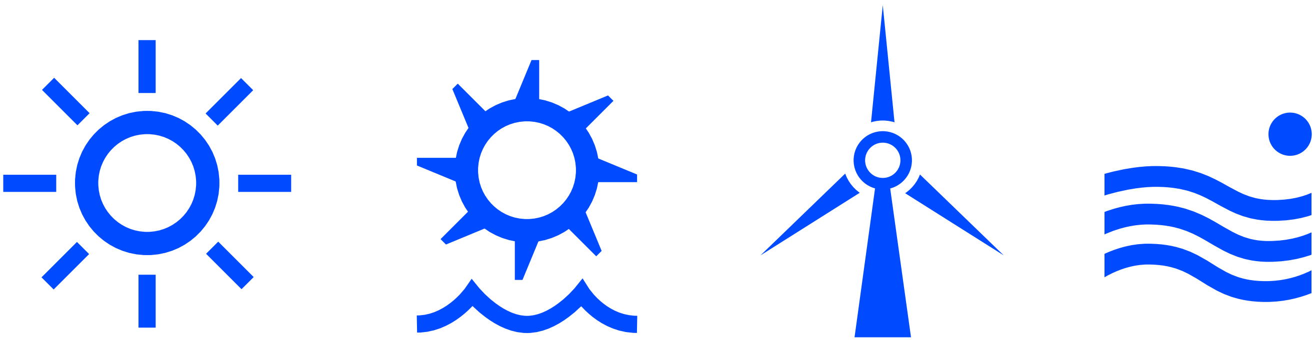
The Economic Costs and Benefits of Renewable Energy Transition in Wales



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IWA – Institute of Welsh Affairs, 56 James Street, Cardiff Bay, CF10 5EZ
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Design: www.theundercard.co.uk

About the author

Calvin Jones is a Professor of Economics and Deputy Dean at Cardiff Business School, and a Visiting Professor at Napier University Business School. He holds a PhD in the Economics of Tourism and Major Sports Events. His recent research has focused on energy economics, including the regional economic impact of renewables and of community energy.

Calvin Jones,
Cardiff Business School
Colum Drive, Cardiff CF10 3EU

Contact:
Professor Calvin Jones
jonesc24@cf.ac.uk
Tel: 02920 875470

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About Re-energising Wales

The Institute of Welsh Affairs' 'Re-energising Wales' project is a three year project (April 2016-April 2019) that will deliver a plan to enable Wales to meet its **projected energy demands entirely from renewable sources by 2035.**

The six core workstreams of 'Re-energising Wales' are:

1 **Energy Demand**

We **established a framework** to collect and report on operational energy demand data, in order to help collate temporal and geographical data and better understand what drives energy demand.

2 **Developing a future energy systems vision**

We used the Swansea Bay City Region (SBCR) as a case study exemplar, **showcasing how the SBCR** can maximise the size and location of its renewable energy resources in order to meet its projected energy demands by 2035. Lessons from this will be applied across Wales.

3 **Setting the economic parameters**

Building on the above Swansea Bay City Region report, we have **outlined the economic opportunity** that arises with a truly transformative approach to energy generation and domestic refurbishment in the Swansea Bay City Region. This current report **assesses the economic costs and benefits of renewable energy transition** in Wales.

4 **Social and Community Issues**

We have assessed the values behind community engagement in energy saving and generation, and how to overcome the barriers to increasing local ownership of renewable energy assets.

5 **Regulatory and political challenges**

We have assessed what political and regulatory powers are required for a new renewable energy regime to be implemented well.

6 **A delivery plan**

We will create a detailed, timed, and costed action plan for developing a credible renewable energy programme for Wales which brings together findings from the project.

The project has also produced two policy papers, the first focused on 'Funding Renewable Energy Projects in Wales, while the second looked at 'Decarbonising Transport in Wales'.

The IWA's 'Re-energising Wales' project is kindly supported by the Hodge Foundation, the Friends Provident Charitable Foundation and the Polden-Puckham Charitable Foundation.

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Executive Summary

This report analyses the potential for regional economic impact consequent on a programme that includes radical decarbonisation of electricity generation, significant investment in domestic refurbishment and a shift toward electrified private transport up until 2035. In particular, this report builds on our picture of a future renewable energy system to 2035 from two prior IWA Re-energising Wales reports: *Swansea Bay City Region: A Renewable Energy Future*, and *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*.

This analysis has found that the development of an energy system that can enable Wales to become 100% self-sufficient in renewable electricity by 2035, according to our best current estimates, requires around £25bn of investment in renewable electricity generation, and £5bn in domestic energy efficiency interventions.

This analysis also indicates that some 40% of renewable electricity gross spending (£9.7bn) could potentially be captured by Wales, along with 70% of domestic energy efficiency gross spending (£3.7bn).

These investments could support some 20,150 jobs annually across Wales during a (notional) 15-year investment period (2020-2035), with around £7.4bn in total Welsh GVA created in total.

As with our earlier Re-energising Wales report *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*, these economic opportunities will be grasped only if relevant supply-side capacity – in terms of firms and skilled workers – can be developed, and indeed be competitive. This is a stark challenge, given the level of required investment and Wales' poor prior energy supply chain performance.

In previous 'energy booms' Wales has proved able to capture only a small portion of total economic benefit, usually that related to local labour, some professional services and rental, sales or lease of landscape. Some of this lack of past economic capture relates to a narrow economic base and lack of locally available skills and relevant companies. Additionally, there is almost no Welsh capital ownership in the energy sector.

