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Might tidal range schemes change the local economic impact dial on renewable electricity generation?

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ABSTRACT

This paper argues that potential future tidal range schemes (TRS) across the UK could change the local economic development dial. Previous renewable electricity generation developments in less economically advantaged parts of the UK have had limited local economic development effects. However, the characteristics of tidal range schemes in terms of technology and construction needs could make for more significant local economy impacts. We structure the review around the potential connections between the development of TRS and local economic development and then framing the dynamic impacts of TRS construction/operations activity in terms of the development of a UK/local supply chain and associated trade development. We finally consider how public interventions might work to improve the economic development prospects of TRS. An identified concern is that the leverage of socio-economic returns from TRS will not be automatic. There has to date been limited progression in the UK to explicitly link the availability of subsidies to socio-economic outcomes in areas surrounding the electricity generation infrastructure. The review reveals that to lever the socio-economic outcomes from future TRS that closer public private partnerships will be needed during the development of the infrastructure.

1. Introduction

UK renewable electricity generation (both existing and planned) tends to be close to areas of persistent socio-economic need. However, the recent history of renewable electricity generation technologies (particularly technologies such as on- and offshore-wind and solar PV) reveals limited local economic benefits in what are often more peripheral economies of the UK. In part this links through to the capital-intensive nature of renewable electricity generation coupled to more limited supply side opportunities in those regions having the natural resources (wind and tidal variation) to support the technologies. Prior research on renewable electricity generation has also revealed that issues of scheme and supply chain ownership are important in understanding the expected scale of local developmental effects, and with more needy parts of the UK economy typically seeing renewable electricity generation capacity owned and controlled by extra-regional or indeed international interests.

This review seeks to frame whether potential future tidal range schemes (TRS) might represent a stronger local economic development opportunity. We adopt a UK local economy lens. The main rationale for tidal range schemes is impounding water in a lagoon or barrage by controlling the flow through the turbines and sluice gates to create an artificial head difference across the scheme. Electricity is generated through conversion of potential energy due to the head difference [1–4]. The schemes can be optimised to maximise electricity generation or by operating tidal range power facilities as a flexible and dispatchable source of electricity and therefore provide ancillary services to the electricity grid [5]. While the focus of potential UK schemes is very much on predictable, reliable and dispatchable renewable electricity generation in a context of reducing the carbon emissions from electricity generation, there remains an important socio-economic developmental context in the areas where schemes could be developed.

One context for the review is that there are few international examples from which one can draw inference on the integration of TRS at scale with energy and economic development plans. The low number of examples links through to tidal energy sectors being at early stage development [6–9]. Moreover there is also limited opportunity to draw any policymaking inference from the small number of TRS in operation

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globally due to different developmental and operational contexts and with some schemes developed long ago [10], and with prior reviews of tidal energy also arguing that much of the research literature has not focused on tidal lagoons and barrages [11]. In terms of existing schemes, the Rance Tidal Power Station in Brittany was developed in the period 1961-66 by the nationalised French energy company EDF [12,13]. This scheme is quite different from many of those being considered in the UK in terms of scale and scope (see for example Severn Estuary Commission, 2025. [14]). The Rance scheme is just 240 MW in terms of capacity and bridges a river estuary and comprises important road infrastructure. Another large operational scheme is the Sihwa Lake Tidal Power Station in South Korea. Sihwa Lake itself was created in 1994 as part of a land reclamation project, but with the electricity generation project developed ex-post and opened in 2011 to deal with environmental problems caused by the original infrastructure. Any UK learning from this scheme is limited because the scheme aimed to deal with a specific environmental problem caused by the earlier enclosure of the Sihwa lake, and with the tidal power project connected with significant ecosystem improvements [15] and with economic development concerns not a key consideration. Then the global scene in respect of tidal range schemes linked to barrages and lagoons reveals few projects at the scale of those being considered in the UK [8,14].

We structure this review around understanding the potential connections between the development of TRS and local economic development. Appendix 1 outlines the method undertaken in our semi structured review. We then frame the dynamic impacts of TRS construction/operations activity at different scales in terms of the development of a UK/local supply chain and associated trade development; and then finally considering whether interventions might work to improve the economic development prospects of schemes.

2. Local economic effects of UK renewable electricity generation

A wide range of studies have explored the impacts of electricity generation on the local, regional and national economy [16–24]. Of development relevance in the UK is the rundown of 'conventional' power generation infrastructure (coal and 'old' nuclear in particular) which was able to provide employment (and often relatively well-paid employment) during the operational stage, and with this often occurring in more needy parts of the UK economy, not least in the case of nuclear power stations scattered around the UK coastal periphery. The electricity generation sector has also been connected with relatively high employment multipliers (i.e. the relationship between direct employment in the process of electricity generation, and then indirect and induced employment supported by wages paid in the industry and payments to suppliers etc. see Ref. [25]). However, these high employment multipliers are typically connected to relatively low levels of employment in UK electricity generation itself which features high levels of capital intensity [26]. This is particularly the case with technologies such as onshore and offshore wind where the operational stage of electricity power generation employs, relative to technologies such as coal, nuclear and biomass, lower numbers of people [25]. The corollary is that much of the economic impact of schemes (whether featuring renewable technologies or otherwise) is focused into the shorter construction and pre-development planning phases [25,27,28]. A series of papers have considered the amounts of direct and indirect employment [25,29–31] and direct and indirect gross value added [32] associated with different electricity generation technologies. Where studies have focused on electricity generation the conclusion is of more limited sustainable economic development effects close to the sites of renewable electricity generation.

Identified drivers of these more negative conclusions relate to how far local (and indeed national) businesses are engaged in construction processes around renewable electricity projects, and how far the local supply side is positioned to benefit from the demands placed by what are often international developers. In the case of conventional gas generation (combined cycle gas turbines), onshore and offshore wind, the development debate has tended to focus upon the local purchasing propensities of high value turbine components and with the industries that make such components often located far away from where the final generating infrastructure is placed [25]. This purchasing orientation can be based on a sound economic rationale with turbine manufacturing offering significant economies of scale [33]. The traffic has not been all one way in this economic development debate with some work showing that smaller scale renewable electricity generation can be associated with more tangible local economic effects (see for example in the case of run-of-river-hydropower [34]).

