Tidal energy in Australia – Assessing resource and feasibility to Australia’s future energy mix

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Abstract— **This paper presents an overview and progress of a recently commenced three year project funded by the Australian Renewable Energy National Agency led by the Australian Maritime College, (University of Tasmania), in partnership with CSIRO and University of Queensland. The project has a strong industry support (OpenHydro Ltd, Atlantis Resources Limited, MAKO Tidal Turbines Ltd, Spiral Energy Corporation Ltd and BioPower Systems Ltd) and aims at assessing the technical and economic feasibility of tidal energy in Australia, based on the best understanding of resource achievable.**

The project consists of three interlinked components to support the emerging tidal energy sector. Component 1 will deliver a National Australian high-resolution tidal resource assessment; in Component 2, case studies at two promising locations for energy extraction will be carried out; lastly, Component 3 will deliver technological and economic feasibility assessment for tidal energy integration to Australia’s electricity infrastructure.

The outcomes of this project will provide considerable benefit to the emerging tidal energy industry, the strategic-level decision makers of the Australian energy sector, and the management of Australian marine resources by helping them to understand the resource, risks and opportunities available.

***Keywords*— Tidal resource assessment, tidal modelling, tidal field measurement, technical and economical feasibility, LCOE**

I. INTRODUCTION

Australia is home to some of the largest tides in the world, with tidal ranges of up to 11.8 m on Australia’s north-west shelf. A preliminary study using the National Tidal Centre tidal model shown in the CSIRO 2012 Ocean Energy Report [1] already showed that several prospective sites for tidal energy exist in Australian shelf waters. This includes locations near to demand (Northern Territory Electricity Network) or the National Electricity Market, and remote locations able to serve remote communities, as seen in Figure 1.

The results already demonstrated the presence of high energy densities up to 3.4 MW/m2. However, the model used is too coarse (~10km) to resolve many features of accelerated tidal flow and therefore potentially overlooking yet unknown high energy sites as well as retuning large uncertainties (>50%) for the energy assessment of the known potential sites. It follows that aside from this basic understanding and preliminary estimates of resource at these few locations, knowledge of Australia’s tidal resource and the spatial extent of available resource remains insufficient for prospective tidal energy companies to make informed decisions of the risk for investment in major projects in Australian waters.

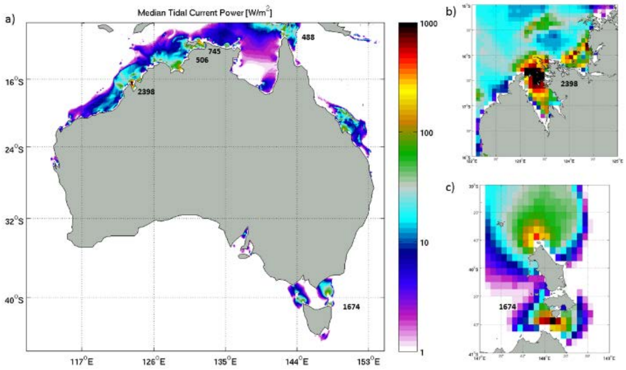

Figure 1: Median tidal current power (1/8° spatial resolution). a) National; b) King Sound; c) Banks Strait. (From [1] *)*

This paper presents an overview of a recently commenced three year project funded by the Australian Renewable Energy National Agency (ARENA) [2]. The project is led by the Australian Maritime College, specialist institute of the University of Tasmania, in partnership with CSIRO and University of Queensland. The project is also strongly supported by the tidal industry, OpenHydro Ltd (a Naval Energies Company), Atlantis Resources Limited, MAKO Tidal Turbines Ltd, Spiral Energy Corporation Ltd and BioPower Systems Ltd, bringing valuable project experience in order to deliver the outcomes. The project will also benefit from collaboration with international researchers from Acadia University, Canada, and Bangor University, UK, both of whom are at the forefront of international research in tidal energy, who will support the project and increase international exposure. Furthermore, the project is followed by an advisory committee which members include representatives from the ARENA, the industry partners and international research collaborators.