For electrification investments, additional (and developmental, rather than short term employment) benefits will arise only with ownership – in part or whole – of the capital and intellectual property that is employed in decarbonisation for Wales, and indeed elsewhere; unless of course Wales can, post-Brexit, attract significant relevant multinational manufacturing operations. Here there is some hope, not least in research on marine renewables, and the activity of SPECIFIC at Swansea University that encompasses research on power-from-buildings, thermal (inter-seasonal) storage, photovoltaics and cutting-edge battery technology.

The challenge, as always, will be the move to commercialisation and scale in Wales. Given the troubled progress of the Swansea tidal lagoon, the lesson of past waves of renewables innovation – that manufacturing and intellectual property capture occurs often in places where national or subnational policy is strongly supportive of the roll out of novel renewables – should not be forgotten.

This report also outlines the broad issues involved in transitioning from a system that produces 100% of Wales' annual average territorial electricity requirements to one where renewable electricity provides power all year around – a key difference. Our scenario and analysis, using the Wales & West Utilities 2050 Energy Pathfinder tool, suggests the need to import winter power, or store energy over a reasonably extended period, totalling an estimated 260GWh for Wales in order to meet the 100% objective above. Financial implications of this suggest around £15m of costs at January 2018 wholesale prices, for example, for the 260GWh.

In areas of current electricity use, and the electrification of both heat and transport, the appropriate matching of demand and supply over time is a significant problem. Intra- or inter-day matching is, arguably, fairly straightforward but inter-seasonal matching – to account for the fact that currently employed UK renewables produce much less power in the winter, when most needed – is far more problematic.

Inter-seasonal matching can be solved in a renewable system via, for example: the storage of biomass fuel for burning when needed; the storage of renewably-generated compressed hydrogen; the storage of electricity in large scale batteries or via 'pumped-storage' approaches whereby water is pumped uphill at times of low electricity demand and released to generate electricity at times of high demand. Lastly, a territory can import electricity (or renewable fuel) from an outside territory when required. Any of the above options implies cost additional to the generation system itself.

There remain areas where it is very difficult (at this stage) to narrate credible renewable solutions, let alone to cost them. Primary amongst these is the issue of domestic heat, which is a significant driver of energy demand in Wales.

One area we cost in relation to transport is a shift towards electrified private transport. Our scenario analysis suggests that fuel costs savings for the private electric fleet (compared to fossil-fuelled cost options) would generate an additional £165m of Welsh GVA annually (£2.5bn by 2035), supporting over 3,000 annual FTE jobs in Wales.

Technical uncertainties in the areas, particularly, of heat and storage, as well as difficulties in painting a detailed picture of future Welsh land use and industry means this is a partial picture.

By providing a compelling picture of the scale of the challenge, as well as the scale of the opportunity, this report is intended as a spur for further debate. What is clear, even from this partial picture, is that Wales needs to take action now to capture the benefits of a transition to a renewable energy future that has already begun.

Visioning a Renewable Energy Future

Visioning a Renewable Energy Future

This report contains a set of seven chapters which seek to outline the potential for regional economic impact consequent on a programme that includes radical decarbonisation of electricity generation, significant investment in domestic refurbishment and a shift toward electrified private transport.

This report serves three functions.

First, it sketches the outline of an energy system that can enable Wales to become 100% self-sufficient in renewable electricity over the period 2020 – 2035.

Second, it estimates the investment cost of this system based on the most relevant cost information from prior Welsh and UK energy projects, implied from UK Contracts For Difference auctions and published in a variety of sector reports.

Third, it outlines the broad issues involved in transitioning from a system that produces 100% of Wales' *annual average* territorial electricity requirements to one where renewable electricity provides power *all year around* – a key difference.

We also comment on some key issues related to a transformation toward 100% renewable energy, including transport and heat. The report draws on intelligence developed from the IWA's three-year Re-energising Wales project[1], which draws together academics, policymakers and key industry players with a remit to develop evidence to inform a practical plan for Wales' renewable future.

In particular, this report builds on our picture of required renewable electricity and energy efficiency interventions from two prior IWA reports: *Swansea Bay City Region: A Renewable Energy Future*[2] by Regen, and *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[3] by Cardiff Business School (the current author).

These two resources provide full detail on data sources, the process of scenario development, the costing of different investments and on the methodology we use to assess the economic impact of investments on Wales. We do not, therefore, replicate that detail here, and interested readers are directed to these two reports to better understand our approach, and the benefits and limitations therein. Each of the chapters within this report is, however, supported by summary data and methodological notes gathered together in a single Technical Appendix where the reader can find key detail on cost and other assumptions.

1 Institute of Welsh Affairs, Re-energising Wales, April 2018

2 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

3 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

Current data and project resource do not allow a full treatment of all (future) energy sources and uses in Wales, and particularly the interactions between them. Whilst there is reasonable clarity across some of the technical landscape, and on consequent financial implications – existing renewable energy generation, and domestic refurbishment for example – in other areas, such as the roll out of hydrogen, biogas, and novel renewables, or the role and feasibility of at-scale electricity or heat storage, there is more uncertainty. We develop our scenario as far as we are able, noting throughout where uncertainties exist.

Readers should note that as the Re-energising Wales project is explicitly about renewable energy, as opposed to 'low carbon' visioning for Wales, we do not include nuclear power as part of our electricity generation mix. We do however recognize the role that nuclear (or fossil) may – in reality – play, either if developed within the territory of Wales, or via future imports of electricity from England to cover generation shortfalls. We discuss this issue in later sections.

