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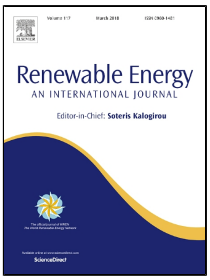

Environmental interactions of tidal lagoons: a comparison of industry perspectives

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Title

Environmental interactions of tidal lagoons: a comparison of industry perspectives

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Highlights

1. The lagoon industry is collectively working towards a good environmental outcome
2. Mismatches in views arise in the detail of impacts, benefits and solution options
3. Understanding behind the differing developer and influencer views is presented
4. It is recommended that lagoon-specific regulatory policy is introduced

Abstract

Tidal lagoons are an attractive renewable energy option that could aid the UK in meeting its ambitious renewable energy targets. One of the main barriers to tidal range development in the UK to date has been regulatory environmental concern. In order for the nascent lagoon industry to move forward into development, the views of the developers and other influential stakeholders such as government bodies, regulators, conservationists and practitioners (herein referred to as 'influencing stakeholders' or 'influencers') need to be aligned. This study is the first of its kind using online questionnaires and semi-structured interviews to present and compare the views of both developers and influencing stakeholders on the environmental interactions of tidal lagoons. We find that, whilst both influencers and developers are working towards the common goal of a good environmental outcome for tidal lagoons, there are mismatches in their views in terms of the priorities given to the key environmental impacts, benefits and potential solution options. The work provides insight into what is at the forefront of developers' and influencers' minds, highlighting the key themes within their views and transforming this information into policy recommendations that will help the industry's development move forward.

Keywords

Tidal lagoon, environmental impact, mitigation hierarchy, tidal range energy

1. Introduction

The deployment of renewable energy is regarded as a strategy to combat climate change through the displacement of fossil fuel energy sources and therefore the reduction of carbon emissions. There have been a number of global agreements aiming to mitigate the impact of climate change, the most recent being the 2015 Paris Agreement. To date, 114 of 174 parties have signed this historic agreement and begun to adopt climate change strategies into their own national agendas [1]. Nationally, the UK has a target to provide 15% of its energy needs from renewable sources by 2020 [2]. There needs to be an increase in the rate of deployment of renewable energy in the UK if it is to achieve this target within the next 3 years. Under 'business as usual' conditions it will fail to achieve this target [3].

There are a variety of renewable energy options that the UK could deploy to meet these ambitious targets. Often overlooked is the vast amount of marine energy available around the UK coastlines, the majority of which is currently untapped. This article focuses on tidal lagoon energy as part of the marine energy sector; Figure 1 shows a breakdown classification of marine energy and how tidal lagoons are placed within this.

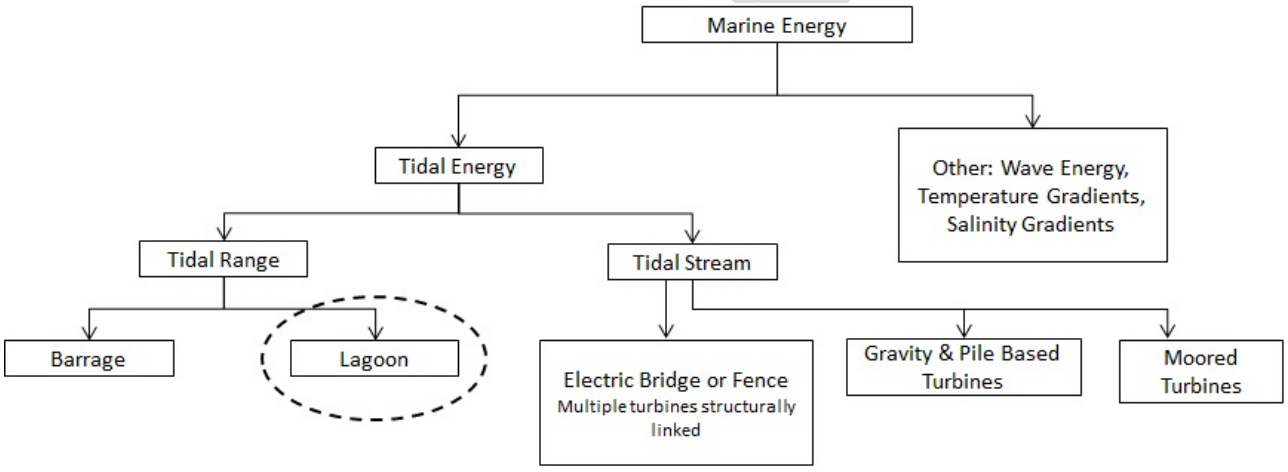

Figure 1: Marine Energy Classification. Source: [4]

Tidal range technologies harness the energy available in the rise and fall of the tides. Traditionally tidal range energy consists of tidal barrages and tidal lagoons. A tidal barrage typically extends the banks of a river or estuary, whilst a tidal lagoon forms a loop attached to one side of an estuary or is completely offshore [5]. Figure 2 shows a basic sketch describing this difference

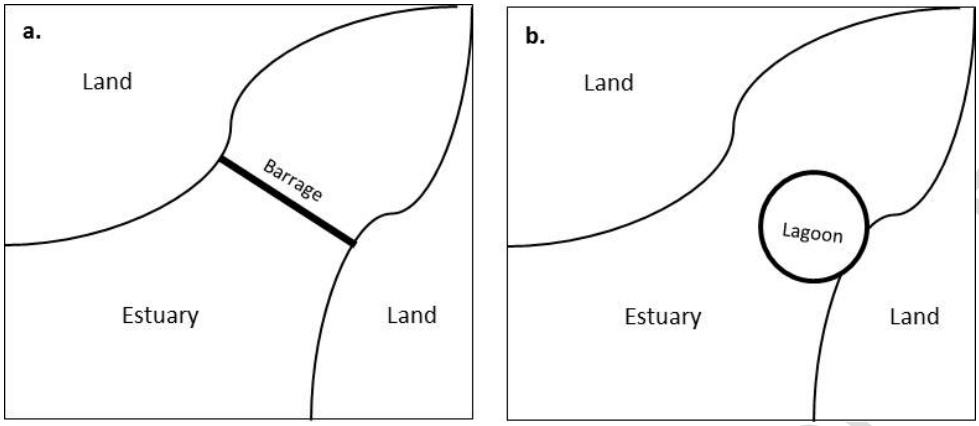

Figure 2: Basic difference between a tidal barrage and a tidal lagoon, both of which provide tidal range energy

Tidal range schemes, including both barrages and lagoons have a theoretical resource potential of 121 TWh/year in the UK [6]. To put this into perspective, in 2015 the UK produced 339 TWh of electricity [7]. In theory, although not necessarily in practice, tidal range schemes could contribute up to 36% of the UK's electricity production, with lagoons contributing 7.4pp, of that figure. Tidal Lagoon Power Ltd, one of a number of companies investigating options for tidal lagoon development, has a framework plan for the UK to develop a fleet of 6 tidal lagoons. It is estimated these could contribute 8% to the UK's total electricity supply [8].