A second strand of economic development questions focuses upon the ownership of schemes and the attendant supply chain and the direction of revenues and profits through the operational phase [27]. The Digest of UK Energy Statistics[1] provides a regular update on the location of electricity generating capacity in the UK, and main developer. Even a casual analysis of these tables reveals how far foreign-owned multinationals are important in the ownership of both large-scale conventional and renewable electricity generation sources in the UK. This has been one driving factor for the devolved governments in both Scotland and Wales proactively seeking to encourage higher levels of local ownership of electricity generation infrastructure, but with some very real problems in achieving this in more disadvantaged areas due to a lack of local capital [35–37].

A further strand in the debate around the economic impact of renewable electricity generation has been around the level of community benefits offered by developers, and how far such benefits packages can be used to garner economic development outcomes [38]. Once again previous literature here is far from encouraging with benefit package monies not always being used to strengthen economic growth prospects for communities, and with some researchers arguing that there are better returns for communities available where they can be encouraged to invest directly in the renewables project and receive a share of the income from the completed projects (see for example, [39, 40]). Unfortunately, these local communities close to electricity infrastructure might be those least able to raise the monies needed to work with developers to build new schemes.

Overall then the potential for renewable electricity generation schemes to support local economic development has been found to be quite limited [40,41]. There is an air of inevitability here because, particularly in the case of onshore wind, the most valuable schemes are placed in parts of the UK economy where there is very limited supply side capacity and capability, and where there are pockets of economic disadvantage. This led Jones and Munday [27], for example, to conclude for Wales in the west of the UK, that with limited evidence for any significant benefits beyond employment from past and underway energy investments, and given the modest nature of employment impacts, that it was very unlikely that the energy sector could be 'transformative' for the local economy under prevalent economic and ownership models.

Following this outlook from the literature there is a challenge to consider whether there is any expectation that conclusions in respect of TRS would be any different and how far such schemes have the characteristics that might lead to more sustained local economic benefits, and then with a corollary on how far such development implications might be picked up in the regulatory and permission process around projects.

3. Framing the economic regeneration benefits from TRS

At the start of 2024 there were a series of UK proposals that are seeking to develop TRS. Unfortunately with no operational TRS at scale in the UK, and few operational in the rest of the world [12,13,15],

[1] See for example *Digest of UK Energy Statistics*, 2023 Table 5.11 see DUKES_5.11.xlsx (live.com).

discussion of economic development prospects around schemes does tend to play a minor role compared to the very large number of academic papers and reports [1,4,8–10,42–49] that have considered the engineering and environmental details of tidal schemes, and the types of problems that need to be overcome, and here with research also embracing issues in respect of UK Government policy towards energy generation [50].

However, it is still necessary to understand the connection between TRS and local economic development in the context of the expected difficulty in gaining planning permissions [51], the large number and generation capacity of projects currently in pre-development phases or in the process of gaining permissions, and perhaps more importantly the very large sums of money connected to pre-development, construction and commissioning (see selected schemes in Table 1). We accept in Table 1 that these are in large measure developer estimates of power outputs, efficiency and associated cost estimates, and with, in some cases, limited information available on the websites on how estimates were derived.

While TRS schemes in the UK are not yet in the construction and commissioning phase, tentative conclusions might be made in terms of the role of such schemes in potentially improving local economic prospects. That said some care is required in filtering previous work here. For example, reports of future economic development dividends from TRS for local economies are often produced by consultancies and other organisations that sometimes have a direct interest in the outcomes of the process.

Table 1
Selected potential tidal range projects in the UK.

Scheme	Power Capacity MW	Annual Est. Power Output (GWh)	Total cost estimates £bn	Sources (last accessedMarch 11,2024)
North Wales Lagoon, near Llandudno, Conwy	2000	4000	7.0	https://www.northwalestidalenergy.com/energy-generation
Centre Port Norfolk	365	800	3.0	https://www.energymonitor.ai/opinion/opinion-centre-port-dam-thats-a-lot-of-men/ https://www.centreport.uk/#about
Morecambe and Duddon Bay Barrages, Lancashire	4000	7800	10.0	https://committees.parliament.uk/writtenevidence/19283/html/
Mostyn Lagoon, North East Wales	128	2986	0.59	https://www.portofmostyn.co.uk/590m-tidal-lagoon-will-create-300-jobs/
West Somerset Lagoon, Severn Estuary	2500	6500	10.3	https://tidalengineering.co.uk/west-somerset-lagoon/
Mersey Lagoon, Liverpool	700	1000	Not known	https://www.newcivilengineer.com/latest/proposed-mersey-tidal-barrage-would-be-largest-engineering-project-in-north-west-30-11-2023/
Swansea Bay Lagoon, South West Wales.	320	TBC	1.7	https://dst-innovations.net/2022/09/26/1-7-billion-project-announced-for-swansea/

In what follows in considering the potential role of tidal range schemes, particularly in more needy parts of the UK, we follow the logic framework presented in Fig. 1. Here the left-hand side reveals some typical attributes of local economies where TRS could be developed (see for example, 14, 52). We accept that these characteristics would not feature in all of the local economies around potential development sites (see Table 1), but such factors would seem to be pertinent to schemes being developed in Wales, and the South West and North West of England where local economies surrounding potential developments are characterised by relatively low productivity, and productivity growth, and with, in some cases, communities with higher levels of deprivation [52,53].

Fig. 1 reveals how project activity and spending (during preplanning, development, construction and commissioning) might be expected to affect local economies directly and indirectly, and then with a series of feedback effects following completion. This framework is not to discount wider UK economy effects, but our review theme is more around local economic prospects. A similar framework would link to TRS activity through the longer operating phase of schemes.

As highlighted above the prospects for local economic returns from established renewables such as onshore and offshore wind is fairly limited [25,54]. This is largely down to the geographical spending profile of projects during construction, the location of managing contractors on construction engineering projects, and then the very limited local employment and spending activity that is supported during the 25–40 year operational phase. Bryan et al. [25] discuss the typical local spend profile through construction phases of onshore and offshore wind and find limited local employment supported per installed megawatt (MW) of capacity. Equally during this relatively employment intensive construction phase there was a strong tendency for high value components to be sourced overseas [55–57] leaving the UK and local economies focused into lower value added elements of the supply chain, and then with local spending during the operational phase typically limited to rates and payments to community benefit schemes [40,58–60].

Reinforcing these conclusions is that for technologies such as onshore and offshore wind there have been contested impacts in terms of factors such as tourism and regional branding [61] although, such schemes have a significant impact on generating low carbon electricity and decarbonising the UK energy system.

So, is there any expectation that genuinely local economic effects could be different in the case of TRS?