1:

A Renewable Electricity Vision for Wales

1 A Renewable Electricity Vision for Wales

As noted earlier, the scenario developed by the IWA and Regen for the Swansea Bay City Region (SBCR) was used as the basis for our Wales-level renewable electricity mix. SBCR is a reasonable facsimile for Wales as a whole, featuring a large urban area, urban 'valleys' hinterland and extensive rural landscape, as well as potential tidal range resource.

The Regen scenario is a sophisticated picture of how SBCR might be renewably powered that takes account of technologies' nearness to market and cost in an informal 'merit order', as well as the seasonal variations in renewable generation that are problematic in terms of winter electricity (and indeed heat).

Our development of a Wales scenario expanded the Regen renewable supply to provide sufficient annual electricity – 21,000GWh (21.8 Terawatt hours is needed to power Wales in 2035 based on the Regen SBCR approach). This estimate is significantly larger than that implied by the National Grid in their Future Energy Scenarios (FES) but readers should note the following, apart from significant differences in underlying methodology:

- FES scenarios include for 2035 a significant reliance on natural (fossil) gas for industry and domestic heating. Whilst our scenario included some natural gas supply (albeit blended with hydrogen or biogas to reduce CO2) we assume a greater shift to renewable electrification for heat uses

- FES does not include tidal range supply whereas we assume 3GW+ / 6.2TWh

- Our over-supply softens (but does not obviate) the need to import electricity in the winter (which may well be nuclear in origin).

Our scenario was pressure-tested by the IWA Re-energising Wales steering group and we amended a number of elements. In each case the installed capacity reflects our collective 'best guess' based on: technically feasible investment and technological readiness; planning and licensing positions; and relative cost. Additionally, in understanding the implication of our scenario, we received vital assistance from Wales & West Utilities via the use of the 2050 Energy Pathfinder tool. This estimates half-hourly energy supply and demand for Wales in any given year, providing outputs (for a given set of inputs) on total and peak electricity and gas supply and demand, imports and exports, unusable power and carbon emissions.

Table 1 presents our scenario for a mix of renewable technologies that could, by 2035, supply Wales' annual territorial electricity demand, although requiring a minimal import of electricity in the winter months (see Section 5).

Table 1:
Re-Energising Wales Renewable Energy Capacity 2035

	MW	GWh
Solar PV	2,670	2,600
Onshore wind	2,545	5,300
Offshore wind	1,700	5,400
Wave	400	1,200
Tidal Stream	110	400
Tidal Range	3,395	6,200
In stream Hydropower	55	200
Fuelled technologies (Biomass, AD, Energy recovery)	115	600
All Technologies	10,985	21,800

For sources see Technical Appendix
May not sum due to independent rounding

2:

The Economic Impact of a Renewable Transition in Generation

2 The Economic Impact of a Renewable Transition in Generation

Using extensive prior Cardiff Business School research, a variety of published sources, and the input of the Re-Energising Wales steering group, we have estimated a set of key variables that will drive the economic impact of this renewable transition, both in the development/construction phases, and in the (much less economically important for Wales) operational phase. These include:

- the gross capital investment cost of each technology per MW installed
- the (typically much lower) operational cost over 15 years
- the proportion of that spending that remains in Wales
- the 'multiplier' effects, in terms of gross value added and employment of this local spending on Wales.

Further detail and data sources are available in the technical appendix and in prior reports. However it is worth noting that, as for SBCR (and after some consideration), we present our generation costs (and impact) in current, 2018 terms (with the exception of marine renewables which are effectively mid-2020s). There is of course a strong argument that by the time much of this investment occurs per-MW renewable costs will have fallen further. There are a number of reasons we stick to current costs:

- to avoid any debate over potential cost trajectories (e.g. for novel technology such as lagoons)
- to reflect the likely higher cost of within- or outside-of- Wales installation compared to UK-optimal locations (as evidenced in UK Contracts for Difference)
- to account for the potentially higher cost of regional capital, especially as increased local ownership is an objective within Re-energising Wales scenarios
- to reflect the potential impact of Brexit on UK interest rates and sterling depreciation (hence higher input costs).

Table 2 presents our estimate of the overall cost of the 11GW of renewable electricity installations required in our Wales scenario, plus our estimate of what proportion of that expenditure is likely to be spent in Wales, either directly or by supply chain companies.

Table 2:
Renewable Electricity: Investment Cost and Regional Sourcing

	MW	Cost/MW (£m)	Capex (£m 2018)	Regional Spending (£m)	Regional Sourcing
Solar PV	2,670	1.5	3,960	1,810	46%
Onshore wind	2,545	0.7	1,860	660	35%
Offshore wind	1,700	2.1	3,590	780	22%
Wave	400	2.0	800	350	44%
Tidal Stream	110	2.4	270	110	41%
Tidal Range	3,395	4.1	13,780	5,460	40%
In stream Hydropower	55	4.8	260	180	69%
Fuelled technologies	115	5.0	580	90	16%
All Technologies	**10,985**	**-**	**25,100**	**9,740**	**39%**

As Table 2 shows we estimate that a renewable electricity generation system for Wales would require investment of some £25bn[4] in today's money (and with this covering capital expenditure and first-15 year operational costs)[5]. Some 40% of gross spending (£9.7bn) could potentially be captured by Wales but *only* if relevant supply side sectors grow substantially, and local skills are available.

This regional spending will create considerable employment and value added, in planning, development/construction and operational phases (we do not include decommissioning or repowering). Figure 1 quantifies these impacts for Wales.