Lagoons therefore have the potential to contribute significantly to the UK's electricity mix. They also have a number of other advantages in terms of their energy production, including a high level of predictability, the differing times of tides around the UK allowing a phase shift for continuous energy generation and a long expected life span (120 years) [9].

Despite these advantages, there is currently no energy generating tidal lagoon in the world. The main barriers to date have been a lack of serious proposals, high capital costs and environmental concerns. There is now a serious proposal, with Tidal Lagoon Power presenting the first of their tidal lagoon developments: Tidal Lagoon Swansea Bay. Swansea Bay was awarded a Development Consent Order (DCO) in June 2015 [10]. The costs of lagoons were investigated in a government commissioned review considering the overall feasibility of lagoons for the UK energy market. This review, published in December (2016), concluded that lagoons did have a cost effective role to play in the UK and recommended that a focus should be on a small pilot scheme initially with sufficient time to allow for environmental monitoring [11]. Whilst tidal lagoons have previously been presented as a more environmentally friendly alternative to barrages [12], the environmental impacts of lagoons are still a concern for the industry, as highlighted by the recent government review [11]. As such, environmental concerns are likely to present additional hurdles in the industry's future development. Consenting and licensing issues are often seen as cross cutting barriers to marine energy [13]; an example in the lagoon industry is the current delays being seen in awarding of a Marine License to the Swansea Bay Tidal lagoon.

Whilst progress has been made in identifying and estimating the potential environmental impacts of tidal range projects, such as the hydrodynamic changes [12–17], morphodynamics [18, 19] and water quality [20, 21], ecological interactions with society [12] and environmental interactions with each other [4], there has been little focus on the industry's view of these environmental impacts. These key environmental changes noted in the literature will have multiple associated environmental, societal and economic implications. Whilst these are too many to document here some examples include; coastal erosion or sediment deposition, increased flood risk, extensive habitat or biodiversity loss, displacement or injury to marine mammals, damage to fish populations, damage or displacement of bird populations, impacts for local marine industry and recreation, impact on underwater marine heritage and changes to local water quality including potential impacts on the water table. Mackinnon, et al (2016) [4] describes a framework to identify and further understand the complex interactions between the environmental impacts of tidal lagoons.

The tidal lagoon industry is in its infancy; there is therefore little tidal lagoon specific research to date and hence finding information through direct industry engagement is appropriate. An additional implication of the nascent lagoon industry is the lack of tidal lagoon specific environmental regulatory guidance. This could present a further issue unless clear communication between influential stakeholders such as government bodies, regulators, conservationists and practitioners (herein referred to as 'influencing stakeholders' or 'influencers') and developers is undertaken and respective views understood.

In order for the sector to move forward in a sustainable and timely way it is therefore essential that the influencer and developer perspectives on the environmental impacts of lagoons are aligned. This will reduce any potential delays in the development process and provide the best chance for future tidal lagoons to contribute positively to the environment through an effective balance of positive and negative impacts (net gain). This study is the first of its kind, analysing the differing views of influencing stakeholders and developers within the nascent lagoon industry, providing understanding of why these views arise and how awareness of them can aid with the industry's future development.

Whilst there are tidal barrage developments elsewhere in the world [24,25], the UK is making significant progress in the lagoon sector, building on its desirable resource potential and recent industry advancements. This study therefore focuses on the UK tidal lagoon industry, and as such, on associated UK developers and influencers. The paper presents an assessment and comparison of the current influencer and developer views on the environmental impacts of tidal lagoon developments in the UK. It has three initial objectives:

1. Survey the views of professional individuals within government, regulatory, conservation, policy, think-tank and practitioner roles(referred to as the 'influencers') on the environmental impacts, benefits, challenges and key outcomes of tidal lagoon developments, through an online questionnaire.
2. Ascertain the views of key individuals within the development industry (referred to as the 'developers') on the environmental impacts, benefits, challenges and key outcomes of tidal lagoon developments, through semi-structured interviews.
3. Compare and contrast the views of the influencers and the developers.

Doing this, we find areas of consensus between influencers and developers and areas where different placements of priorities have been given. We find that whilst influencers and developers agree on a broad level that lagoons should work towards achieving a good environmental status, the details on achieving this outcome presented some contrasting views. The study highlights the main barriers and challenges still facing influencers and developers and outlines how information provided by their views can be used to determine policy and regulation that can stimulate further development of the sector.

The next section describes the methodology used to address these objectives, with the key results of the study highlighted in Section 3. These are discussed in detail in Section 4 with the paper concluding with a set of recommendations in Section 5.

2. Methods

2.1 Data Collection

The data collection consisted of web-based questionnaires for influencers and semi-structured interviews for developers. Due to the infancy of the industry and therefore relatively small pool of potential participants, the focus of the engagement was on including all of the relevant participants within key industry organisations rather than obtaining a large sample size of non-relevant participants.

The questionnaires included a mix of closed and open questions and were conducted using an online survey tool 'Typeform' [26]. The questionnaires targeted individuals in decision making roles and focused on obtaining a range of different government (33%), conservation (19%), regulatory (29%) and practitioner (19%) organisations, referred to in this paper as the influencers. Participants were sent an email with the questionnaire link and a cover letter explaining the research objectives. An email reminder was also sent following initial contact. The questionnaire received a 51% participant response rate, with a total of 24 individuals from 21 different organisations participating (see Table 1). This response was deemed sufficient to allow for descriptive analysis and conclusions to be drawn.

In order to gain a deeper insight into the industry perspective, semi-structured interviews were conducted with developers. The semi-structured interviews consisted of a select few open questions to guide the participants towards particular topics (Table 2), but no other direction was given. Interviews were conducted face to face or via Skype. Participants were sought from tidal lagoon developers in addition to related industries, such as tidal barrages, tidal fence or bridges and hydroelectric projects. Each interview was recorded and later transcribed for analysis. A total of 8 developers from key organisations participated in the interviews (see Table 1).