4. Will TRS change the dial on local economic effects?

The local economic effects associated with the construction of TRS might be quite different from those associated with other renewable electricity technologies at scale. Clearly robust conclusions here are difficult simply because there are no schemes operational in the UK. Moreover, as revealed earlier, drawing inference on construction and development costs from the small number of tidal lagoon/impoundment projects overseas where labour markets, planning regimes, environmental permissions and the manufacturing supply side are very different is not really defensible (for other major TRS schemes overseas [43] and for components of tidal range power plants see Ref. [8]). Even where UK projects in early development have tried to estimate costs and quantities, and then come to conclusions on economic effects of construction spending, there has been an issue on how far it is assumed there is capacity available to develop projects, not least in connection with the availability and development/design of large dimension turbines [62] and competing demands for the goods and services offered by the UK supply side. This latter could have a significant role in inflating costs during the construction process. So, for example, the costs associated with a major lagoon build in North East Wales might be affected by the presence of a major nuclear build nearby or the construction of other energy infrastructure. Indeed these construction and development uncertainties, coupled with the long expected operational duration of

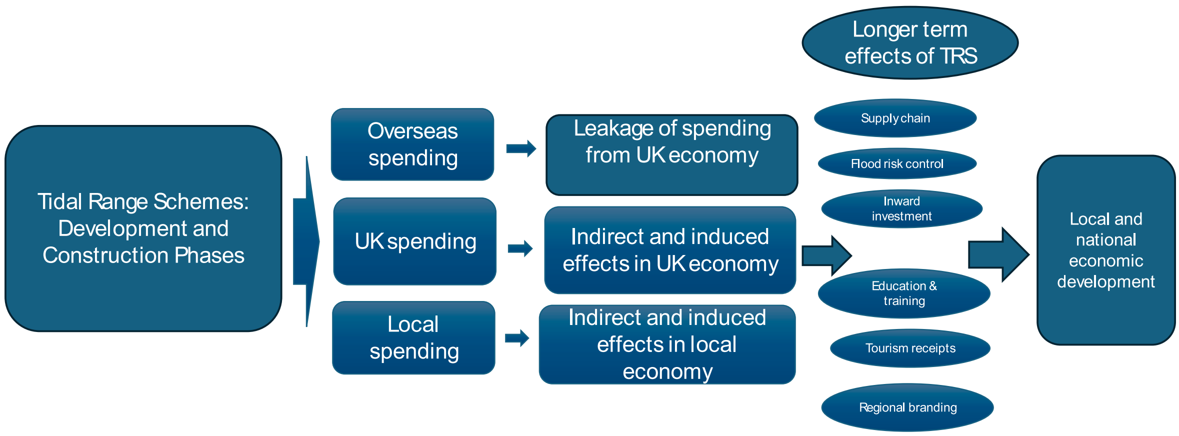

Fig. 1. Framing the local economic development implications of tidal range projects.

schemes (up to 100–120 years in the case of projects shown in Table 1) are a reason why large scale tidal range schemes could be difficult to progress under the current UK contract-for-difference framework and may require private-public sector cooperation through a regulated asset base framework which provides investors with returns through the risky pre-commissioning phase [63,64]. We return to this specific issue in the conclusions.

In outline the key elements of our argument below in respect of why there could be a larger local economic impact in the tidal range case rest on the.

- project scale of construction,
- expected higher levels of local sourcing,
- potential to change the supply side of the UK economy,
- long term nature of the construction process.

A crucial point in terms of TRS is that there is potential for high levels of inputs to be sourced geographically closer to schemes. Indeed this factor was picked up by the work of the Severn Estuary Commission examining the future economic impact of tidal range energy in the Severn Estuary in the South-West of the UK [14]. Here it was suggested that as much as 85 % of supply chain spend around TRS development in the Severn Estuary could be captured in the UK economy. However, it is important to note that supply chain gains might be contingent on the total number of projects moving forward such that a supporting industry can develop.

Following from the above the factors discussed below suggest a potential for more significant local economic effects associated with the development and construction phase of TRS.

First, the scale of TRS in development in the UK (see Table 1). The scale of these projects ranges from small, pathfinder schemes, such as the 128 MW Mostyn Lagoon to the 4 GW Morecambe and Duddon Bay Barrage complex. This is reflected in the projected costs of the projects, ranging from £0.59 billion to £10 billion, and with expected costs inflating every year. Clearly, it is unlikely that more than a small proportion of projects could go ahead, but given this development scale, even were a relatively small proportion of spending to be focused on the local economy it could have significant effects in terms of the support of employment and trade.

We seek to illustrate this conclusion in very broad terms. We use information from the sources in Table 1 (i.e. in terms of the expected scale of project costs) and more detailed data shared with the authors by selected scheme developers in Wales and the South West of England.[2] This included information provided by North Wales Tidal Energy of the costs associated with the development, construction and operation of their tidal lagoon [65]. We also benefited from the model of costs of tidal range power generation schemes by Vandercruyssen et al. (2023) [66], and with information provided in respect of the estimated cost breakdown of NWTL between turbo generators, power house, sluices, bund and contingencies. Data here comprised the approximate cost breakdown of schemes during pre-development, commissioning, construction and operational phases. This information was used to develop three scenarios (i.e. not directly linked to any scheme currently under consideration to protect commercial confidentiality of schemes being planned) of schemes at very different installed capacities (Schemes A–C below). This information was then combined with data from Ahmadian et al. [52] on the expected purchasing propensity of goods and services for a tidal range project during the construction and development phase.

[2] These developers were on the steering group of the EPSRC Target project; see acknowledgements.

Table 2
Summary assumption set for exploring Wales-level economic effects through development and construction phases of tidal range schemes (money items in £2023).

	Scheme A Low	Scheme B Medium	Scheme C High
Installed power capacity	250 MW	750 MW	3000 MW
Potential start date	2034	2040	2047
Pre-construction/development phase time	5 years	7 years	8 years
Construction phase time	5 years	6 years	8 years
General assumption on operational lifetime	120 years	120 years	120 years
Estimated total scheme cost (development and construction) £2023	£0.9bn	£2.4bn	£8.5bn
Operational and maintenance costs (average annual £2023)	£13.5m	£30.0m	£85.0m
OP cost/K investment	1.50 %	1.25 %	1.00 %

Total capital and development costs assumed to be distributed as follows: Pre-development costs and planning 5 % of total and 50 % of this spent in local economy of Wales; Construction of caissons/bund, main surface works 15 % of total and with 40 % of this spent in Wales; Turbine core capital costs 50 % and zero spend in Wales; Turbine area works and associated civil engineering 20 %, and 30 % of this spent in Wales; Other costs 10 %, and 50 % spent in Wales. The net result of these assumptions is that around 20 % of total development and capital spending would be assumed to be in Wales. See Appendix 2.
Welsh economy capital and development stage spending assumed to be distributed between industries including mineral products, fabricated metal products, machinery and equipment, repair and installation, construction, real estate and professional services; The supply side of these sectors in Wales leads to assumptions on how far goods and would be available to TRS developers. See Appendix 2 for further details here.