4 As a reminder, in our Swansea Bay City Region: A Renewable Energy Future report, we noted that it would require around £4.6bn of investment in renewable electricity generation to meet our scenario for the Swansea Bay City Region.

5 Note that these estimates are based in large part on past investments in Wales. Whilst we have sought to rebase and adjust to £2018 some mis-specification will remain. For example, past Solar PV was largely domestic and small-scale, driven by Feed-in Tariffs subsidies, but current and future investments are likely to be larger sites with greater generation per pound spent, but then also lower economic impact per MW installed.

Figure 1:
The Economic Impact of Renewable Electricity Transition

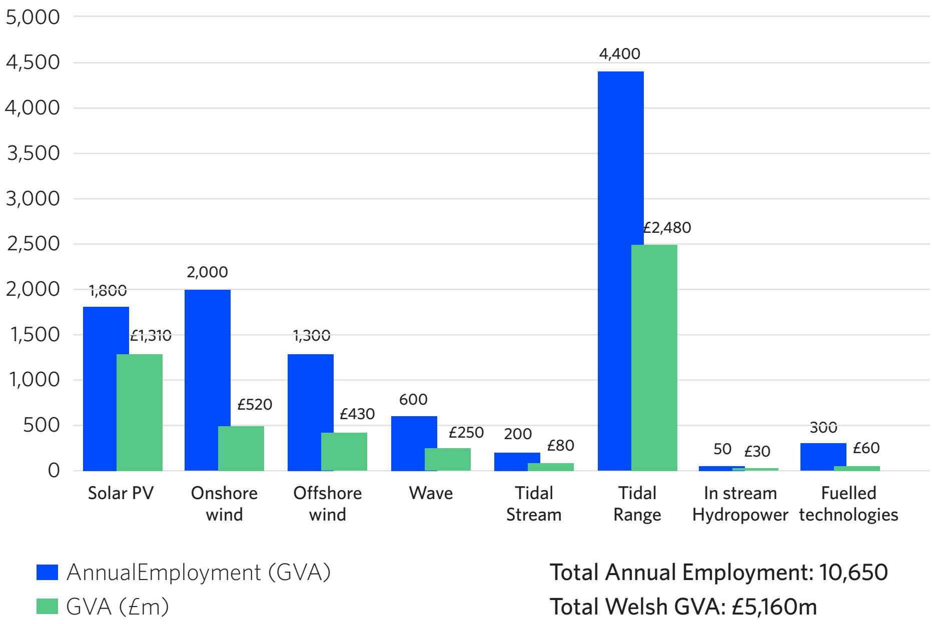

Figure 1 suggests that the investment of £9.7bn will create almost 11,000 annual full-time equivalent (FTE) jobs in Wales over a notional 'construction plus 15 years operation' period. Some 40% of this employment would be created in (largely the construction of) 3.4GW of tidal range power. Over 5,000 annual FTE jobs would be supported across the more established renewable sectors of onshore and offshore wind, and Solar PV.

We estimate this investment would create just over £5bn of gross value added in Wales across the development and operational period. Again, tidal range investment is the largest single source, at £2.5 billion, but of course this represents over half of the required capital expenditure. Indeed the relatively strong economic impact performance of marine renewables overall reflects that. Activity represented here effectively represents (even with mid-2020s costs) expensive and labour-intense proof of concept and early-stage deployment phases (which would of course be different for any viable commercial development).

Solar PV performs well in terms of regional economic impact, requiring around 16% of initial investment but delivering 25% of GVA. This is due to the relative labour intensity and local nature of the installation process, compared to offshore wind for example.

The above analysis in part depends on the relative cost of installation and maintenance, but our scenario does not enforce a strict merit order. An alternative approach could, of course, exclude relatively expensive marine renewables, particularly tidal lagoon, but with consequent impacts on the required scale of land and sea-bed use, and winter electricity shortfalls (when established renewables are less productive).

3:

Domestic energy efficiency refurbishment

3 Domestic energy efficiency refurbishment

In *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[6] report, we estimated the cost and economic impact of a programme of domestic energy efficiency refurbishment that would deliver a 20% reduction in heat and electricity demand by 2035. This saving was taken from the Regen renewable scenario and, whilst on the face of it appeared perhaps unambitious, reflected the wide variety of existing property efficiencies (with already-efficient properties more expensive to further treat), and the various difficulties inherent in whole-house efficiency interventions.

This section, in line with other approaches, applies the SBCR intervention at the scale required for Wales. As a reminder, the *Swansea Bay City Region: A Renewable Energy Future*[7] suggested the targeting of 202,000 SBCR properties across the range of EPC bands as a 'central' scenario (energy saving programme A, as highlighted in Figure 2); one that we then costed at £1.2bn.

Figure 2:
Step change needed in energy efficiency to achieve 20% energy demand reduction in the Swansea Bay City Region by 2035[8]

EPC Rating Band	A	B	C	D	E	F	G	A–C rating	D–G rating
Current SBCR bandings based on EPCs lodged 2008-17	0.2%	7.1%	21.2%	37.1%	22.5%	8.7%	3.3%	**28%**	**72%**
Example of step change needed in EPC bandings to achieve 20% energy efficiency savings targets								Overall change	
Energy saving programme A "Across the board"	5%	21%	36%	21%	13%	4%	1%	**62%**	**38%**
Energy saving programme B "more focus on the worst"	4%	15%	39%	31%	11%	0%	0%	**58%**	**42%**
Energy saving programme C "more focus on the best"	8%	24%	26%	22%	13%	5%	2%	**59%**	**41%**

6 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

7 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

8 This table was created by Regen as part of the Swansea Bay City Region: A Renewable Energy Future report

Our review of housing refurbishment costs undertaken in our *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[9] report revealed the difficulty of estimating the cost of 'climate refurbishment' on a per-property basis, driven by the variety of building characteristics which drive a 'per intervention' cost-benefit approach[10]. A further review of the literature has revealed no further useful sources, and we therefore apply our SBCR costing and hence economic impact approach to Wales as a whole.

