (MEECE) in Pembroke Dock, Wales. The Selkie cross-border project between Wales and Ireland is also bringing together businesses and researchers to improve the performance of marine renewable devices and technologies.

Source: https://www.marineenergywales.co.uk/wp-content/uploads/2021/07/State-of-the-Sector-2021.pdf

4.2.3 Other entities and funding schemes

There are other major funding entities or organisations in Wales that are either associated with the Welsh Government or work independently to channel finance and support to key areas in Wales, such as energy and environment. These include:

- **The Development Bank of Wales**, previously **Finance Wales**, officially established in 2017. It is the UK's largest funder of its type, overseeing several funding programmes for businesses with the aim of unlocking sustainable economic development potential in Wales. It is backed by both public and private funds and manages over £694 million across 10 business funds (e.g., **Wales Business Fund**, a £204 million programme part-funded by ERDF and Welsh Government), as well as the equity loan scheme 'Help to Buy'. The Bank is equally investing in community-owned energy projects, with about £12.5 million for the **Local Energy Fund**, launched in 2016 by the Welsh Government and managed by the Bank;[73]
- **Business Wales**, a free service partly financed by the Welsh Government and the ERDF which provides support for businesses. The organisation includes specialist sustainability advisers and offers support on grants, renewable energy, environmental sustainability, and the Green Growth Pledge;[74]
- **Funding Wales**, a new funding search platform created by Third Sector Support Wales, and especially aimed at charities, community groups or social enterprises. It includes information on grants and loan finance opportunities from local, national, and international sources;[75]
- **Salix** is a non-departmental public body owned by UK Government, and funded by BEIS, Welsh and Scottish Governments, providing support in energy efficiency. It has provided £971 million in funding for over 18,700 projects with more than 3,100 public sector bodies. Salix Finance SEELS loans have been used by 92 different Welsh public sector bodies since 2009, and more than £59 million has been invested in Welsh energy efficiency projects which are forecasted to save approximately £170 million. Other Salix schemes include the Clean Growth Fund and the Recycling Fund.[76]
- **Higher Education Funding Council for Wales (HEFCW)**, which provides support for innovation and engagement activities through the **Research Wales Innovation Fund (RWIF)**, designed to both incentivise and reward performance at Welsh institutions at about £15 million per annum.

Funding schemes are also available in Wales for communities to support action on climate change. These include the Sustainable Management Scheme (SMS), designed to support

[73] https://developmentbank.wales/about-us/development-bank-wales
[74] https://businesswales.gov.wales/business-wales and https://businesswales.gov.wales/green-growth-pledge-0
[75] https://funding.cymru/
[76] https://www.salixfinance.co.uk/about-us and https://www.salixfinance.co.uk/loans/welsh-loans

Welsh Government deliver on its sustainable development commitment; and the Landfill Disposals Tax Communities Scheme, supporting local community and environmental projects in areas affected by disposal of waste to landfill. More information on these schemes can be found in the Prosperity for All strategy.[71]

4.3 Priority areas for Research and Innovation

This section sets out the priority areas for research and innovation, which can be identified based on the Welsh outlook for the energy and environmental sectors, while also considering the objectives and actions of relevant strategies, plans and other policy documents. These include the Low Carbon and Net Zero Carbon plans, the Decarbonisation plan for the public sector, and other economic, environment and energy statements. Previous research and stakeholder consultations under the TRACER project are also referenced in this section, as they provide further input enabling for the narrowing down of investment areas.