The broad assumption set is shown in Table 2. This reveals the estimated costs of schemes at different scales with different start dates, and with developed assumptions on the distribution of capital and development costs. Here we assume the 'local economy' in question is Wales (i.e. projects would be primarily in Wales), close to the Severn Estuary. We believe that Wales is a useful lens through which to examine potential local economic effects because of size of the marine energy resource and the number of projects being considered there [14,38,67–69].

Table 3 then shows the possible scale of economic effects for a local economy based on the 3 scheme scenarios. We use the framework of the Welsh Input-Output tables (a simple economic model of the Welsh economy and with the input-output methodology often employed to examine the development impacts of different renewable technologies, see for example, [22, 25; 70, 71, 72]) to estimate how the project spending might support local activity. It is assumed here that the spending during scheme development and construction (a proportion of the capital costs in Table 2) represent shocks to the demands for goods and services from local industries which include: non-metallic mineral products; fabricated metal products; installation; manufacture of machinery and equipment; construction; real estate and professional services. The estimates of the local economic effects that follow are estimated net impacts assuming nothing else in the economy changes as a result of TRS construction and development activity. For example, we are not considering scenarios where potential TRS displaces other economic activity in the economy. We also assume for this basic example that there are no changes in the percentage distribution of development and capital costs by category between the lower and the higher development scenarios.

Table 3 reveals findings for a Low Development Scenario. As highlighted previously this assumes that a conservative 20 % of the total of capital and development spend is in the local economy. The modelled assessment suggests that the £180m of local spend over a 10-year duration to commissioning creates supply chain and household effects (induced income effects) of £142m in the local economy, would support close to £150m of local gross value added, and support (directly and indirectly) close to 300 jobs a year over the 10 year horizon. These effects are multiplied in the Medium and High development scenario. Table 3 in the final two rows also hints at related impacts on the Rest of the UK (RUK) economy using the framework of UK Input-Output tables[3] to gain estimated economic effects. We accept uncertainty in these estimates, but the basic modelling reveals that the local purchasing propensity of projects will be important in determining local economic effects. This would also suggest that small increases in the local purchasing propensity of TRS projects could garner significant increases in local economic impacts.

Second, and implicit in the above example is that the construction of TRS may require relatively (compared to other renewable technologies) higher levels of local and UK sourcing of goods and services, and indeed assembly of components locally close to construction sites. So, for example, existing studies have highlighted the potential for tidal range schemes to undertake construction engineering of bunds, gates and caissons close to the actual site of the power generation, and with the largest schemes expected to require turbine development 'closer to home' ([43,66,73,74]). Critically here while schemes in development in the UK might see the capital costs associated with turbines comprising the majority of the total capital costs, there would still be a requirement for more local economic activity to support the development of public realm and surface works, bund/caisson construction, associated pre-casting yards, power housings, gates, craneage and construction of sluice gates.

Table 4 reveals the major expected cost categories - assuming here the dam enclosure is developed on caisson technology and with cost categories largely derived from Ref. [52]. Table 4 then considers the significance of the cost category in the total capital and development cost and whether it is likely goods and services could be sourced in the UK. While, as in many other renewable electricity technologies there is the possibility that the main turbines and mechanical equipment are sourced overseas, the very large civil engineering inputs associated with caisson development, bund construction, sluices etc. would likely be sourced in the domestic economy. It is accepted here that in terms of concrete and associated steel reinforcement the supply chain could be

Table 3
Estimates of local economic effects connected to construction and development phase of TRS: Welsh economy example.

£m 2023 unless otherwise stated	250 MW-Low	750 MW-Med	3000MWHigh
Capital costs	**900**	**2400**	**8500**
Estimated development and construction stage years	10	13	16
Local shock 20 % capital and development spend	180	480	1700
Supply chain impact in Wales	89	238	843
Induced income effects in Wales	53	141	498
Total output supported	**322**	**859**	**3043**
Direct value-added impact in Wales	81	216	765
Total value-added impact in Wales	**150**	**400**	**1415**
Direct employment impact (full time equivalent employees - FTE)	1530	4080	14450
Total employment impact (FTE) over construction and development phase	**2876**	**7670**	**27166**
Average local employment over development and construction phase (FTE)	**288**	**590**	**1698**
Rest of UK economic effects			
RUK shock 50 % capital and development spend	450	1200	4250
RUK output effects (supply chain only)	819	2184	7735

Table 4
Key expected cost categories for TRS and expected purchasing propensity.

Component/cost category (note)	Proportion of capital cost	Expected UK sourcing potential
Turbines and mechanical equipment	High	Low
Generators, switchgear and transformers	High	High
Associated installation and transport of above	High	High
Turbine caissons inc. powerhouse & gantry cranes	High	High
Sluice caissons, gates and cranes	High	High
Plain caissons	High	High
Embankment works	Low	High
Dredging for caisson foundations	Medium	Low
Caisson towing, installation, fit out	Low	High
Lock construction and installation	Low	High
Onshore works; access roads and sub station	Low	High
Grid connection and related	Low	High
Project development and consents/ certification	Medium	High
Mitigation and compensation costs	Low	High

Note: Component categories based on material from project developers.

[3] See https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed.

overseas, but the actual building activity might possibly be undertaken close to sites for cost and logistical reasons (and such that advantage can be taken of tight weather and tidal windows in the construction and commissioning process).

Third, while prior analyses have focused on the very limited supply side in the UK for high value components going into renewable electricity projects [25,53,75], there is some expectation that projects of the scale (see above Tables 1–3) of potential TRS could work to fundamentally change the supply side of a local economy as supply chain businesses relocate to areas where there are significant tidal resources or, as importantly, local firms seek to diversify to meet the needs of the projects.