Discussion at the Re-energising Wales steering group and reference to the first Re-energising Wales report, *Building a Picture of Energy Demand in Wales*[11], reveals no prior reason to expect properties across Wales to be systematically more or less expensive to retrofit. However, in order to address any differences, here we gross up the number of affected households based on household-sector final energy demand (for 2016) as reported by BEIS for SBCR and Wales, which will in part account for any differences in housing stock (but include other drivers such as behaviours).

Following this analysis, we estimate a domestic refurbishment programme to deliver 20% efficiency savings across the Welsh domestic stock would need to target a (daunting) 870,000 households, and cost around £5bn. Unlike for electricity generation, the majority of this spend has the potential to be local if the supply side can be developed in good time. This means the potential exists for almost 10,000 FTE jobs to be supported across Wales during a notional 15-year implementation period. This programme could result in the creation of around £2.2bn in Welsh gross value added.

Table 3:
The Cost and Economic Impact of Domestic Refurbishment

Number of Households Covered	870,700
Average Cost per Household	£5,750
Total Investment Cost (£m)	£5,010m
Total Welsh Spend (Direct) (£m)	£3,670m
Employment	
Person years	142,500
Per annum (15-year programme)	9,500
GVA (total)	£2,240m

9 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

10 See Technical Appendix for sources

11 Cardiff University for Institute of Welsh Affairs, Building a Picture of Energy Demand in Wales, April 2018

4:
Transport

4 Transport

Assessing the cost and (any) economic impact of decarbonised transport for, and in, Wales is extremely difficult. In the first case, it is not clear that expenditure on lower-carbon vehicles – especially private cars – will comprise any net additional cost over fossil-fuelled options over the next 15 years. The price of hybrid and especially electric vehicles continues to fall as range improves. Indeed, the UK Government has committed to ending the sale of fossil fuel vehicles by 2040 and is already under some pressure to be more ambitious[12]. The vehicle replacement cost of going fully or part electric over our scenario period will likely be similar to that of a fossil fuel vehicle.

There may indeed be potential savings associated with electrification of transport – private, public and commercial/industrial in terms of vehicle whole-life-costs – although these are very dependent on government grants and taxation policy and suffer uncertainty in comparisons across fuel types[13].

As an illustrative example, families in Wales spent approximately £1.7bn on private vehicle fuel in 2017, with the majority of this in excise taxes that do not accrue to Wales[14]. A hypothetical switch to 34% fully electrified vehicles (EV) by 2035 in the SBCR (as outlined in the *Swansea Bay City Region: A Renewable Energy Future* report[15]) would therefore reduce this bill by £575m per annum but require additional electricity to be consumed. Here, then, there are opportunities to link EV use with the potential to generate electricity from domestic properties, with benefits for both domestic travel and electricity bills, intra-day electricity storage and climate-friendly domestic investments[16].

Grossing up to Wales-scale from the 230GWh required for electric vehicles in the SBCR-scenario[17] provides an estimate of 1,100 GWh of demand. At a retail electricity price of 14.4p per kWh this suggests around £160m in fuel costs for the private electric fleet – a net saving of £415m per annum[18]. Manipulation of the Input Output Tables for Wales suggests this

12 Anushka Asthana and Matthew Taylor, Britain to ban sale of all diesel and petrol cars and vans from 2040, July 2017

13 Jack Carfrae, Whole-life costs analysis: Plug-in hybrids, August 2016

14 Albeit with some of the fuel potentially originating from the Valero refinery in Milford Haven.

15 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

16 David B.Richardson, Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration, March 2013

17 Here using BEIS 2016 ratios for SBCR-Wales transport energy demand

18 Similar analyses could be undertaken, albeit with perhaps even more uncertainty for commercial and public transport vehicles, here with benefits accruing to commercial and public organisations. We do not cover these here for reasons of time and resource.

saving, if translated into household spending, would generate an additional £165m of Welsh GVA annually, supporting over 3,000 FTE jobs. If a renewable electricity system was in part (or substantively) Welsh-owned, the regional economic impact would be considerably higher. There is, of course an additional cost not captured here: that of the additional charging infrastructure required to enable the EV switch, be this privately or publicly borne, and any required grid upgrades. The poor state of the Welsh rapid EV charging network, despite some policy attention[19], is then a concern for this transition[20].

This analysis of course relies on a large number of future unknowns, not least the relative cost of electricity and fossil fuels, which is very dependent on relative demand, supply and regulation – and hence on UK Government policy in relevant areas, and especially in ensuring an affordable and reliable future electricity supply. The relative capital costs of vehicles, including battery replacement, will be additional.

As important will be an electricity supply *and* grid that enables 24/7/365 use of electric vehicles. For Wales, the energy supply vision laid out in Chapter 1 of this report provides enough GWh in aggregate for the suggested 500,000 electric vehicles and probably more, but such electrification of transport would place additional demands on scarce winter supply. Whilst vehicle batteries may be useful for diurnal storage, they are not for inter-seasonal.

We return to this critical issue of inter-seasonal storage in our final chapter.