The data collection consisted of two different methods for influencers and developers. Questionnaires were deemed suitable for influencers given the higher number of participants from a range of non-lagoon specific backgrounds. Interviews as opposed to questionnaires were appropriate for developers given the smaller number of participants and the specific and detailed sector knowledge that they have. The data was collected differently and as such has been analysed differently to reflect this. Whilst the different methods may pose differences in the results, the general perspectives of both the influencers and developers were obtained and these general perspectives are what is being compared

Table 1: List of participating organisations

Influencer Participant Organisations
BMT Group
Centre for Environment, fishing and aquaculture science (Cefas)
Energy Technologies Institute (ETI)
Environment Agency
Jersey Government (States of Jersey)
John Muir Trust (JMT)
Lloyds Register
Marine Management Organisation
Marine Scotland
Natural England
Natural Resource Wales
New Economics Foundation
Ofgem
ORE Catapult
Scottish Government
Scottish Natural Heritage
Sustainable Energy Authority of Ireland (SEAI)
The Carbon Trust
The Crown Estate
The Wildlife Trusts
Welsh Government

Developer Participant Organisations
Tidal Lagoon Power Ltd
North Wales Tidal Energy
North West Energy Squared
Electric Mountain
Solway Energy Gateway
Wyre Tidal Energy
VerdErg
Cardiff University – Associated with Severn Barrage

The participants were asked to answer questions in their professional opinion and not on behalf of the organisations they are employed within. Due to the infancy of the lagoon sector many organisations do not yet have a standard stance or practice for lagoons. Therefore by selecting individuals in key decision making roles within relevant organisations the collected data provides the best representation of the industry's current perspectives on tidal lagoons. For privacy reasons, the identities of the questionnaire and interview participants are not disclosed.

2.2 Data Analysis & Presentation

Software QSR NVivo 10 was used to code the interview transcripts and open ended questionnaire responses [27]. Coding is a method of qualitative data analysis, where passages of text are assigned a code-label relating to a particular theme or topic, and passages with the same label are judged to be of the same topic. This method allows patterns to be identified within qualitative data [28]. Some code-labels were pre-determined based on previous questionnaire topics and literature review (A priori codes) [29]; others were developed based on the new findings arising within the data itself (grounded theory) [29].

Descriptive statistics such as percentage distributions were used to analyse the closed question data and subsequently the coded qualitative data from the interviews and open ended questions. It was not deemed appropriate to use more rigorous statistical analysis given the exploratory nature of the research and the lack of an empirical hypothesis to validate [30]. Reflecting the analysis, the results are presented as percentages; either as percentage mention, percentage selecting, or percentage participants to mention.

Table 2 shows a summary of the questions asked, the type of question and how the results have been analysed and presented.

Within the questionnaire there were a number of multiple choice questions, the options of which were developed around information obtained from a general literature review. The code-labels for the solutions or the categories are very broad and encompass many different individual solution strategies and as such need further explanation. Table 3 provides definitions of the multiple choice options where the meanings are not immediately obvious, in addition to definitions and examples for the broad solution categories.

Table 2: Summary of the methods, including data collection, analysis and presentation

		Collection, Analysis and Presentation of Data							
		Question Asked		Question Type		Data Analysis		Data Presentation	
		Interview (developers)	Questionnaire (influencers)	Interview	Questionnaire	Interview	Questionnaire	Interview	Questionnaire
Engagement Topic	**Outcome**	If you had to say the project had one goal, mission or priority outcome, what would you say that was?	Of the outcomes below, please select one which you believe to be the most important for future tidal lagoon developments. [1]	Structured	Multiple choice[1]	Coded response to question	Number of options selected	% mention	% to select
	Impact	What do you consider to be the top three environmental impacts?	What do you consider to be the top three most significant direct environmental impacts of tidal lagoons?[2]	Structured	Multiple Choice[2]	Coded response to question	Number of options selected	% mention	% to select
	Benefits	Participants spoke freely about the benefits	Other than low carbon electricity and the direct economic benefits, what would you consider priority opportunities that a tidal lagoon could offer?	Non-structured	Open ended	Coded benefits section of transcripts	Coded question responses	% mention	% mention
	Solutions	Participants spoke freely about solution options	Please select ways in which environmental impacts could be addressed through technological or environmental solutions.	Non-structured	Open ended	Coded solutions section of transcripts	Coded question responses	% participants to mention	% Participants to mention
	Challenges & Developer Focus	Participants spoke freely about industry challenges. They were also asked: "suggest how the regulatory process could be improved"	In your professional opinion, where should developers be focusing to reduce the environmental impacts posed by tidal lagoon developments?	Non-structured	Open ended	Coded challenges and improvement sections	Coded question responses	% Participants to mention	% Participants to mention
	Participant Background or Role	Participants spoke freely about themselves	What broad category would you place your current role into?[3]	Non-structured	Multiple choice[3]	Coded introductions	Number of options selected	% local connection	% to select

[1]High public acceptance, good environmental status, speedy deployment, maximising public goods and services, reliable supply of electricity, cost competitiveness of produced electricity, providing resilience to climate change, reliable technology.

[2]Sediment regime alteration, changing hydrodynamics, restricted passage and migration, blade interaction with marine life, noise and vibration, introduction of invasive species, benthic habitat loss, other.

[3]Engineering, environmental, technological, policy, financial, socio-economics, other.

Table 3: Definitions and examples of multiple choice options needing further explanation and solution categories requiring more background information

Topic	Option Choice	Definition/Examples
Outcome	Good Environmental Status	Reducing environmental impacts and enhancing benefits as far as possible to achieve the best environmental status
Outcome	Maximizing Public Goods & Services	Providing services or goods through the development of the lagoon in which the general public would benefit from e.g. leisure and recreation, area regeneration, positive aesthetics
Impact	Restricted Passage and Migration	Restricting any migratory route or passage of any species of fish or marine mammal
Impact	Introduction of invasive species	The accidental introduction of a non-native species through development of a lagoon or the 'natural corridor' effect that the lagoon might have, connecting different habitats to each other and allowing the movement of species into habitats that they would not normally reside in
Solution	Engineering Design & Technology	Any solution mentioned that is related to changing the initial engineering design or the choice or design of the technology itself with the view to avoiding environmental impacts. E.g. Turbine blade number, shape of the lagoon wall, material used for the wall, built in additional habitats etc.
Solution	Operation & Maintenance	Any activity undertaken after the construction phase which attempts to reduce or restore environmental impacts e.g. Zonation activities based on breeding seasons, temporarily pausing generation to allow species migration, manipulation of the water levels within the basin for environmental benefits such as flood control rather than purely for energy generation.
Solution	Compensation & Catchment Measures	Any activity based on compensation or offsetting of impacts through the use of offsite areas. E.g. habitat creation or restoration, Payment for Ecosystem Services (PES) schemes, catchment management measures.