Fourth, the nature of the construction and engineering process attendant on developing TRS might yield more local benefits actually deriving from the long-term nature of the process. While there have been several attempts to scope and understand the expected development and construction phases of TRS and effects on employment and gross value added [76–79] there has been less focus in reports on potential process benefits i.e. long term supplier development and upskilling, training and education benefits of large infrastructure projects and how the TRS development process might create new learning and education networks. This has been shown to be important in other long term physical infrastructure projects such as roads [80]. Indeed, in understanding the economic effects of TRS proposals it is likely that inference is better drawn not from other renewable electricity technologies but rather from large scale international schemes in terms of pumped storage and hydro-electric where there have been seen more significant impacts during development phases [81–83] and indeed general infrastructure development.

5. How might local economic activity be supported during operations of TRS?

Following construction and commissioning the expectation with TRS is for a relatively long operational phase covering as much as 120 years [84,85], and with this long operational phase coupled to very high initial capital costs [86] being one barrier to development particularly in terms of securing private finance capital, and with the long time period between development and commissioning placing a high degree of risk onto any private developer. There is some uncertainty around both the detailed categories of TRS operational spending, and with uncertainty around major maintenance turnarounds on different elements of the turbine and associated infrastructure. Also it is difficult to make broad assumptions on operational spending because the schemes outlined in Table 1 would be expected to vary considerably in operational costs in respect of the different maintenance turnarounds and the different requirements for specialised services such as dredging. Operational spending profiles are likely to be quite lumpy because of this. The approach in previous analyses is often to assume that operational spending represents some arbitrary fixed percentage of the capital funding [66,87]. For illustration we adopt a similar rationale below i.e. basing the example on assumptions on operating cost per annum as a proportion of total capital and development spend.

Table 5 again provides a Wales-based example. The data sources are the same as used to develop the material in Tables 2 and 3, but here the focus is on the scale of operational spending. Appendix 2 provides more detail on the assumptions, but again here the Table is used to show the expected magnitude of annual effects in the Welsh economy example. Here in the medium development scenario operational costs per annum are estimated at 1.25 % of total capital and development costs.[4] Average annual operational spending is then around £30m and with 75 % assumed to be spending in the Welsh economy. This higher proportion than that assumed in the construction phase is based on a stronger Welsh supply side available in services such as maintenance, dredging, financial services and inspection/environmental services. There are also local wage effects here connected to those directly employed on schemes with, for example, Scheme B medium scenario directly supporting an estimated 193 FTE jobs pa in the operational phase, and then 332 once account is taken of multiplier (supply chain and household spending) effects in the Welsh economy. The point being made here is that such TRS projects would have potential to create employment opportunities in the local economy with the nature of operational spending targeted on sectors where there is a local supply side.

Table 5
Estimates of local economic effects connected to operational phase of TRS: Welsh economy example.

	Scheme A Low	Scheme B Medium	Scheme C High
Installed power capacity	250 MW	750 MW	3000 MW
Potential start date	2034	2040	2047
General assumption on operational lifetime	120 years	120 years	120 years
Estimated total scheme cost (development and construction) £2023	£0.9bn	£2.4bn	£8.5bn
Annual operational costs as a % of capital investment	1.50 %	1.25 %	1.00 %
Operational and maintenance costs (average annual £2023)	£13.5m	£30.0m	£85.0m
Operational spending in the Welsh economy £2023 (see assumptions Appendix 1) pa	£10.1m	£22.5m	£63.8m
Total output supported in Wales including supply chain and household income effects £2023 pa	£16.8m	£37.4m	£105.8m
Total value-added impact in Wales pa £2023	£8.2m	£18.3m	£51.8m
Direct employment impact in Wales pa FTEs	86.9	193.1	547.1
Total employment impact in Wales pa FTEs	149.4	332.1	940.9

Annual operational costs as a percentage of total capital costs based on a range of estimates from developers. Operational costs are subdivided into key cost categories including turbine, sluice, bund/caisson maintenance; dredging; financial and public services; direct employment and inspection/environmental services. These spending categories are treated as demand shocks to regional sectors including utilities, construction, transport, financial services, public administration and professional services.

By way of broad comparison here onshore wind is a useful example. The nature of operational spending with onshore wind tends to preclude any significant local economic effects with schemes monitored discretely and maintained by roving teams of engineers [22,25]. Local spend is then largely restricted to rates and community benefits. In terms of offshore wind, the evidence suggests rather more local economic activity is supported through the operational phase because of increased needs for inspection and with employment supported in ports and on inspection vessels, and indeed in new port infrastructure to support such activities [16,28].

However, in the case of TRS the key categories of operational spend are expected to link through to a higher level of local purchases, for example in terms of sluice maintenance, bund/dam maintenance,

[4] See Ref. [66] Vandercruyssen et al. (2023); in their tidal range cost model they have an assumption that operating spending is 1.5 % of the total capital spend per year over 40 years; we vary this assumption across our low to high development scenarios i.e. 1.5 % falling to 1.0 % in the high scenario; there are expected to be some scale economies according to size of scheme).

dredging, insurance and rates, inspection and environmental protection costs, and then payments to staff employed by the developer/owner [66,74,76,88]. Given that TRS entails enclosing large bodies of water and with some planned schemes close to centres of population, then there is some expectation of high levels of employment being supported per installed MW compared to other selected renewable electricity technologies [25]. Our broad conclusion here is that during the operational stage of TRS that schemes could support relatively higher levels of local employment and activity when compared to other renewables such as on/offshore wind, and solar PV. The nature of new employment creation is an unknown. However, Severn Estuary Commission (2025) suggests main distribution of employment during the operational phase of TRS would be in manufacturing, utilities, wholesale and retail, accommodation and food, professional and technical, administration and support services [14]. One might then expect skills development in terms of engineering maintenance, monitoring, but also tourism-facing industry skills (see below).

6. Would TRS be connected to more significant tourism effects?

Research in the UK has considered the impacts of renewable electricity generation on local tourism. Much of this has focused on the impacts of onshore and offshore wind, and with concerns about depreciation of landscape value on tourism revenues [61,89]. Tourism growth has been identified as a possible future benefit in the literature examining prospective operational tidal lagoon/barrage schemes. The reasons for this include such factors as amenity and recreational changes creating opportunities for increased tourism visitation, and then with spillovers to increased spend and employment opportunities in the given locality [53,90,91]. Moreover, selected of the schemes outlined in Table 1, for example at Swansea in West Wales (see further below), include specific plans for enclosed lagoons to be used for leisure use. Contrastingly, and to a lesser extent, there have been arguments raised that tidal lagoon schemes may act to the detriment of tourism in an area [90,91] and with perhaps fewer visitors attracted to a locality as a result of reduced opportunities for activities such as recreational angling following changes in fish movements and nature tourism, or following impacts on other wildlife environments, such as bird patterns [90].