19 National Assembly for Wales, Electric vehicle charging in Wales, accessed October 2018

20 Zap Map, Zap Map, accessed October 2018

5:

The Issue of Storage and Balancing

5 The Issue of Storage and Balancing

In areas of current electricity use, and the electrification of both heat and transport, the appropriate matching of demand and supply over time is a significant problem. Intra- or inter-day matching is, arguably, fairly straightforward, for example with the use of smart meters and tariffs, household or vehicle battery storage and moderate behaviour change. Inter-seasonal matching – to account for the fact that currently employed UK renewables produce much less power in the winter, when most needed – is far more problematic.

Inter-seasonal matching can be solved in a renewable system via, for example, the storage of biomass fuel for burning when needed; the storage of renewably-generated compressed hydrogen; or the storage of electricity in large scale batteries.

Thermal storage (to provide winter heat) is also a possibility, although not employed at scale[21]. Additionally, Wales has the opportunity to build on existing 'pumped-storage' approaches whereby water is pumped uphill at times of low electricity demand and released to generate electricity at times of high demand[22]. Lastly, a territory can import electricity (or renewable fuel) from an outside territory when required. Any of the above options implies cost additional to the generation system itself.

We are some way from storage systems that are capable of annual electricity balancing at the scale required. For example, the largest lithium-ion battery plant in the world, built by Tesla in South Australia, is rated at 100 MW and can store 129 MWh of electricity – around 1hr supply for 30,000 homes[23] rather than the potentially multiple hours or days across the 150,000 Welsh households that are the base for our 2035 scenario (to say nothing of businesses) which would task a Welsh inter-seasonal storage system.

Recent estimates of the capital cost of storage by Lazard suggest that lithium-ion, the most competitive battery technology is around $400-$1,000 dollars (c£307-£767) per MWh[24]. The *Swansea Bay City Region: A Renewable Energy Future* report[25] scenario envisaged 1,500 MWh of storage, here then implying a range of £600,000 - £1,500,000 for storage. Notably, however,

21 J.Xu, R.Z. Wang, Y.Li, A review of available technologies for seasonal thermal energy storage, May 2014

22 See Electric Mountain, Dinorwig Power Station, accessed October 2018. Further, large scale developments are limited currently by environmental and other issues, and ultimately by issues of topography. See, however The Quarry Battery Company, Helping to deliver a low carbon World, accessed October 2018 for a North Wales example in development

23 Jay Weatherill, South Australia turns on Tesla's 100MW battery: 'History in the making', December 2017

24 Lazard, Lazard's Levelized Cost of Storage Analysis, November 2017

25 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

the Regen scenario still assumes that 600GWh+ of electricity – 12.3% of consumption – is imported to the region.

As Wales depreciates its large gas fired generation fleet in moving towards 100% renewables, its position as a significant exporter of electricity – currently almost half of generated power is exported[26] – also changes. Whilst our Pathfinder analysis with Wales & West Utilities shows a significant net surplus of territorially generated electricity, more of this will be generated in the summer, when power is more plentiful (on a more renewable-dependent UK/EU grid), reducing prices or perhaps meaning even that power generated in Wales in the summer cannot be profitably exported to any paying customers. Conversely, the Pathfinder analysis suggests the need to import winter power, or store over a reasonably extended period, totalling an estimated 260GWh for Wales.

This is a modest proportion of total consumption: perhaps 1.5%-2% depending on other factors, linked no doubt to our assumption of a large, year-round tidal range resource. Failing to supply would still however lead to 500+ hours where significant and economically disruptive demand management would be required to balance the lower supply. Financial implications are also modest: around £15m of cost at current January 2018 wholesale prices for example for the 260GWh.

There is, however, a more problematic conceptual issue here. Power imported for winter baseload will, by 2035 on current UK trajectory, be in large part nuclear generated. Whilst we have explicitly excluded nuclear power from our Re-energising Wales scenario (as it is not renewable), even if the Horizon Wylfa Newydd nuclear development is not built, but other parts of the new nuclear fleet (e.g. Hinkley Point C) go ahead, Wales will rely, for some parts of the year and across some of its geography, on imported electrons that are fission-fuelled.

This may not matter to many people who are not nuclear-opposed, or who simply wish to avoid new nuclear build within the boundaries of Wales. However, as debates over nuclear waste and now 'nuclear mud' show[27], the implications of nuclear electricity generation are complex, and extend well beyond any one UK region, raising the question of the appropriate framing of regional (or national) aspirations for 'renewable' status.

In Wales, the Well-being of Future Generations (Wales) Act 2015 requires that we consider the impact of policy made in Wales *outside* Wales. The Act, then, provides an appropriate framing for discussions on electricity generation in the same way that it frames debate around decarbonisation more generally, to include wider global greenhouse gas footprints, embodied carbon and other supply chain issues.

26 Department for Business, Energy & Industrial Strategy, Electricity generation and supply figures for Scotland, Wales, Northern Ireland and England, 2013 to 2016, December 2017

27 Steven Morris, Activists call for halt to 'nuclear mud' dumping off Wales, October 2018

6:

What’s Left? Heat, Industry and Everything Else

6 What’s Left? Heat, Industry and Everything Else

We have, in this report, attempted to present the economic implications of a 100% renewable future for Wales – in terms of both costs and benefits – but there remain areas where it is very difficult (at this stage) to narrate credible renewable solutions, let alone to cost them.