First, Welsh Government strategies, plans and statements set out decarbonisation or the transition to a low carbon society as a cross-cutting priority, touching on different policy themes and sectors. The decarbonisation of the public sector is a key priority, with a significant share of emissions, namely related to procurement,[77] and as a sector that can serve as an exemplar for others on how to approach the green transition. Decarbonisation of the public sector encompasses local government, health and social care, Welsh Government, higher education, tourism, culture and natural resources. Areas emphasised in the decarbonisation of this sector include:

- Mobility and transport, particularly aiming towards an integrated sustainable transport system that can reduce emissions and improve connectivity;
- Buildings, namely regarding housing retrofit, the implementation of energy saving measures and the reduction of the carbon footprint of buildings, particularly aimed at more disadvantaged communities;
- Land use, with carbon sequestration, natural resources and touristic potential of land;
- Procurement, with criteria and rules having the potential to help drive emissions reductions by requesting suppliers for low carbon options in several areas.

In general, areas off the gas grid should be prioritised to allow the delivery of low carbon heat and transport technologies, leaving no community behind. There is also a need to ensure connectivity is prioritised to create employment in areas where well paid jobs are less readily available. Related to this is the provision of training for these more deprived communities, especially those previously reliant on the coal industry. A prioritisation is foreseen for financial and other forms of support for clean and green jobs leading to a decarbonised economy.

Given the different needs of communities across Wales related to energy and environment – exemplified by the greater impact the transition from coal has had on communities previously reliant on that industry – priorities should also have a regional/sub-regional differentiation. This will be tackled in the Regional Economic Frameworks and the Local Area Energy Planning in development in Wales.[78] The latter, especially, informs on key aspects of the transition to a low carbon energy system, and supports energy efficiency retrofit, heat, transport, economic development, and the overall energy grid.

The energy and environment outlook in section 2.2 of this report, as well as the R&I vision for these sectors in Chapter 3, have highlighted key areas where objectives have been set and

[77] https://gov.wales/sites/default/files/publications/2021-10/net-zero-wales-carbon-budget-2-2021-25.pdf
[78] https://gov.wales/written-statement-regional-economic-frameworks-update and https://es.catapult.org.uk/report/local-area-energy-planning-the-method/

outcomes are expected. These areas are reflected in the prioritisation for the coming years and decades and are listed in Figure 7.

Figure 7: Priorities in energy and environment for the next decade

Source: Own elaboration based on Welsh Government strategy documents and plans.

Results from the TRACER research and stakeholder consultation reflect these priorities, and propose a focus on areas of need and opportunity for R&I for the energy transition in Wales:

Table 10: Vision for R&I in the energy transition in Wales based on TRACER stakeholder consultation

	Areas of Need	Areas of Opportunity
Political, regulatory and financial incentive frameworks	• Transition incentives; • Mapping of energy needs and R&D in Wales; • Align Welsh needs with UK and potentially other funding and development sources.	• Public procurement & seed funding; • Local leadership (e.g. city-region deals); • Alignment with Welsh Government economic, energy and related policies and strategies.
Infrastructural and sectoral investments	• Decarbonising heat; • Upgrading and decentralising energy grid; • Improving public transport; • Investment in energy storage; • Reduce energy dependency; • Sustainable and considered green energy shift.	• Retrofitting houses & building design; • Mix of renewables (solar, tidal, wind, nuclear, hydrogen); • ICT, artificial intelligence and high-value manufacturing; • EV infrastructure, methane and CO2 capture; • Circular economy;
Labour market, skills and community support	• Public ownership of energy transition; • Promote local infrastructure and wealth creation; • Access to education and training and skills development; • Creating good quality jobs; • Effective communication of transition benefits for energy literacy; • Identify locational dynamics (e.g. job & residence location);	• Digitalisation; • Large scale initiatives; • Connecting training providers with businesses and policymakers; • Create and/or promote “centres of excellence” in energy; • Community energy projects; • Co-creation of internationally recognised skills, qualifications and progression frameworks for energy and environmental work.

	• Address deprivation, especially in former coal mining areas.	

Source: Michie et al. (2021)

4.4 Evaluation and Monitoring

Evaluation and monitoring are meant as an evidence-based way to track progress towards targets and goals and assess potential for improvements. This section describes the monitoring, reporting and evaluation systems in place for the energy and environment sectors, as present in related strategies in Wales (e.g., Low Carbon Delivery plan). These form the framework that will be utilised in the next decades to track achievements in research and innovation for energy and environment.