So significant are expected effects in this domain, for example, that *The Environmental Impact Assessment Scoping Report* for the proposed Cardiff Tidal Lagoon [92] set out a methodology of measuring negative tourism impacts through the identification of existing major tourism attractions in the area, the likelihood of each being impacted by the scheme, and the effect on the local economy if an attraction were to close as a result of the scheme.

One of the ways in which tourism benefits are understood in the literature is in terms of impacts on local spending with associated impacts on local gross value added (a measure of the value of goods and services produced in the economy), and job creation - as visitors may be attracted to the area by amenities such as a purpose-built infrastructure-related visitor centre. The *Severn Tidal Power Feasibility Study* [93] identified a range of possible tourism impacts of an energy scheme visitor centre associated with a variety of proposed tidal barrages and tidal lagoons in the Severn Estuary between England and Wales - with the visitor centre having the potential to attract new visitors into the region as a tourist attraction in its own right. Here, it was estimated that the benefits to the regional economy, resulting from the visitor centre, could be as high as an extra £27m with an additional 130 in employment following the development of a large barrage between Cardiff and Weston-super-Mare. Hendry [74] noted that La Rance, France attracts between 40,000 and 70,000 visitors per year and Annapolis, Canada drew 40,000 visitors annually to a visitor information centre.[5]

Further tourism benefits raised in the literature include opportunities for multiple use of space. Neill et al. reviewed plans for a proposed tidal lagoon in Swansea Bay, noting that the location could become a larger hub for boating, and arts, cultural and sporting events [43]. Studying the same location, Jones and Munday [53] observed that an operational TRS project could support tourism in Swansea and surrounding areas and represent an important addition to visitor facing infrastructure in South West Wales and estimated that weekend national sports events held at the site could potentially draw 6,000 to 8,000 visitors per event.

The review here then suggests that compared to other renewable electricity generation technologies TRS might have more significant effects associated with additional tourism consumption at a location. Associated here could be that large scale infrastructure of a unique architectural aspect may be recognisable on a global as well as a local scale [90]. This could then be helpful in the re-branding of an area to a wider audience, with associated competitive advantages, as location branding has repercussions for individual decisions to visit, move to, or invest in an area [94]. It has also been argued that urban brand value can significantly impact the psychological non-monetary or non-material satisfactions of local residents [95]. Indeed, while not used for power generation, the Cardiff Bay Barrage that enclosed a very large waterbody in South East Wales has been important in rebranding of the South of the city and is associated with new investment into the area [96].

7. Other developmental outcomes

The review has focused on spending effects linked to TRS leading to employment and economic development opportunity. This is not to discount other economic effects. For example, a further potential developmental benefit of tidal range energy schemes could be education and learning benefits. In their paper considering the auxiliary opportunities that tidal range projects can offer besides energy production, Petley et al. [90] outline aspirations for a Merseyside, England, barrage scheme encompassing a world centre for hydropower research – bringing together academic research, and creating collaborative working opportunities with global institutions, as well as offering public education.

Besides being energy producing schemes, selected tidal barrages and lagoons have the capacity of multi-functional infrastructure acting to provide flood mitigation [90,97,98] although it has been argued that, historically, the potential for tidal barrages playing a strategic role in flood defence and transportation planning has been inadequately addressed [99]. Prime et al. [100] concluded that tidal lagoons and barrages may present flood risk benefit and could combine with other local strategies to reduce flood risk in coastal areas (see also 98). However, tidal range schemes providing flood protection can also lead to limited localised increase in flood risk outside the impoundment [1,100]. Hammond et al. indicate that a proposed tidal barrage from Cardiff to Weston-Super-Mare in the UK may offer flood alleviation benefits to low-lying areas of the locality - although these were expected to be marginal to the economic case for its construction ([73], see also [101]).

There are connections between flood risk/coastal defence and economic benefits from property values and reduced insurance. For example, an analysis of the economic impact of a potential tidal

[5] The decision was taken in 2021 to shutdown the Annapolis Tidal Generating Scheme after owners Nova Scotia Power decided that further investment at the site would be halted after rising costs, an electrical failure, and a notice issued by Fisheries and Oceans Canada on 1 April 2019 that continued operation would require authorization under the Fisheries Act. Source: https://www.offshore-energy.biz/north-americas-oldest-tidal-power-plant-set-for-closing/.

impoundment project in North Wales, UK, noted that coastal areas on the existing railway line route between Crewe to Holyhead would gain from the proposed energy infrastructure's ancillary role as a sea wall flood defence [102]. General literature (non-tidal lagoon/barrage energy specific) on the property price impacts of the construction of flood defences, indicates that prices effects may vary considerably. The building of flood defences can result in prices of urban houses in the locality increasing by 12.6 %–16.7 % [103].

Benefits to transportation in the area of proposed tidal energy projects are also important [104]. The Tidal Range Power Station at La Rance in Brittany (France) includes a road connection over the water body. Hendry notes the prospective site at Morecambe and Duddon Bay, UK, had the potential to create 5 GW of power, while "*incorporating dual carriageways, providing improved connectivity and transport*" [74]. Petley et al. [90] note a proposed monorail system, as part of plans for a Mersey Barrage in the UK, providing links to extant railway networks, as well as a new commuter route connecting Liverpool and the Wirral. Neill et al. also comment that the Annapolis Royal Generating Station, Canada, provided a key transport link for the area [43].

8. Conclusions

The purpose of this review was to consider whether tidal range schemes could have significant effects in terms of local economic development. Fig. 2 provides a summary of the review findings and then the policy implications discussed later in this section.

While large-scale TRS are expected to be evaluated in terms of their role in efficient power generation, the review and associated examples reveal that there could be significant local economic development returns from the infrastructure development which are not always evidenced in the case of other renewable technologies, at least in the UK. Then while analyses of potential TRS renewables electricity generation in the UK has rightly prioritised the potential role of schemes in reducing carbon emissions, and proving a route to reliable electricity, this review suggests that due consideration needs to be given to a wider set of local economic effects associated with development.