Primary amongst these is the issue of domestic heat, which is a significant driver of energy demand in Wales. Gas, mostly mains, provides 13,800 GWh-equivalent energy in domestic properties, with the greatest demand for gas usually occurring at the same time of low wind and solar-PV generation. Switching this demand to electricity is therefore far more daunting than imagining even a *fully* electric Welsh private vehicle fleet[28].

It is likely then that decarbonisation of heat will require a mixed approach including some electrification (especially off-grid where LPG and oil are used) but also the blending of renewable gas – hydrogen or biogas – with natural gas, as well as behavioural changes. It is currently possible to purchase ‘green gas’ (from waste) in the UK although it is an open question as to how far supplies can be expanded[29]. Meanwhile, Re-energising Wales partners Wales & West Utilities are at the forefront of hydrogen gas developments in the UK and interested readers are directed to Wales & West Utilities for further information[30]. Hydrogen would, of course, have to be supplied after compression using (renewable) electricity so this would still require additional supply, although seasonality may be addressed via storage before or after blending.

At this stage it is difficult to assess the cost of hydrogen or biogas supply, although hydrogen certainly remains expensive to compress and deliver, involving energy losses that are significant, although manageable[31]. Certainly, if hydrogen is usable for domestic heat in blend with natural gas, elements of concern in its vehicular use, the lack – and hence cost – of a delivery infrastructure do not apply.

28 Perhaps 3,000GWh+ but arguably much easier to substitute with active travel, more efficient public transport or fewer miles travelled

29 Green Gas, The Green Gas Certification Scheme, accessed October 2018. Suppliers include Ecotricity and Good Energy

30 David Thorpe, Could the UK’s Gas Grid Be Converted to Hydrogen?, July 2016

31 National Renewable Energy Laboratory, Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs, May 2014 & Kyle Field, Hydrogen Fuel Cell & Battery Electric Vehicles — Technology Rundown, August 2018

A number of substantive issues remain outside the scope of these chapters including:

- commercial and industrial emissions
- agricultural emissions
- international aviation and shipping
- electricity grid renewal.

There are additionally a number of developments in Wales that provide economic opportunity in the area of renewables: for example in marine energy[32], as well as in community energy, policy innovation and local energy balancing. Some of these elements are addressed in existing or forthcoming IWA Re-energising Wales reports.

32 Swansea University, Energy and Environment, accessed October 2018

7:

Summary and Key Issues

7 Summary and Key Issues

This report has sought to outline the potential for regional economic impact consequent on a programme that includes radical decarbonisation of electricity generation, significant investment in domestic refurbishment and a shift toward electrified private transport.

We do not claim this as a fully-fledged and immediately implementable programme for Wales. We abstract, of course, from many funding, regulatory and behavioural constraints. Technical uncertainties in the areas, particularly, of heat and storage, as well as difficulties in painting a detailed picture of future Welsh land use and industry means this is a partial picture. As with all IWA Re-energising Wales documents, it is intended as a spur for further debate. This report does, however, provide a broad-brush picture of the challenge as well as the opportunity.

Table 4:
Re-Energising Wales Renewable Energy Capacity

All £2018 equivalent	**Capital Investment**	**Total Welsh Spend (Direct)**	**Annual FTE Jobs in Wales**	**Gross Value Added (15yr)**
Renewable Electricity	£25.1bn	£9.7bn	10,650	£5.2bn
Domestic Refurbishment (20% efficiency savings)	£5.0bn	£3.7bn	9,500	£2.2bn
Private Vehicle Electrification (34% of fleet)	?	?	3,000	£2.5bn
Total	**£30.1bn**	**£13.4bn**	**23,150**	**£9.9bn**
Heat. Industrial & Commercial decarbonisation. Land Use, National Grid ...	...		...	...

As with our earlier report *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[33], we make the point that these economic opportunities will be grasped only if relevant supply-side capacity – in terms of firms and skilled workers – can be developed, and indeed be competitive. This is a stark challenge, given the level of required investment[34] and Wales' poor prior energy supply chain performance.

For electrification investments, additional (and *developmental*, rather than short term employment) benefits will arise only with ownership – in part or whole – of the capital and intellectual property that is employed in decarbonisation for Wales, and indeed elsewhere; unless of course Wales can, post-Brexit, attract significant relevant multinational manufacturing operations[35].

Here there is some hope, not least in research on marine renewables[36], and the activity of SPECIFIC at Swansea University that encompasses research on power-from-buildings, thermal (inter-seasonal) storage, photovoltaics and cutting-edge battery technology. The difficult trick, as always, will be the move to commercialisation and scale in Wales.

Given the troubled progress of the Swansea tidal lagoon, the lesson of past waves of renewables innovation – that manufacturing and intellectual property capture occurs often in places where national or subnational policy is strongly supportive of the *roll out* of novel renewables[37] – should not be forgotten.

33 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

34 About twice that of Wylfa Newydd, at 2015 cost estimates, Miller Research, Nuclear Industry in Wales: Capability Study, accessed October 2018

35 E.g. Tesla's Gigafactory in Nevada hopes to eventually employ 10,000 but this location was chosen after a fierce bidding process, requiring significant state subsidy, Fred Lambert, Tesla Gigafactory now employs over 850 workers, 1,000 more to come in first half of 2017 with production ramp up, December 2016

36 Menter Mon, Menter Môn, accessed October 2018 and Marine Energy Wales, Marine Energy Wales, accessed October 2018

37 Joanna I. Lewisa and Ryan H. Wiserb, Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms, March 2007

8:

Technical Appendix

8 Technical Appendix

Scenario development: Renewable Electricity

After consideration of potential methodologies using the SBCR-share of GVA or population, Wales (gross, annual) territorial electricity requirements were estimated from the *Swansea Bay City Region: A Renewable Energy Future*[38] report using the total electricity demand ratio SBCR-to-Wales from UK Government local authority energy demand estimates[39].