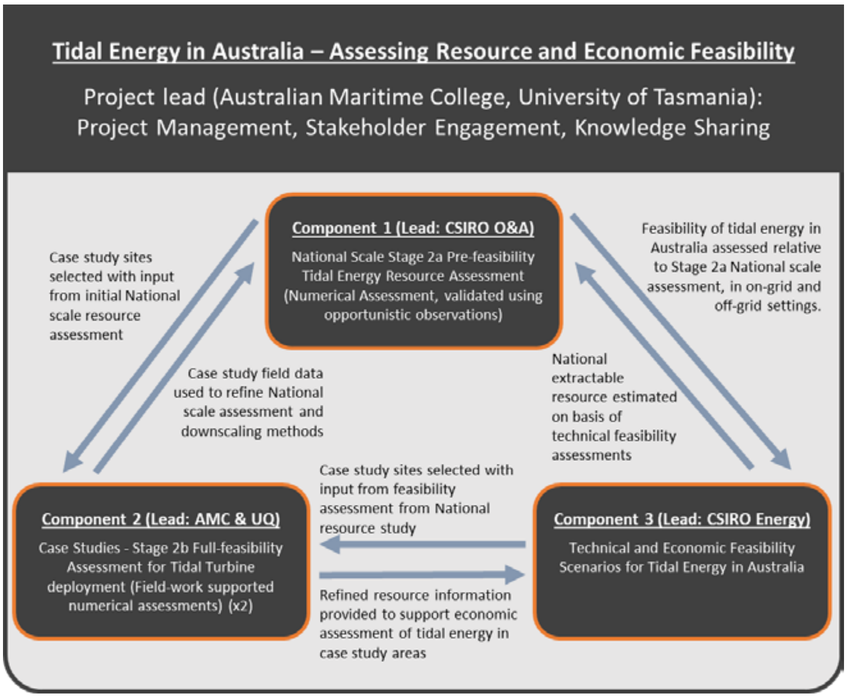

Fig. 2 Project description summary, outlining interdependencies between project components

The aim of the advisory committee is to provide guidance as needed to ensure the project delivers benefits to users and will meet twice per year. Furthermore, a stakeholder workshop will take place in November 2018 to discuss the needs of the different sectors, share outcomes of the project, obtain peer review of project's work and support the delivery of the project objectives.

The project aims at assessing the technical and economic feasibility of tidal energy in Australia, based on the best understanding of resource achievable. It consists of three interlinked components to support the emerging tidal energy sector (as seen in Figure 2). Component 1 will deliver a National Australian high-resolution tidal resource assessment; Component 2 comprises focussed case studies at two promising locations for energy extraction; and Component 3 will deliver technological and economic feasibility assessment for tidal energy integration to Australia's electricity infrastructure.

II. COMPONENT 1

Component 1 will identify nationally attractive tidal energy resource sites, as a contribution to Australia's marine energy atlas through:

- the development of an unstructured high resolution (500 m spatial resolution – Stage 2a assessment, table 1) National scale hydrodynamic tidal model, to quantify national resource and identify most promising regions for tidal energy extraction.
- resource characterisation by tidal energy, amplitude, tidal current velocity and associated kinetic energy, at multiple levels for selected regions
- an open access web-based delivery via the Australian Renewable Energy Mapping Infrastructure (AREMI), alongside Australia's Marine (Wave) Energy Atlas [3].

A. Overview

The primary task of Component 1 will be to develop a national-scale, high-resolution (~500 m in priority areas) tidal model for Australia. This model will be developed using a state-of-the-art hydrodynamic model developed by CSIRO Oceans and Atmosphere (COMPAS – Coastal Ocean Model Prediction Across Scales) and will be used widely for a range of oceanographic applications. The national-scale model will undergo several levels of refinement, with an early available model being used to identify priority locations at which to carry out case study assessments in Component 2 of the project. Large quantities of forcing, calibration and validation data will be compiled, including the assessment of different global tidal forcing models best suited for Australia as well as integration of bathymetric datasets from multiple sources. Field and downscaled model data collected in Component 2 will be used to further refine the national model. Both the opportune data and targeted data provided from Component 2 will be used to validate the simulated tidal flows in the model to ensure accurate, reliable and verified estimates of tidal resource.

Sites of primary interest for tidal energy extraction (i.e., prospective sites for Component 2), will be identified as those locations where the mean annualised power densities exceeded 1.5 kW/m2 and a depth greater than 15 m (e.g., following [4], study for UK waters). [5] defined prospective sites in the Irish Sea based on the magnitude of the peak spring tidal velocities exceeding depth-averaged velocity thresholds of 2.5, 2.0 and 1.5 m/s for 1st, 2nd and 3rd generation tidal energy converters respectively. Similar tidal energy resources with speeds of > 2.5 m/s and mean tidal energy outputs of up to 2 kW/m2 have been identified in Banks Strait north of Tasmania [6].