The development of TRS in the UK will not be without problems see also [8,48,86,105,106]. There are limits in terms of realising benefits in terms of the expected hurdles in projects gaining development consent orders coupled with the challenges of an appropriate subsidy regime and with an early planned project (the Tidal Lagoon Swansea Bay) having faced problems in agreeing an appropriate price for the electricity generated and failing to gain government support [107]. Indeed, Pappas et al. (2025) argue that developing a strong economic viability case for TRS remains a research gap [9]. Expected problems in gaining development consents and the high upfront costs in gaining such consents are one of the reasons why private capital might be wary of funding such projects and with this leading some to conclude that TRS development will have to involve public-private partnerships. Investment and relatively high levels of risk have been independently identified as the most significant obstacles for ocean energy developers [49]. For example, ORE Catapult (2024) have suggested that due to the upfront capital costs of tidal range schemes and here including significant costs occurring prior to DCOs being gained, that public-private partnerships are necessary such that public sector investors develop the lagoon infrastructure (and with this aligning with public sector objectives such as flood protection, preserving biodiversity) while the private sector invests in the electricity generation assets [108]. Here then public ownership in terms of leading on the lagoon infrastructure could lead to the prioritisation of local employment creation during the capital development phase. Others have concluded that public-private partnerships in TRS development are only needed until development consent orders are obtained, and that the private sector might be more willing to commit capital when permissions to build are in place.

The review also suggests that even in more disadvantaged economic areas that TRS could bring a higher level of supply chain development opportunities than is the case with other renewable electricity technologies. Critical here are the construction engineering aspects of projects which entail a measure of assembly and manufacture closer geographically to where the electricity is actually generated. In getting schemes underway more value would be added to construction activity close to the site of the power generation than would be the case with renewables technologies such as onshore wind, and the reviewed material and economic modelling suggests that the operations of the power generation infrastructure might support significant levels of employment during the relatively long operational phase.

Local economic development gains from energy infrastructure development are rarely automatic. In some parts of the UK where there has been significant renewable electricity capacity already developed, there has been pressure for developers to make as much use of local suppliers and subcontractors as possible, or to package contracts such that local firms are encouraged to bid for work. In regions such as

- **GEOGRAPHY**: Renewable electricity generation technologies often located in more needy parts of the UK economy.
- **IMPACT**: Local economic impact of schemes is typically focused into the shorter construction and development phases.
- **IMPACT DRIVERS**: links to local purchasing patterns and the underlying ownership of the schemes (locally owned or otherwise).
- **TRS IMPACTS**: potential for higher level of local economic benefits due to future project scale, local purchasing patterns, length of the construction process, supply chain development, tourism impacts, local area branding, and environmental effects that could lever further economic returns (flood defence and coastal resilience).
- **POLICY**: Leveraging socio-economic returns from TRS will not be automatic; challenges to better integrate non-price factors into subsidy frameworks and development consent orders.
- **FUTURE**: Progression of TRS expected to require public-private partnerships due to the risk profile of projects, and with public involvement a further means of leveraging local economic returns.

Fig. 2. Main findings. Tidal Range Schemes and Local Economic Development.

Scotland and Wales the devolved governments have encouraged higher levels of local involvement in the ownership of schemes partly in the expectation that this might increase the involvement of local firms in development processes around renewables [71,109].

In terms of government support in the UK for renewables there has to date been limited moves to explicitly link the availability of subsidies to socio-economic outcomes in areas surrounding the electricity generation infrastructure. Clearly, the regulatory framework in terms, for example, of contracts for difference around renewables are a UK-wide issue and with devolved governments (Scotland and Wales) having limited scope to modify these processes such that projects which promise more local economic benefits are somehow more favoured in the subsidy and support process. Indeed the objective of the subsidy regime is focused on growing low-carbon electricity generation, and with the expectation of longer-term economic benefits deriving from the operating infrastructure. Then it is expected that it is the UK Government which has more scope to influence the scale of local economic benefit corresponding with the construction process and operations of TRS. In this respect prior reviews of renewables development have revealed the importance of the quality of institutional governance between governments and market supporting institutions being critical in renewable transitions not least in supporting investor confidence [110]. While the predominant Contract for Difference subsidy process in the UK focuses on price there is scope within such frameworks to build in non-price factors such as community and supply chain benefits. Indeed there has been a UK Government recent call for evidence on this very issue on introducing non-price factors into the Contract for Difference scheme [111,112]). However, to leverage or guarantee greater local economic returns from TRS it is also likely that the established contract for difference subsidy framework might not be fit for purpose. For example, Severn Estuary Commission cited that: “Related to contractual requirements, many stakeholders indicated that mechanisms such as Contracts for Difference (CfDs) would likely deliver lower levels of UK content than desired due to a significant focus on price, as well as wider challenges related to project risk” [14]. Then the established CfD framework might also not attract sufficient private capital because of the high upfront development and capital costs and the high risk that this places on the TRS developer [108]. Indeed recent research around UK TRS options has suggested a Regulated Asset Base model might be most appropriate such that the developer is able to lever financial gains prior to commissioning of a power plant (the approach taken with the Sizewell B Nuclear facility in the UK). Here then more risks are placed on the consumer. However, where consumers and government pick up more of the developmental risk there may be more scope to build local content and skills development conditions into agreements [113].

At the time of writing the UK has a new Labour Government committed to rolling out more renewable energy generation infrastructure with aims to flex the planning system to encourage development and support local employment and supply chains. There is as yet little clarity of how far tidal range schemes will feature in the vision for Great British Energy,[6] but this review suggests that among available renewable electricity generation technologies, tidal range schemes might score relatively well in their ability to support local and national industry and support local employment in more needy parts of the economy. There remain challenges to more effectively linking social, economic and trade outcomes to the evolution of public subsidies towards supporting emerging renewable electricity generation technologies.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Max Munday reports financial support was provided by Engineering and Physical Sciences Research Council. Reza Ahmadian reports financial support was provided by Engineering and Physical Sciences Research Council. Nathan Formosa reports financial support was provided by Engineering and Physical Sciences Research Council. Karen Turner reports financial support was provided by Engineering and Physical Sciences Research Council. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. Literature review method

There was a semi structured literature review to support the development of this paper. Elements of the literature (particularly in terms of UK policy papers, UK policy background) reviewed in this paper were collected/contributed as part of the project TidAl Range schemes as configurable Grid-scale Energy sTorage facilities (TARGET) under a grant from the Engineering and Physical Sciences Research Council (EPSRC), grant number EP/W027879/1.

In addition this review also made use of a structured search methodology using:

Google Scholar database where search terms used included “Tidal Range Scheme”, “Socio-economic development” and “Tidal energy”. A custom date range of 2010–2025 was set, and the preliminary number of articles found was 17,600. These were ordered by “relevance”, and then the first 200 articles were examined for direct importance as papers of interest– here abstracts, highlights and the articles themselves, if required, were read when a judgement of direct relevance could not be made from the title alone. Filtering out papers that were deemed non-relevant left a total of 21 papers of interest.