3. Results

The results provide an insight into what is currently at the forefront of the influencers' and developers' minds, regarding the environmental impacts of tidal lagoons. We will discuss participant backgrounds, lagoon outcomes, impacts and benefits and finally solution options and further industry development in that order.

3.1 Participant Background

In order to understand the industry's perspective on environmental impacts of tidal lagoons, it is first important to consider the angle from which the participants are coming. Figure 3 shows how influencers categorised their current role. Of the influencers who participated, 67% are from either an environmental or policy role, with the remainder residing in technological or socio-economic categories.

The review of developer backgrounds shows a pattern of strong local connections between developers and the local area of the proposed or planned project or development, with over half of the developers mentioning this local connection whilst introducing themselves in the interviews. It was often the case that the developer organisations were formed from locals, local business people or local forums, as opposed to large multi-national organisations which is often the case in other energy sectors. An example

here is Wyre Tidal Energy which was formed by three local business-men passionate about the local area of Fleetwood and its regeneration [31].

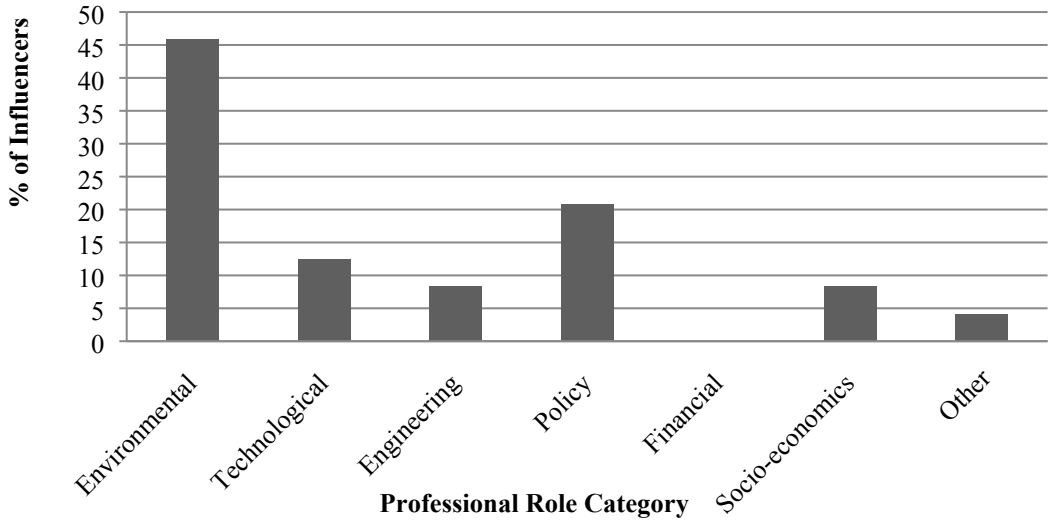

Figure 3: Influencer's professional backgrounds displayed as percentage number of influencers

3.2 Priority Lagoon Outcomes

Participants were asked about which outcomes they believed to be a priority for a future tidal lagoon development (Figure 4). Influencers selected 'Good Environmental Status' and 'Cost Competitiveness' as the key outcomes. 'Good Environmental Status' here is defined as reducing the environmental impacts and enhancing environmental benefits where possible[1].

For developers, 'Area Regeneration & Wealth' received the highest percentage mentions with 'Reliable Electricity Supply' and 'Good Environmental Status' in joint second. Neither influencers nor developers considered 'Speedy Deployment' as an important outcome at the time of engagement. There are other differences seen here, for example, with 'Cost Competiveness' and 'Reliable Technology' showing different levels of priority for influencers compared to developers.

Figure 4 shows what influencers believe to be the key outcomes based on their respective professional backgrounds (stacked bars). We can see from this that the majority of participants selecting a good environmental status are from an environmental background and that participants with technology, policy or socio-economic backgrounds found cost competiveness a key priority outcome.

[1] This is not related to the Marine Strategy Framework Directive (MSFD) which defines 'Good Environmental Status' differently [38].