4.4.1 Monitoring approach

The approach to monitoring the progress of energy and environment plans varies depending on the sector or theme at hand. Nevertheless, the overall approach is established in the 2020 'Prosperity for All' Wales strategy and plans. The central monitoring approach is a 'theory of change' approach to understand what is intended by each action – and therefore determine the best way in which to monitor and evaluate progress. This includes establishing the outputs of the proposed action, the desired impact, the reduction of risks and vulnerabilities, and the best indicators, baselines, or measures to monitor and evaluate progress. Both quantitative and qualitative indicators may therefore be involved.

Several steps are foreseen for monitoring progress:

1. Establishing indicators and gathering evidence;
2. Discussion of evidence and monitoring of progress by relevant delivery leads representing the environment and energy sectors in Welsh Government. In particular regarding climate, Climate Change Portfolio Governance Board (CCPG) is the relevant body, meeting every eight weeks to discuss progress in plan delivery;
3. Reporting.

Both internal and external discussion groups or committees are foreseen to aid in the governance of the monitoring and evaluating system. The Prosperity for All strategy establishes a Core Internal Adaptation Group (CIAG) to provide policy expertise and discuss (potential) actions and their delivery, and an External Stakeholder Adaptation Group (ESAG) to collaborate on joint issues and provide input and feedback for consideration. The Clean Air Plan for Wales[79] also foresees the implementation of a national air pollution monitoring and assessment service by December 2022. It is expected to support annual reporting on the state of air quality in Wales and make recommendations on interventions required to reduce negative impacts. Local authorities, Natural Resources Wales, Public Wealth Wales and other entities have worked collaboratively to design the monitoring, modelling assessment and evaluation framework.

4.4.2 Indicators

Indicators enable detailed progress tracking of individual actions and policies. They allow for both implementation and effectiveness to be tracked, with this information establishing a feedback mechanism for policy adaptation or termination depending on outcomes and impacts achieved. The Well-being of Future Generations (Wales) Act established 46 national well-being indicators to measure progress in achieving the seven well-being goals (a prosperous, resilient, healthier, more equal, globally responsive Wales, with cohesive communities and

[79] https://gov.wales/sites/default/files/publications/2020-08/clean-air-plan-for-wales-healthy-air-healthy-wales.pdf

vibrant culture).[80] Out of these 46 indicators, 11 relate directly to energy and environment, including indicators on air pollution and greenhouse gases (Indicator 4, 41, 42), renewable energy (12), energy performance (33), ecosystem health (13, 43, 44, 45), and ecological footprint and waste management (14, 15).[81]

The National Indicators described above function as a base for several energy and environment plans. For instance, the Clean Air Plan for Wales includes these in the suite of indicators it is developing to monitor the state of biodiversity and air quality. The Low Carbon Delivery Plan[82] also considers carbon metrics for monitoring and evaluation, namely energy efficiency and performance. The plan includes a £1.2 million Innovative Housing Programme monitoring and evaluation programme, run independently and using a consortium of ten leading UK universities, which goes beyond quantitative metrics to also measure tenants lived experience.

Moreover, indicators in the Low Carbon Delivery Plan are divided in three 'tiers' that seek to track progress from the national level down to the policy level:

1. Emissions estimates which are consistent with the Environment (Wales) Act 2016 target definition for each sector;
2. Specific activity data or emission factors that provide information on the underlying drivers of GHG in Wales;
3. Policy-tier indicators monitoring the policies and proposals which Welsh Government is actively doing or aiming to do to reduce GHG emissions. This will also include the monitoring of UK policy delivery where it contributes to the delivery of Welsh targets. In addition, further performance indicators are to be explored to track progress on the realisation of the wider well-being benefits identified in the Plan and to track wider contextual factors that influence Welsh emissions such as population and economic factors (i.e., GVA).