Science Direct database. Search terms used included “Tidal Range Scheme”, “Socio-economic development” and “Tidal energy”. A custom date range of 2010–2025 was used for the papers and a total of 2211 initial articles were found. These were ordered by “relevance”, and then the first 200 articles were examined for direct importance as papers of interest– here abstracts, highlights and the articles themselves were read when a judgement of direct relevance could not be made from the title alone. Filtering out papers that were deemed non-relevant left a total of 11 papers of interest.

Finally, we employed Elicit AI Research Assistant query to draw on a more varied range of sources. The Elicit app searches across over 126 million academic papers from the Semantic Scholar corpus. The research questions to help with the academic paper search were input into the application as follows: “Might Tidal Range Schemes change the local economic impact dial on renewable electricity generation? How far might tidal range schemes represent a local economic development opportunity, and with many of the planned projects in the UK close to areas of socio-economic need?” The application subsequently found 498 articles deemed most relevant to the query.

[6] See https://great-british-energy.org.uk/.

Sources that met the following criteria were screened in.

- Tidal Range Focus: Does the study examine tidal range energy schemes with economic analysis components?
- Economic Impact Scope: Does the study analyse local or regional economic impacts using quantitative or qualitative indicators (e.g., employment, GDP, business development)?
- Geographic Relevance: Is the study conducted in a coastal region where tidal range schemes are technically and economically viable?
- Publication Type: Is the publication either a primary research study with empirical data or a systematic review/meta-analysis of tidal range economic impacts?
- Stakeholder Inclusion: Does the study include analysis of stakeholder perspectives (community, business, or government) on economic development impacts?
- Publication Format: Is the full text of the publication available?
- Economic Focus: Does the study include more than just technical engineering analysis?
- Energy Technology Focus: Does the study specifically focus on tidal range energy rather than other renewable energy technologies?

A total of 40 papers were included for extraction and analysis, of which 11 were identified directly relevant. (Some papers in the 40 had already been identified via the initial Google Scholar and/or Science Direct searches).

Appendix 2. Local Purchasing Assumptions underlying Economic Modelling in Table 3

Construction and development cost category	Estimated % of total capital and development costs	% of spending in Wales	Basis of assumptions and sectors shocked in economic model of Wales
Preliminary development costs	c. 5 %	50 %	Assumed to be a demand shock to Welsh sectors including professional and technical services, engineering services and design, real estate/rental services.
Constructions cost (bund and/or caissons and associated)	c. 15 %	40 %	Represents the main expected public realm and surface works including bunds and/or caisson construction. Assumed elements of this activity will occur close to development site. In the economic modelling treated as a shock to the demand for goods and services from the construction and mineral products sectors.
Turbine core capital costs	c. 50 %	0 %	A large proportion of the total capital costs. Prior analysis of energy projects in the Welsh economy [25] reveal very limited supply side here and assumed this would represent spend in the rest of the UK or overseas economies from where products imported.
Turbine are works and civils	c. 20 %	30 %	Would include elements such as powerhouse, sluices, gates, craneage. Supply capacity available in Welsh economy. Assumed for economic modelling to represent a demand shock to sectors such as fabricated metal products, machinery, construction and installation.
Other expected project costs	c. 10 %	50 %	Expected to embrace wider public realm around projects, visitor infrastructure, grid connections etc. Assumed for economic modelling to represent a demand shock to sectors such as fabricated metal products, machinery, construction and installation
Identified operational cost category	**Estimated % of total operational costs**	**% of spending in Wales**	**Basis of assumptions and sectors shocked in economic model of Wales**
Turbine maintenance	10 %	0 %	Little capacity in Wales expected rest of UK or overseas contractor **machinery**
Sluice maintenance	10 %	100 %	Wales-based contractor, assumed to be annual shock to construction sector
Bund maintenance	10 %	100 %	Wales-based contractor, annual shock to construction sector.
Dredging	10 %	100 %	Wales based contractor assumed. Demand shock to shipping services.
Insurance and rates	30 %	50 %	Welsh spending assumed to be shock to financial services and public administration (rates).
Direct staff employed by developer	25 %	100 %	Wages and salaries largely to local people assumed to the utilities sector
Inspection/environmental	5 %	100 %	Wales based spending assumed as a shock to engineering services and testing sector.

Appendix 3. The Welsh Input-Output model

The local economic multiplier effects of the scenario TRS projects were estimated using the framework on input-output tables for Wales. This framework is based on the assumption that new economic activity in Wales can have economic impacts, according to the level and nature of related spending and how that spending links to other parts of the Welsh economy. To examine the economic significance of a tidal range scheme it is important to differentiate between the direct and the indirect economic consequences (see Fig. 1 in main paper).

Direct consequences are those associated with the activity itself, usually expressed in terms of outputs (or turnover), gross value added and jobs. Here then the scenario tidal range projects could be associated with different amounts of capital spending through the construction and development period.

These direct economic impacts are a part of the economic impact. Direct spending associated with a TRS would have indirect consequences according to how monies are spent locally. The project developers could buy as inputs some of the outputs of other Welsh industries, such as electricity, professional services, security etc. This local purchasing then leads to further local spending and so on. These ‘supplier’ effects then depend on the level of local sourcing for the particular sector and on levels of regional sourcing by its suppliers etc.

This ‘supplier’ effect is just one element of local economic effects. In addition the employment supported directly and indirectly by the TRS adds to local household incomes and some of these incomes are also spent locally, and this adds to local economic effects. Similarly, regional suppliers to the TRS also add to local incomes, as will their suppliers etc. These are called ‘induced-income’ effects and when added to ‘supplier’ effects they form the total indirect consequences of the direct regional economic activities, which can be expressed in terms of spending, incomes and jobs.

To estimate these indirect or multiplier consequences a model of the regional economy that shows how the various sectors fit together in terms of their trading relationships is required. This then allows the effects of activity in one sector to be traced through the entire local economy. In Wales there are a developed framework of Input-Output tables which can be used for this analysis, such that the material in Tables 3 and 5 makes use of output, value added and employment multipliers to establish relationships between estimated TRS capital and operational spending and then wider Wales-level impacts in terms of employment, value added and output supported. Further information on the Wales Input-Output tables is available in Jones et al. (2022) [70].

The Welsh Input-Output tables have been used in prior studies to estimate the effects of different types of renewable energy technologies on the Welsh economy [25,34,52,53].

Data availability

The authors do not have permission to share data.

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