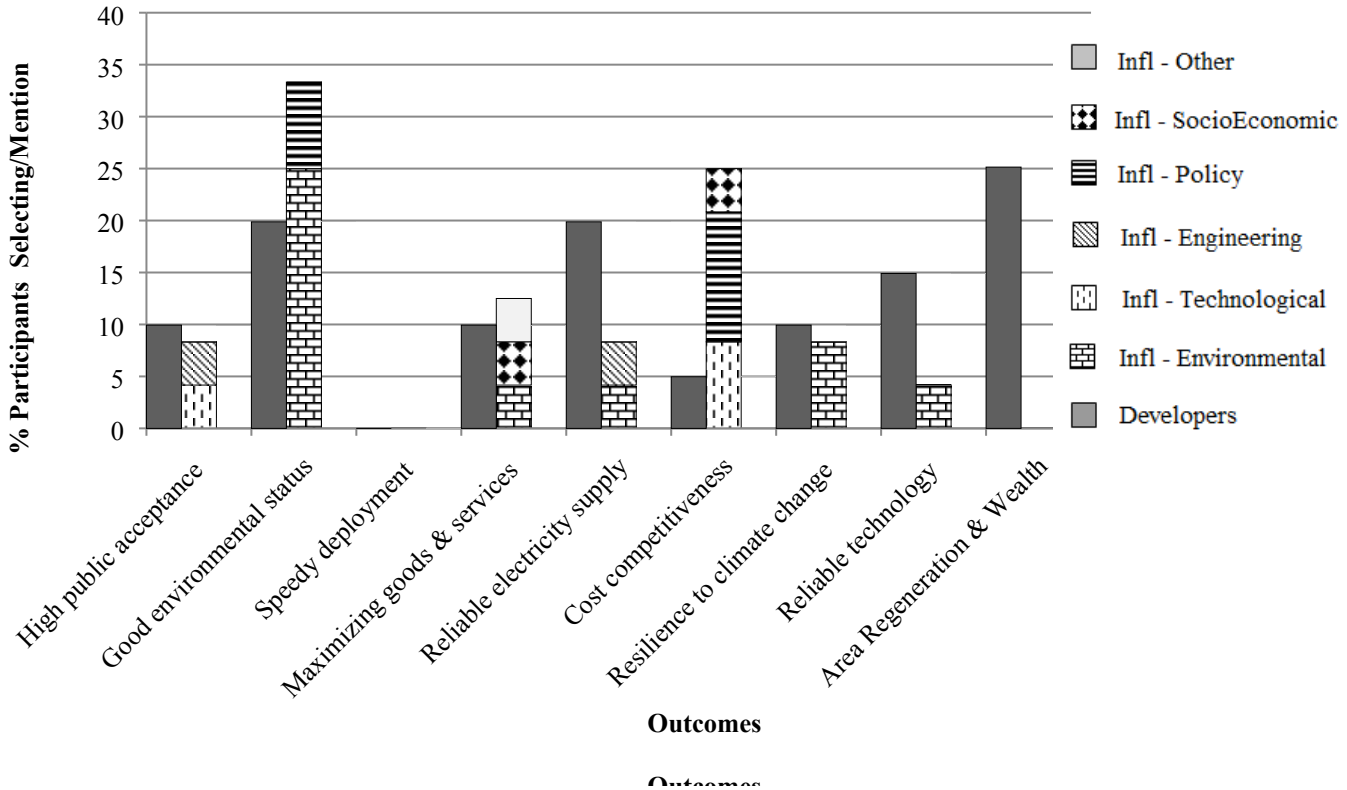

Figure 4: Participants desired outcomes for future tidal lagoons. Developers and Influencers shown, with influencers shown as stacked bar representing the different professional background categories

3.3 Environmental Impacts & Benefits

Whilst both influencers and developers agree that a 'Good Environmental Status' is a priority outcome for tidal lagoons, it is important to further understand which specific environmental impacts and benefits are underlining this outcome and how the regulator and developer views compare on these specifics.

Figure 5 shows what participants believe to be the top three environmental impacts of tidal lagoon developments. The top two most significant impacts in the view of both the influencers and the developers are 'Sediment Regime Alterations' and 'Changing Hydrodynamics'.

Developers and influencers selected different options for their third most important impact. Developers believe that 'Water Quality' is the third most significant impact of lagoon developments, whilst influencers selected 'Restricted Passage & Migration' for that position. Although the two impacts are linked, 'Water Quality' was not mentioned at all by influencers (a box for 'Other' impacts was provided in the questionnaire), despite it being in the top three environmental impacts for developers. Whilst influencers placed more weight on 'Restricted Passage & Migration', developers still had this impact in mind, with it lying in fourth position in terms of its significance as an impact.

Participants were asked what they deemed to be the priority opportunities a tidal lagoon could offer aside from low carbon electricity and any direct economic benefits (Table 4). Influencers' most mentioned benefits include 'Flood Defence & Control', 'Habitats & Biodiversity' and 'Leisure & Recreation'. In contrast, developers most mentioned benefits were 'Area Regeneration & Socio-economics', 'Local Employment' and a 'Local Economy Boost'. These benefits were also areas of high percentage difference in mention between influencers and developers (green cells Table 4). This further suggests that influencers and developers have different priorities when considering the benefits of tidal lagoons. Benefits which had little to no difference in the percentage mention (red cells Table 4), suggesting an overall consensus in the priority given to them by influencers and developers include 'Base load potential', 'Multiple use opportunities', 'Tourism' and 'UK image'.

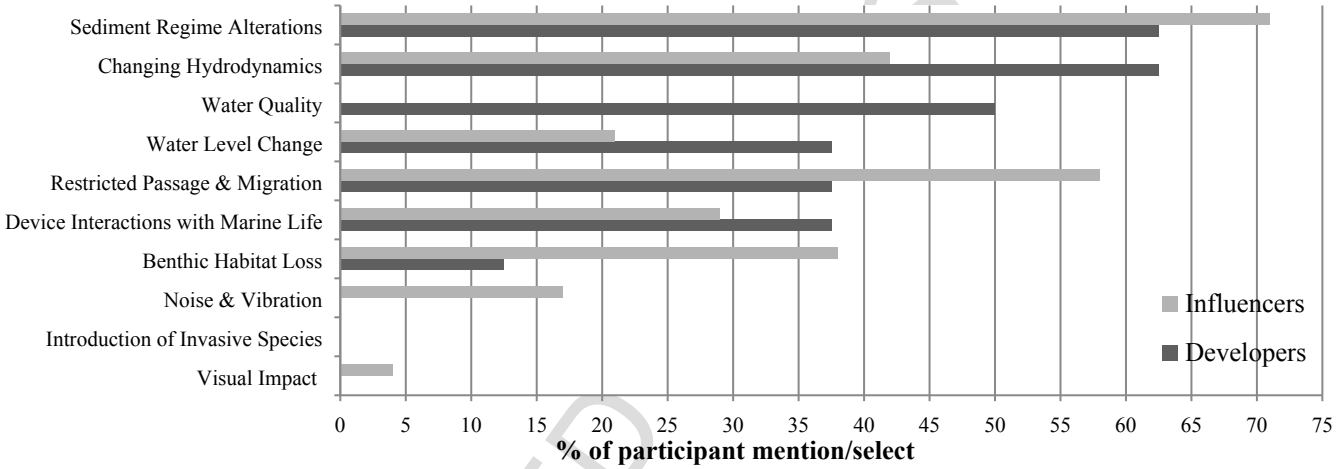

Figure 5: Participants key environmental impacts of tidal lagoon developments

Table 4: The benefits of tidal lagoons as % mention by developers and influencers. Colour is assigned to the highest % mention for each benefit between influencers and developers, i.e if the colour is on developer side then developers mentioned this benefit the most. The actual colour depends on the scale of this % difference, (Green = ≥5% difference in % mention, Amber = ≥2 % ≤4 %, Red = <2%)

Benefits	% mention Influencers	% mention Developers
Area Regeneration & Socio Economic Benefits	6	14
Coastal Erosion Protection	8	4
Community Share	2	4
Education & Research	5	7
Energy Base Load	3	4
Export Opportunities	3	4
Flood Defense & Control	16	9
Habitat Biodiversity	14	6
Leisure & Recreation	13	4
Local Economy Boost	3	9
Local Employment	3	11
Multiple Use	6	6
Renewable Energy Acceptance	6	0
Supply Chain	3	5
Tourism	6	7
Transport & Connectivity	0	5
UK Image	3	2

3.4 Impact Solutions

Environmental impact solutions can be grouped into three broad categories; 'Engineering Design & Technology', 'Operation & Maintenance' and 'Compensation & Catchment Measures' (see Table 3 for further definitions). Both developers and influencers were asked about what the potential solutions could be to addressing environmental impacts, and the responses are summarised in Figure 6.