The national scale tidal model will be validated against the best available tidal current and elevation data. This data will be predominantly opportune data (previously collected) and in-situ data from two high-resource regions (defined by Component 2 of the project). Further in-situ data will be used for validation if available (from interested developers or prior data deployments). The project will follow standard methodologies for assessing resource (e.g., [7]). Archived data from the tidal model will include maps of tidal resource, including spatial maps and data of resource characteristics (mean annualised power, spring power, neap power, spring tidal range, neap range, spring peak flow, neap peak flow, and percent exceedances of 1 and 2 m/s thresholds). Layers and associated data, characterising the tidal resource for each region, will be contributed to the ARENA Wave Atlas (Marine Energy Atlas), served via the AREMI portal. The multiple-use marine layers delivered through the AWavEA project will complement tidal resource layers.

The modelling will enable the spring-neap variability of tidal currents to be determined for priority locations for tidal energy extraction on Australia's continental shelf. This will provide data for developers to assess performance of a given tidal energy device (with given power curve) to determine the performance of their device (capacity factor) for the defined resource. Furthermore, it will provide a dataset from which the potential contribution of tidal power can be integrated into Australia's future energy needs (Component 3 of project). This assessment of Australia's tidal energy resource is required in order to identify the magnitude of the resource and support prospective tidal energy developers in Australia's waters.

B. Progress

A prototype implementation of COMPAS on a national grid has been carried out for the project, having 212686 2D cells, with a minimum resolution of ~54 km and a maximum resolution of ~450 m. The mesh is constructed using a dual weighting function, being a function of both bathymetry and tidal amplitude, to achieve highest resolution in regions of higher interest. A neap-spring simulation has been completed, with ongoing development of COMPAS code (parallelisation), refinement of the model mesh, calibration and validation activities ongoing.

III. COMPONENT 2

Component 2 will characterize candidate sites (energy resource potential, environmental parameters and effects, validation of fine-scale models) through:

- field campaigns to verify two promising candidate sites for tidal energy development. The proposed fieldwork will meet and exceed current international standards for tidal site characterization;
- the site analysis which includes water column flow, tidal range, bathymetry and physical water properties, wind and wave climate etc;
- the development and validation of fine-scale numerical models with respect to amplitude, surface elevation, tidal current velocity and associated kinetic energy, seafloor characteristics etc. at multiple levels for selected regions;
- the calculations of power density, power and resource predictions, and resource extraction effects for general and/or specific TEC devices (and their characteristics) in single and/or arrays;
- the full feasibility study completed with recommendations made for potential sites for device deployment.

A. Overview

Component 2 comprises detailed case studies at two promising locations for energy extraction, involving rigorous field based and high-resolution numerical site assessments. The first site is currently being investigated (Banks Strait, TAS) and one is to be chosen on basis of work completed in components 1 and 3.

Tidal resource assessments will be conducted according to guidelines for tidal measurement to standardise tidal site characterisation outlined in [7, 8]. A set of protocols will be followed and even exceeded to correctly measure, analyse and report the tidal stream at potential candidate sites. Component 2 focusses on Stage 2b with site specific assessments including field studies and high resolution numerical models. Outputs such as power density, power and resource predictions, and resource extraction effects for general and/or specific TEC devices (and their characteristics) in single and/or arrays will be provided. The results will feed back into Component 1 to refine the National stage 2a assessment, and will be used in Component 3 to determine mean annual electrical power, annual energy production and economic benefit analysis. Furthermore, recommendations to device developers based on the findings from the candidate sites could be provided to meet stage 3 (design development) of the EMEC recommendations.

1) Field Campaigns: Two Case Study Sites

The survey of the candidate sites will employ Acoustic Doppler Current Profilers (ADCPs) using several types of Teledyne and Nortek profilers to obtain horizontal and vertical velocity profiles. The ADCPs will be deployed on the seafloor (in > 25 m water depth) and measure velocities throughout the water column, with high vertical resolution (1 m bin sizes) and time average intervals of approximately 5 min. The deployments will be at least one month in duration to capture two full tidal cycles at each site. In addition, ship-mounted ADCP transects will be carried out to record velocities within a 20-30 m range at sampling frequencies of approx. 1 Hz. The combination of bottom-fixed ADCP arrays with transect measurements guarantees a local resolution of tidal currents over a much larger area. This information is paramount for fine-tuning and validating the numerical models to further quantify the dynamics at the test sites.

Wave climate at the field site will be observed with AWACs and ADCPs including wave mode capabilities and pressure sondes attached to the mooring frames to observe the local waveclimate. Wind and atmospheric forcing data (wind speed, wind direction, air temperature, atmospheric pressure etc.) are collected with mobile weather stations that will be deployed close to the test sites for the entire duration of the field campaign.