Our renewable technology mix was based initially on figures from the *Swansea Bay City Region: A Renewable Energy Future* report[40] and then advice taken from the Re-energising Wales steering group in terms of making this more realistic on an all-Wales basis. Key amendments included:

- tidal technologies were increased somewhat in relative share to reflect potential developments; for example related to Anglesey Energy Island, with the assumption that a Cardiff or Conwy lagoon is developed at ~3GW
- our onshore and offshore wind capacity is based on the industry view regarding likely investable sites, with this then in part dependent on issues such as planning and seabed licensing etc. Some floating offshore wind is expected in the Pembrokeshire demo zone along with the predicted wave energy capacity
- our Solar PV share is somewhat lower than SBCR, based on somewhat more limited opportunity outside south west Wales (landscape and solar intensity), also accounting for the impact of the foregoing amendments.

Readers should note that our mix reflects both technological readiness and (related) cost per MWh, although we do not develop a formal merit order, rather seeking to reflect regional opportunities more holistically.

Our load factors are based on data from the *Swansea Bay City Region: A Renewable Energy Future* report[41], supplemented by the Digest of UK Energy Statistics[42] and other UK level estimates, including for novel technologies[43], choosing mid-point estimates as appropriate. See also the work done across the piece by the Renewable Energy Foundation[44].

38 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

39 Department for Business, Energy & Industrial Strategy, Total final energy consumption at regional and local authority level, September 2018

40 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

41 Regen for Institute of Welsh Affairs, Swansea Bay City Region: A Renewable Energy Future, April 2018

42 Department for Business, Energy & Industrial Strategy, Digest of UK Energy Statistics (DUKES) 2018: main report, July 2018

43 Department of Energy and Climate Change, Small-Scale Generation Cost Update, August 2015

44 Renewable Energy Foundation, Renewable Energy Foundation, accessed October 2018

Cost per MWh

Please refer to our report *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[45] for methodology.

Note that:

- some estimates of cost per MWh have been moderately amended from *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region* report[46] following consultation with the Re-energising Wales steering group
- all costs are as close to 2018 costs as practicable, reflecting most recent Contracts for Difference auctions etc., with the exception of wave and tidal stream (effectively mid 2020s)
- costs for tidal range based on Tidal Lagoon Power outline for a Cardiff lagoon[47]
- our estimates seek to incorporate capital and operational spend, tied to a notional 'construction+15 year' time period. They are not comparable to published Levelised Costs of Electricity (LCOE) estimates although much of the underlying information is common.

Economic Modelling

Please refer to Section 2 of our report *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[48] where our methodology is described in detail. Note that the estimation of 'local', ie SBCR, economic capture is not required for this report. More background on the Input-Output Tables for Wales, and the specific application to energy activities can be found in both the *Input-Output Tables for Wales* report[49] and the *Regional electricity generation and employment in UK regions* report[50].

45 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

46 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

47 Tidal Lagoon Power, Harnessing the second highest tidal range in the world, accessed October 2018

48 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

49 Cardiff University, Welsh Economy Research Unit, accessed October 2018

50 Jane Bryan, Neil Evans, Calvin Jones & Max Munday, Regional electricity generation and employment in UK regions, April 2014

Retrofit

Please see our report *The Economic Impact of Energy Transition in Wales: A Renewable Energy System Vision for Swansea Bay City Region*[51] for detailed methodology. Costs derived from a number of sources including at both UK level via the *Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK* report[52], the *WHAT DOES IT COST TO RETROFIT HOMES?* report[53] and the *an introduction to low carbon domestic refurbishment* report[54], and regionally via the *Cutting Carbon, Creating Jobs* report[55], the *Did ARBED I Save Energy in Wales' Deprived Dwellings* report[56] and the *Evaluation of arbed Phase One* report[57]. Note that the estimation of 'whole building' retrofit costs is somewhat problematic, depending on the age, type and location of property. Additionally, a number of cost sources are out of date. We are therefore indebted to Professor Philip Jones and Professor Ian Knight of Cardiff University in helping develop a reasonable average cost across all building types.

Transport

Our average cost for UK Electricity was taken from UK Power[58]. Estimates of gross spending were taken from the 2017 *Family Spending in the UK - All Data* survey[59]. We model the impact of fuel saving using Input-Output methodology from the *Input-Output Tables for Wales* report[60].

51 Cardiff Business School for Institute of Welsh Affairs, The Economic Impact of Energy Transition in Wales, September 2018

52 Department of Energy and Climate Change, The Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK, November 2012

53 Department for Business, Energy & Industrial Strategy, What Does It Cost To Retrofit Homes?, April 2017

54 Construction Products Association, An introduction to low carbon domestic refurbishment, June 2010

55 Stop Climate Chaos Cymru, Cutting Carbon: Creating Jobs, March 2011

56 Atkinson, J., Littlewood, J., Geens, A., & Karani, G. Did ARBED I Save Energy in Wales' Deprived Dwellings, December 2015

57 Eco Centre Wales, Evaluation of arbed Phase One, 2012

58 UK Power, Gas & Electricity Tariff Prices per kWh, accessed October 2018

59 Office for National Statistics, All data related to Family spending in the UK: financial year ending 2017, accessed October 2018

60 Cardiff University, Welsh Economy Research Unit, accessed October 2018

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