Due to the infancy of the lagoon sector the solution options identified by participants (both developers and influencers) were often around transferable solutions from other industries. For example under engineering design there are multiple strategies, one example of which is using ecological criteria in the building design, such as the rock pools built into Sydney Harbour wall [32]. Numerous operation and maintenance strategies arose throughout the engagement with both influencers and developers; these were largely based around the pausing and restarting of generation depending on important ecological seasons, temporal or spatial zonation of activities and control of in-basin water levels for environmental gains. Measures based around habitats and biodiversity creation and restoration were mentioned by both influencers and developers for the compensation and catchment based measures solution option.

Overall developers had a broader view of the potential solution options than influencers, demonstrated by the larger triangle of representation in Figure 6. All of the developers interviewed mentioned some form of solution under the 'Engineering & Technology' category, with 75% also mentioning a 'Compensation & Catchment Measures' solution. These two categories were also identified by influencers, 67% of them mentioning a solution in both 'Engineering design & Technology' and 'Compensation & Catchment Measures'. 'Operation & Maintenance' was mentioned the least by both influencers and developers, with 50% and 22% mentioning them respectively.

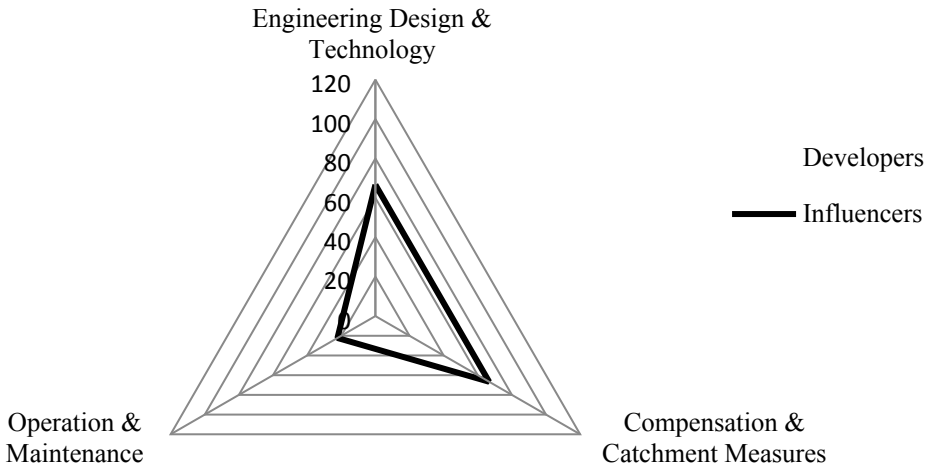

Figure 6: Developer and influencer suggested solution options for environmental impacts grouped into three broad categories and presented as % participant mention

3.5 Further Industry Development

Influencers were asked to suggest areas in which developers should be focusing their efforts to reduce environmental impacts of tidal lagoons. A variety of suggestions arose; however, a clear theme relating to location developed with 29% of influencers suggesting a focus on site selection to avoid impacts in the first instance. Of equal focus (29%), influencers wanted to see developers focusing on the issues of intertidal habitat loss.

When developers were asked what they believe to be the key challenges in the industry 33% mentioned finding a suitable site. Whilst influencers wanted to see a focus on site selection, developers believe this to be one of their key challenges. Other key challenges for developers were found to be lack of

information and experience in the lagoon sector, maintaining interest in lagoons as a form of energy generation and securing funding.

When developers were asked specifically where improvements could be made in the regulatory process, 50% stated that clearer more accessible lagoon-specific policy or guidance was required, with 63% suggesting a reduced process time for consents.

4. Discussion

The industry is collectively considering achieving a 'good environmental status' as the lagoon sector begins its development. Whilst both the influencers and developers are working towards this outcome, previous research has yet to explore whether their views on the details of the environmental impacts of lagoons are aligned. Aligning their views on these details such as the key impacts, benefits, solutions and key challenges would allow for a smoother transition from lagoon planning to development and towards achieving a good environmental status in future lagoons. This study provides the first step towards achieving this industry aim, by identifying the views of the influencers and developers, considering the areas of contrast and consensus and providing recommendations on how to move the industry forward in light of this information

The priority outcomes selected by influencers and developers reflect their likely key objectives. For example the nature of an environmental influencer's role in the industry is to protect the environment, where as a developer is most concerned with generating a reliable and predictable supply of electricity and to obtain the associated revenue. Many developers also have strong local connections to the area of a development and as such their priorities with local area regeneration and wealth is also not surprising.

'Speedy Deployment' was not a priority for influencers or developers at the time of engagement. It is clear that other outcomes are a priority for tidal lagoons at this stage. This is surprising given the current urgency towards transitioning to a low carbon economy. There is also a risk that ocean energy will not be sufficiently mature before that capacity is taken up by other forms of renewable energy, hence the need for a speedy deployment should not be overlooked. The relative infancy of the lagoon sector and the fact that there has yet to be a single tidal lagoon development in the world could provide the reasoning behind the lack of priority on speedy deployments. The consensus suggests that it is better to go slow with the first development and ensure that other higher priority outcomes are achieved first and foremost to bolster investor certainty and set a sustainable precedent for future tidal lagoon development.

This is further reinforced by the solution options participants are considering. Developers are currently concerned largely with the engineering design and environmental solution options, whilst influencers are considering the future compensation considerations should lagoons be constructed. Neither party in the industry is yet in the position where they are prioritising operation and maintenance strategies. This does not mean to say that considering these strategies early on would not be advantageous in allowing the maximum environmental net-gain in future lagoons to be achieved. It is therefore a recommendation that further focus be placed on these strategies to reduce the shortfall currently seen in the industry.