State of the art high-resolution velocity profilers (Nortek Signature 500 and 1000 instruments will be employed to measure small-scale water velocity fluctuations at frequencies of 8Hz. The information gained from these fast-response current meters is of utmost importance for describing the local turbulence which will be used to estimate the loading on turbine structures and validate fine-scale numerical models.

Conductivity-Temperature-Depth (CTD) casts will be carried out frequently to observe changes in the water column characteristics (temperature, salinity) over hours, days and tidal cycles.

Multi-beam seafloor surveys will be conducted at both sites as a critical component for tidal site characterization with an interferometric ship-mounted system (Bathyswath v.1 234 kHz, ITER Systems). Given the potential differences in water depth, tidal flow and sediment type at the candidate field sites, a variety of sediment characterisation techniques will be available to ensure confidence in the results obtained. Surficial sediments will be collected using a Van Veen sediment grab whilst sediment profiles will be collected using boat mounted or diver operated coring. All these techniques are restricted to relatively shallow water depths and have to exploit tidal windows for sampling. Free fall penetrometers will be used for spatial substrate surveys. In addition to the manual sediment characterisation methods, geophysical surveys across the candidate sites using a sub-bottom profiler (StrataBox HD, Sqywest Inc., Cranston, RI, USA) will provide better understanding of the lower sediment strata.

The use of various-instruments and survey techniques will provide high resolution seafloor bathymetry (at the order of < 5 m horizontally, 0.25 m vertically) to improve the resolution of computational grids of existing and future numerical models. In addition, the obtained seafloor characteristics and also allow for robust estimates of bottom friction coefficients as input parameters. Seafloor and sediment characteristics will support environmental monitoring of renewable energy sites and ultimately environmental impact statements. Furthermore, the seabed characteristics feed into the design development of a full-scale turbine.

The final stage of tidal site assessment is only completed once the exact location of TEC installation is known. This includes deployment of a minimum of two ADCPs to measure and record water velocity constituents for a minimum of 3 months. In addition, the bathymetry should be defined at a resolution of less than 5 m and detailed information about the seabed condition is required. The numerical model should also include the effects of device installation within the grid and the effects this will have on the velocity field. Although the identification of the exact locations for TEC is beyond the scope of this project, valuable deliveries for future development such as detailed bathymetry in some areas of a resolution less than 5 m and the seabed condition via sediment grabs will be made available from this project.

The majority of the outlined methods has been successfully tested in a pilot study to evaluate tidal energy resource in the Tamar estuary in Tasmania, Australia [9].

2) Outputs derived from field campaign and fine scale numerical modelling

The purpose of tidal site characterisation is ultimately to estimate the extractable power from the tidal sources. The most important parameter obtained from ADCP deployment is the average power density which is defined as the power from kinetic energy per metre squared (W/m2). The power production hinges on the average velocity cubed, and therefore the biggest uncertainty in the coefficient of power, or AEP, stems from uncertainties in flow velocities. Any error affects the result to the power of three, thus the estimate of the average velocity must be taken with great care.

Using hydrodynamic modelling to predict the environmental effects of energy extraction is of crucial importance for tidal energy development. The local and far-field effects of energy extraction upon the tidal flow are usually modelled using 2D shallow water equation solvers ([10, 11][12]). A numerical model must first be developed which accurately simulates natural conditions. The field data will be used to validate development of high-resolution models of the case study sites.

Once the numerical model has been calibrated and validated against site data, the incorporation of tidal turbines into the model will be conducted to study the implications on the tidal flow. Several concepts have been developed to account for the interaction of a turbine in the free stream flow, e.g. using a friction coefficient [10], a damping effect where a retarding force in direction of the tidal flow is incorporated into the model to simulate the power extracted and its environmental effect ([13]), or by adapting both the momentum and turbulence transport equations to account for the presence of tidal turbines ([14]).

3) Deliverables

Deliverables from the site assessment for the two locations identified in Component 2 will include;

Site conditions derived from the field campaign, e.g.:

- Tidal range
- Harmonic analysis (tidal constituents of 20 at a minimum)
- Wave conditions; including wave height and period
- Wind data
- Water properties including CTD
- Velocity measurements from bottom mounted ADCPs (for a period of 1 month at minimum) and transects from vessel mounted ADCP; observations will provide time series, velocity distribution, maximum/mean water velocity, vertical profile, vertical shear, flood/ebb symmetry, power density.