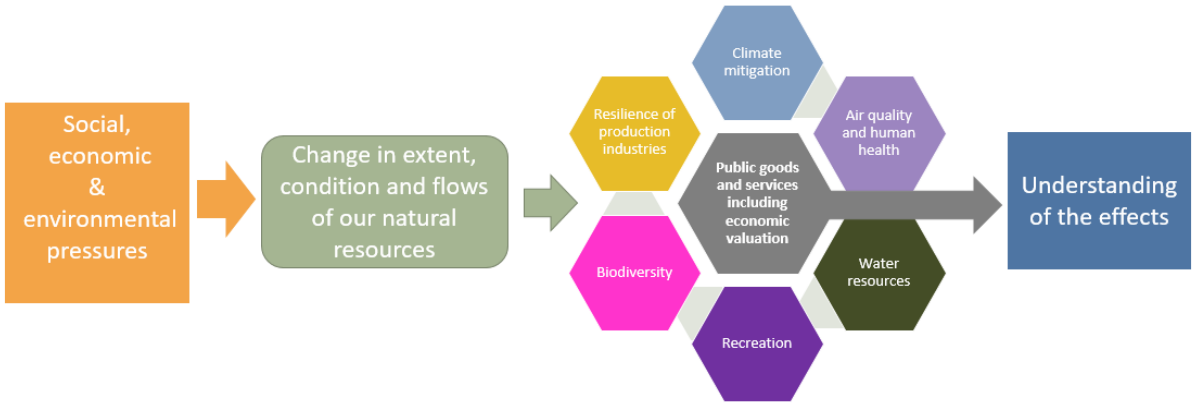
In the Prosperity for All strategy, several other indicators are proposed related to energy and environment. These include, among others: number of research projects completed for all climate related research supported through Welsh Government; documentary review of how climate risk has been factored into projects; condition of restored afforested deep peatland sites; number of schemes enabling nature-based solutions; carbon balance of woodlands; and number of households living in fuel poverty in Wales. Regarding research and innovation, the monitoring of the financial sustainability of the R&I base in universities is foreseen in the 2019 'Research and Innovation: The Vision for Wales' strategy,[83] although with limited references to the energy and environment sectors.

4.4.3 Evidence-base

Plans and strategies in Wales aiming to build social, economic, and environmental resilience often rely on the Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) to evaluate programme implementation.[84] This programme collects data across the Welsh landscape related to, among others, soil degradation, forest, biosecurity, linking any changes in these areas to their impacts on a wide range of benefits (Figure 8). Modelling is undertaken in ERAMMP to provide an evidence-base for the design and evaluation of programmes delivering on decarbonisation, economic and natural resources policy (e.g., Clean Air Plan, Low Carbon Delivery Plan).

[80] https://gov.wales/wellbeing-wales-2021
[81] https://gov.wales/national-wellbeing-indicators-2020-21-quality-report-html#section-77404
[82] https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf
[83] https://www.hefcw.ac.uk/wp-content/uploads/2020/09/Research-and-Innovation-the-vision-for-Wales-English.pdf
[84] https://erammp.wales/en/r-year3

Figure 8: ERAMMP modelling approach



Source: https://erammp.wales/en

Regarding the evidence-base for the energy sector, this is usually based on statistics related to fuel poverty, energy efficiency, energy prices, heating and energy measures (e.g., heat demand density), renewable energy assessments, battery storage, state of the energy industry, among others. These are developed both 'in-house' by Welsh Government bodies (e.g., Energy Generation in Wales report[85] or the National Survey for Wales), and by academic and other research and consultancy organisations. There may be an argument for additional 'positive' indicators, which measure progress towards Net Zero goals.

4.4.4 Reporting

Welsh legislation requires the production of assessments against carbon targets and budgets every five years. Scrutiny from the Senedd and its committees, as well as independent progress reports are also often a part of the reporting on progress of plans and strategies.