The environment is at the forefront of both influencers' and developers' minds in terms of a priority outcome for lagoon developments. However there are also a number of other outcomes seen as priorities by the industry. It is vital that whilst the industry strives towards a positive interaction with the environment it does not lose sight of a lagoon's primary purpose; to generate low carbon electricity at a cost competitive rate. In addition, whilst there will be a number of local environmental impacts, there is an overarching environmental benefit which should not be forgotten; that tidal lagoons are contributing towards tackling global climate change.

4.1 Impacts & Benefits

An ecosystem is a complex web of interactions amongst the living (biotic) and non-living (abiotic) environment. Any environmental impacts of a tidal lagoon will therefore have a complex impact on inter-tidal, marine and terrestrial ecosystems. It will also have knock-on implications for the wider environment, people, society and economics. In this sense, determining the top three environmental impacts allows us only to scrape the surface of this vast web of interactions. However, there is use in asking influencers and developers to consider the top three, as this shows us what impacts are currently being focused on in the industry, and therefore in practice

Sediment regime and hydrodynamics are seen as key abiotic drivers of an ecosystem, this may suggest why they have been selected as key impacts by both developers and influencers. These impacts also interact with each other, with changing hydrodynamics influencing the sediment regime and a change in the seabed morphology as a result of sediment regime change influencing the local hydrodynamics. These impacts are also well studied [14–21], which could explain why they are at the forefront of the industry's mind. Or perhaps that is why the impacts are well studied; because the industry has been placing a focus on them. Never-the-less, this does represent an area of consensus between influencers and developers.

Conversely, the impact of 'Water Quality' represents an area of differing prioritisation amongst developers and influencers. This was a key impact raised by developers and was not mentioned directly by influencers. This question to influencers was a multiple choice question in which 'Water Quality' was not an option, although an 'other' box was provided for influencers to raise the issue this style of questioning may have resulted in the differences seen. The water quality impact here is related to the entrapment of water in a basin, which may also entrap pollutants, similar to the eutrophication issue previously seen at Sihwa Barrage [33]. This impact could potentially be worsened by run off from surrounding land. It could be that the influencers who were questioned are not aware of this issue, or, that they do not consider this issue to be of higher concern than the other impacts. Influencers did consider 'Restricted passage and migration' as a key issue, which can be linked to issues of water quality; this may also explain the difference seen in prioritising key impacts.

Environmental impacts can be categorised into knowns, known unknowns and unknown unknowns [4]. All of the impacts in this engagement have to be knowns or known unknowns, and the uncertainty surrounding impacts may have been one of the factors influencing participants' choices. The engagement work cannot take into account the unknown unknowns and these will only become apparent if a tidal lagoon is given the go-ahead, in which case careful monitoring will be required.

Often overlooked, tidal lagoons will also have a number of positive environmental impacts or benefits, and therefore beneficiaries such as people, society and the wider environment. The key benefits mentioned by influencers and developers were different and as such would have different beneficiaries. Developers mentioned key benefits where the beneficiaries will mostly be the local area, the local economy and the local people. In contrast, the influencers' priority benefits provided a spread of beneficiaries across society, the local ecosystem and individuals.

This result can partly be explained by the participants' backgrounds. Over half of the developers had local connections to the area of the project or development they were associated with; it is not surprising then that they chose benefits that would ultimately provide opportunities for the local area and its community. In addition, local benefits are likely to increase local support for a project, reducing public opposition. As influencers are not necessarily linked to an individual project's locality, they are more likely to take a more holistic view and consider the wider potential benefits of a project.

If the positive environmental impacts can outweigh the negative for a particular development then an overall net gain can be achieved for society in terms of the overall impact a lagoon might have on the environment. For this to be achieved a holistic approach needs to be taken with the wider implications and beneficiaries of both impacts and potential solution options considered. Environmental impacts can be described, appraised and valued [34] then incorporated into economic appraisals to allow developers to find a financially and environmentally effective means of providing environmental net gain that goes over and above regulatory requirements.

4.2 Solutions & Industry Development

Environmental impact solution options are often applied working down the mitigation hierarchy (Figure 7). Within this, avoidance of an impact is addressed first, then reduce, restore and finally looking to offset as a last resort. Arguably, what is missing from this list is to enhance potential environmental benefits, and for a project to leave a lasting 'net gain' legacy. There are a number of solution options within these hierarchy steps (Figure 7) and for simplicity they were grouped for the study into the three broad categories: 'Engineering Design & Technology', 'Operation & Maintenance' and 'Compensation & Catchment Measures'.

Both influencers and developers are considering solutions at the top end of the mitigation hierarchy in terms of the avoidance of impacts through engineering design and technology choice. There is yet to be a lagoon developed and so it is understandable that the industry is looking to avoid as many impacts as possible in the first instance through these solutions. Given the relative infancy of the industry, the majority of work to date has been on the engineering design and technology planning and so this might explain the large percentage of industry participants mentioning these solution options, in particular the developers.

Alongside this, site selection as another avoidance strategy is also being taken into consideration by all of the participants. Influencers believe developers should place more focus on this, whilst developers consider choosing a suitable site to be one of their biggest challenges. An issue arises here in that the areas with the best tidal range often provide a unique habitat to be protected e.g. the Severn Estuary [35],

therefore selecting a site that has the best resource for energy generation and that also avoids sensitive habitat is a challenging endeavour. Conundrums like this allow for other solutions further down the mitigation hierarchy to come into play.

The results suggest that the industry is considering either avoiding impacts or compensating them via strategies such as changing lagoon wall design, turbine technology or habitat creation. The middle section of the hierarchy to 'reduce' and 'restore', for example through operation and maintenance strategies, is not being highlighted as a focus in the industry's minds at the time of engagement. This could represent an area where further research is required to fill the gaps in the solution options being considered. Further attention on the reducing and restoring strategies such as 'Operation & Maintenance' would allow a full mitigation hierarchy of solutions to be provided to the industry, thereby reducing the environmental impacts of tidal lagoons as much as possible. An example of potential operation and maintenance strategies that could address the key environmental impacts of hydrodynamic and sediment regime changes are managing ebb and flood generation times and considerate dredging techniques.

The scope within solution option 'Compensation & Catchment Measures' is wider than the suggestions arising from participants or by this study thus far. There is an opportunity here to consider innovative solutions such as Payment for Ecosystem Services (PES) for example. Incorporating the benefits these solution options might have in terms of enhancement over and above that of regulatory requirements for the environment, society and the economy would allow for a stronger case for tidal lagoons in the future. A vital avenue for further research is therefore the consideration of the overall environmental and economic benefit of differing solution options that will allow for the largest positive net gain in future tidal lagoons to be realised.