The Environment (Wales) Act 2016 establishes that Welsh Ministers must prepare and publish a plan for each budgetary period setting out policies and proposals for meeting the carbon budget. The second Carbon Budget (covering the period from 2021-2025) sets out to accomplish a 37% average reduction in emissions against the baseline. The statement must justify why targets have or have not been met, including the specific contribution of each policy for the target.

A Well-being of Wales report must also be published annually, providing an updated assessment of short and long-term changes to Wales' economic, social, and cultural well-being, and namely drawing on the national indicators and milestones set, alongside other data. The Prosperity for All strategy also establishes a reporting framework, with reports being produced from governance meetings which discuss outcomes, a submission of the report to the Minister for Energy, Environment and Rural Affairs for comment and approval to be published, and a commission and development of an external report for publication. These reports inform on any needed changes and proposed actions to be added to the strategy and thus further progress on climate change and low carbon goals.

5 Concluding note

The Welsh context benefits from multiple strengths and advantages related to energy and environment. Wales possesses both the ample natural resources and the institutions and collaborative networks that can allow it to gain competitive advantage in the field of decarbonisation. This is evidenced in the rapid developments in the field of renewable energies

[85] https://gov.wales/sites/default/files/publications/2019-10/energy-generation-in-wales-2018.pdf

in Wales, namely offshore and onshore wind and marine and tidal. Similarly, higher education and research institutions in Wales are developing expertise in both the technological and the behavioural aspects of the 'green' transition, and there is promotion of collaborative links with industry to allow for the development of innovative solutions and processes that can allow for the scale-up of projects.

However, current plans for the energy and environment sectors in Wales lack integration with broader research and innovation strategies and goals. This is potentially related to the existence of several different government silos that generate fragmentation in efforts. At the same time, the post-Brexit context brings with it uncertainty regarding changes in priorities, funding opportunities and the governance of research and innovation in these sectors.

In this context, and given Wales' offshore energy resources, there is an opportunity to seek further alignment with the other UK nations (Northern Ireland and Scotland), as well as collaboration with EU partners at national level (e.g. Ireland) and with regional partners such as the Basque Country. The integrated Innovation Strategy currently being developed by Welsh Government could further integrate these efforts and opportunities for the transition, as could the new climate change ministry within Welsh Government, as it brings together the portfolios for environment and energy (along with housing, planning and transport).

This report has detailed current objectives and expected outcomes for R&I in the energy and environment sectors in Wales, further proposing key priority areas for investment in the coming years. These include the promising energy sectors of hydrogen, wind and marine energy, and the development of technologies related to carbon capture and the storage of energy to promote decarbonisation and enable the efficient and continuous utilisation of renewable energy sources and the sustainable substitution of fossil fuels in the Welsh energy mix. Further recommendations related to areas of need and opportunity are advanced based on the previous TRACER work, focusing on three main categories:

- Political, regulatory and financial incentive frameworks (e.g., creation of transition incentives and promotion of collective leadership and sustainable approaches in the public sector);
- Infrastructural and sectoral investments (e.g., improvement of public transport networks, house retrofitting, and the upgrading and decentralisation of the energy grid);
- Labour market, skills, and community support (e.g., promotion of community ownership of the energy transition, new learning and progression opportunities across vocational, further and higher education to assure workforce capability and skills for (and beyond) the transition, and the creation and development of "centres of excellence" in energy and environment R&I).

All of these are relevant areas for investment in the transition. However, the latter category might be especially important for the broader preparedness and behaviour change that must be promoted throughout Welsh society for the country to take advantage of emerging opportunities. Education for the transition is something that takes considerable time, and therefore should be prioritised to build a foundation on which new ideas, technologies and processes can be developed. Broader conceptualisation of research and innovation that consider the social aspect of the transition should thus be promoted and figure in strategic prioritisations.

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Annex

Stakeholders included or envisioned for consultations related to the net zero transition

Source: adapted from https://gov.wales/sites/default/files/publications/2021-03/engagement-approach-for-low-carbon-delivery-plan-2.pdf

General stakeholders	Academia & Higher Education Institutions, Business Wales, NGOs, Local Authorities and Wider Public Sector, Business and supply chains, Community Groups, Private Finance, Council for Economic Development, European Union, Industrial Clusters and Research Groups, Industrial Companies, Industry Bodies, SMEs, Social Enterprises, UK Government, wider society, Further Education Colleges, Members of the Welsh Parliament, Public Service Boards, wider Third Sector representatives, Members of UK Parliament
Energy	Consumers, DNOs, Energy Intensive Industry, Energy Companies, Energy Systems Catapult, Energy UK/Marine Energy, National Infrastructure Commission, OFGEM, Regional Skills Partnerships, Wales Energy Service
Buildings	Active Building Centre, Banks, Business Wales, City region boards, Communities and Citizens of Wales, Construction Excellence Wales, Developers, Development Bank for Wales, Decarbonisation of Housing Group, Energy Intensive Industry (Waste Heat), Energy Systems Catapult, Higher & Further Education Institutions, Homeowners, Housing Associations, House builders, Insurance Companies, Mortgage Providers, OFGEM, Private Rented Sector, Public Health Wales and wider NHS, Public Regional Skills Partnerships, Registered Social Landlords, SPECIFIC, Tenants, Wales Energy Service
Industry & Business	City region boards, Confederation British Industry (CBI), E&T Ministerial Advisory Board and MAB Foundational Economy, Energy Systems Catapult, Federation of Small Business, Foundational Economy, Menter a Busnes, Network Wales, Institute of Directors, Trades Union Congress, Wales Cooperative Centre, Welsh Retail Consortium
Transport	Active Travel Board, Bus Operators, Cardiff Airport, Confederation of Passenger Transport, Haulage Companies and Freight Operators, Municipal bus companies, Transport for Wales, Vehicle Manufactures and supply chains
Agriculture and Land Use	Animal Welfare (variety of stakeholders) Auctioneers, Country Landowners Association Wales, DEFRA, EU Transition (formerly Brexit) Stakeholder Roundtable, Farmers Union of Wales, Farmers, Food and Drink Industry Board, Food retailers, National Farmers Union (NFU), Forest owners and workers, national parks, Quality Welsh Food Certification, Rural Community Groups, Woodland Strategic Advisory Panel (WSAP).
Public Sector	All public bodies defined under the Well-Being of Future Generations (Wales) Act 2015: the Welsh Ministers; Local Authorities; Local Health Boards; the following NHS Trusts – 1) Public Health Wales; 2) Velindre; a National Park authority for a National Park in Wales; Welsh fire and rescue authorities; Natural Resources Wales; the Higher Education Funding Council for Wales; the Arts Council of Wales; the Sports Council for Wales; the National Library of Wales; the National Museum of Wales. Future Generations Commissioner (FGC), Local Councils and One Voice Wales, Public Health Boards, Public Service Boards, Welsh Local Government

	Association, Welsh Ambulance Service Trust, Welsh Police Forces, Partnership Council for Wales
Resource Efficiency and the Circular Economy	Council for Economic Development, E&T Ministerial Advisory Board and MAB Foundational Economy, Foundational Economy Network, Industry (waste heat), Natural Resources Wales, Scottish Government, Waste operators, WRAP, Water Companies, CERIG
International	Climate Group, CBI, FGC, We Mean Business
Cross Cutting – relates to multiple sectors	All aspects of Welsh public/society, Climate Group, Council Leaders, Extinction Rebellion, Innovation advisor council Wales, National Lottery, Press & Media, Well-being Economy Government Network, Innovate UK, UKRI (UK research innovation - funders), UK Committee on Climate Change, Valleys Taskforce, Welsh Language and Equality - representative organisations of people from protected groups
Young People	Children's Commissioner, Eco Schools, Local Education Authorities, Size of Wales, Students Teachers, Youth Groups and youth projects, Wales' Youth Parliament