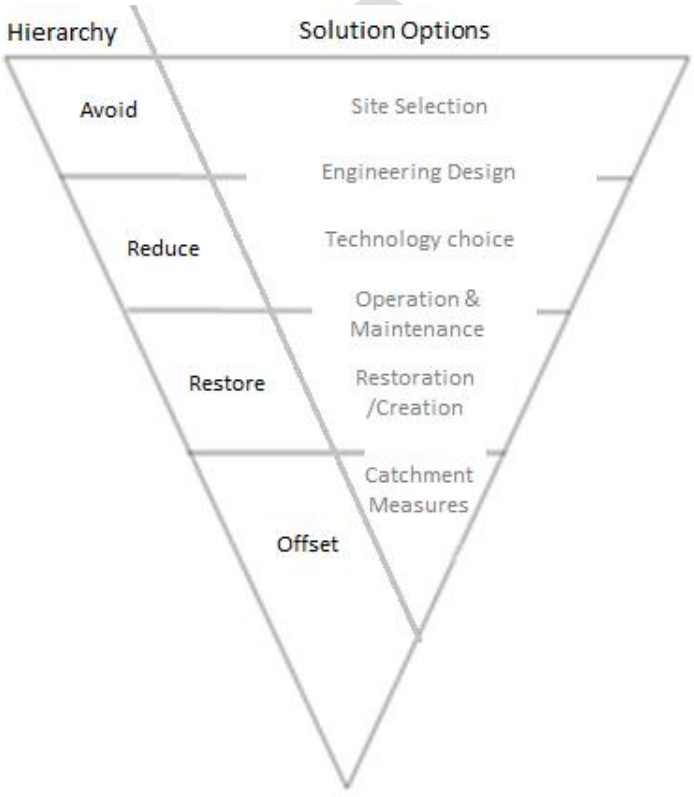

Figure 7 : Mitigation hierarchy for environmental impacts. Hierarchy adapted from source: [39]

One of the key requirements for the industry's development is that influencers and developers work together to move forward through the planning and regulatory process ensuring that lagoons are developed efficiently and sustainably. The key challenges in the industry include a lack of clear and accessible guidance available for developers, in addition to lengthy regulator processing times.

The infancy of the industry means that to date there is no specific lagoon guidance and instead the industry relies on adapting guidance from other sectors. If lagoon-specific guidance were to be developed this would provide certainty of information to developers and indeed the influencers themselves, in addition to reducing regulatory process times. Clarity and consistency of specific guidance may also reduce the costs often associated with the requirements of a precautionary approach to development as suggested in the Ocean Energy Forum's Strategic Roadmap [13]. It is essential that any lagoon-specific guidance is set up prior to the first lagoon project; this ensures that the process is in place to support the industry through the development process.

Lack of industry experience and information is an issue, for developers and for influencers. Developers have no blueprint of plans to work with in development and influencers lack the evidence they need to ensure compliance with legislative regimes and environmental directives. This issue will improve with time and thorough monitoring will allow for updated and enhanced regulatory guidance and smoother developer deployments. It will also provide opportunities in terms of exportable skills, experience and information as the world's first movers in the tidal lagoon industry.

5. Conclusions & Recommendations

The study presents a first identification and analysis of the regulator and developer views on the environmental impacts of tidal lagoons. Aligning the views of the influencers and developers on this topic is vital to allow for a smooth transition of tidal lagoons from current planning to future development. This study provides a starting point to realising this sector aim.

Both influencers and developers are ultimately working towards 'Good Environmental Status' as one of the priority outcomes for tidal lagoons, and so this provides a foundation of a common goal to strive for. It is important to keep in mind that other outcomes are also of high priority and that the primary goals of a lagoon are ultimately to produce low carbon electricity at a cost competitive rate. In addition, whilst lagoons will have a number of local environmental impacts, it is essential not to forget the overarching global benefit of their potential contribution towards tackling climate change through the displacement of fossil fuels.

Environmental impacts of a lagoon will have complex implications to the intertidal, marine and terrestrial ecosystem in which it is developed [33,36]. The impacts in this study look at the known and known unknown impacts, since the unknown unknowns will only be apparent once a tidal lagoon is operational. 'Sediment Regime Alterations' and 'Changing Hydrodynamics' are at the forefront of influencers' and developers' minds as the key impacts of tidal lagoons. Whilst there is some differences in the priorities

given to 'Water Quality' and 'Restricted Passage and Migration' by influencers and developers, both impacts are considered to be of high priority by the industry as a whole.

A number of key benefits of tidal lagoons were highlighted by influencers and developers. Influencers' key benefits provided beneficiaries spanning the ecosystem, society and individuals whilst developers focused mainly on the benefits to the local area and its people. It is expected that this result is due to the strong local connections the developers have with the local project areas. Effective management of environmental benefits and impacts of a lagoon could result in an overall positive impact on the environment (net gain), that goes over and above regulatory requirements.

The industry is focusing largely on avoiding or compensating impacts through engineering design, technology and compensation measures. There is a short-fall in the focus being placed on restoring and reducing environmental impacts through operation and maintenance strategies and an underestimation of the potential scope of contribution that compensation and catchment based solution measures could provide. In addition, one of the biggest hurdles currently being presented to the industry is the lack of clear and accessible regulator guidance providing a focused connection point between influencers and developers.

The three key recommendations from this paper are as follows:

- Lagoon-specific regulatory guidance or policy should be developed providing clear and accessible information to both influencers and developers to ensure a smooth development of the sector and reduction in regulatory process times.
- Further research should be undertaken into reducing and restoring environmental impacts through the use of operation and maintenance strategies.
- There needs to be further acknowledgement in the lagoon industry of solution options that go over and above regulatory requirements to provide environmental and economic enhancement to achieve overall project net gain. In particular this should be further investigated within the compensation and catchment based solution options.

These recommendations provide a starting point for research that works towards marrying the views of the influencers and developers on the environmental interactions of tidal lagoons. The study provides a snapshot of what is at the forefront of the minds' of key industry participants, highlighting the relevant information that will aid in the industry's development moving forward. Further work building on this study as a platform will contribute towards a smoother transition from lagoon regulatory planning at present to the world's first tidal lagoon development in the future.

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