- Turbulence measurements from bottom mounted ADCPs (for a period of 1 month at minimum) providing turbulent kinetic energy (TKE), turbulence intensity and turbulence length scales.
- Bathymetry at a resolution of 20 m or less
- Sediment characteristics

Numerical modelling component, e.g.:

- Both 2D and 3D models with results from numerical simulations (runs of 3 months at minimum), calibrated and validated against field data
- Grid resolution of < 20 m with further grid refinements in promising areas identified
- Comparisons between numerical models and field data.

Presented with the field results will be instrument types, number of instruments deployed, locations, deployment dates, raw data, bathymetry and identified constraints in the areas surveyed, and detailed data analysis methodology and uncertainty analysis.

Presented in the results from the numerical study will be: water levels used to drive ocean model, boundary conditions, bottom friction parameterisation and data, wind stress formation and data, low frequency forcing, exact data and period of analysis and references to all data sources.

Outputs from the field campaign and numerical models will provide power density, power curves and resource predictions, and resource extraction effects (also called environmental effects) for general and/or specific TEC devices (and their characteristics) in single and/or multiple arrays, and to ensure minimised tidal resource over-extraction.

These outputs will be used in Component 3 to determine the mean annual electrical power and annual energy production. The key findings from Component 2, e.g. field data and numerical model results, will be made available to the stakeholders and partner organisations through the life of the proposal. In addition, the collected data and findings will be available for the public through the Arena webpage and/or the universities' project pages.

B. *Progress*

1) *Bank Straight field campaign*

The first of three legs of field campaigns took place from the 13 March to the 29 March in 2018 using the 35m trawler *Bluefin* owned by the Australian Maritime College. In total, nine mooring frames with ADCPs and AWACs were deployed in depths between 30 m to 60 m and another mooring constitutes of temperature loggers. The goal is to redeploy the instruments after 6-7 weeks at slightly different locations during the second leg and to extend the survey to a total period of 3 months. The 3rd leg comprises the retrieval of the stationary instruments. As this area was unchartered waters, the mooring locations had to be picked based on bathymetry data that was obtained prior to deployments of the frames. In total, an area of ca. ~200 km^2 was mapped. In addition to the moorings and bathymetry mapping, multiple Penetrometer casts were carried out to gain more insight into the sea-bottom substrate. Further surveys included camera footage of the seafloor and CTD and turbidity casts at deployment locations as well as across the Bank Strait. The data is currently being analysed and the 2nd leg is scheduled for early June 2018.

2) *Numerical models*

Fine-scale numerical models with grid resolutions of < 20 m are currently under development for the Eastern Bass Strait site, with efforts concentrating on calibration and validation of 2D and 3D models with opportune surface elevation data. Software development to incorporate tidal turbines into the hydrodynamic model is also underway, focusing on the friction coefficient model and validation against theoretical channel results. Once the field survey is completed, efforts will turn to validation of the developed fine-scale models using both opportune and collected survey data.

IV. COMPONENT 3

Component 3 will develop technical and economical feasible deployment scenarios for tidal energy in various locations around Australia through:

- a tidal energy converters survey, building up an understanding of their technical and performance characteristics;
- estimation of the potential electricity generation output with high temporal resolution over one year for suitable tidal energy converters;
- estimation maximum tidal farm size in suitable locations identified in Components 1 and 2;
- the collection of characteristic information regarding existing and expected electricity grid in suitable tidal locations with a focus on identifying upgrade requirements or other grid issues where tidal energy could provide support;
- determination of the optimal tidal farm size using grid characteristics, network cost data and earlier assessment of the maximum tidal farm size;
- a competitiveness study of tidal energy with other forms of electricity generation under various scenarios and use this to update tidal farm size in these scenarios.

A. *Overview*

Component 3 will deliver technological and economic feasibility assessment for tidal energy integration to Australia's electricity infrastructure, including important issues such as grid integration and competitiveness against existing and new sources of generation, intermittency and farm design. This component will identify the benefits and or potential issues of tidal energy as a predictable and largely consistent source of renewable energy in electricity networks in Australia and will also examine broader regional impacts at the specific locations chosen in components 1 and 2.

A survey of tidal energy converters will be performed. This will seek to identify suitable tidal energy converters for the regions that will be identified in Components 1 and 2. Characteristics of tidal energy converters that need to be considered include their performance in the types of waters that are under investigation, expected lifetime in real conditions, ease of maintenance, size, materials of construction, noise characteristics and whether there may be any environmental issues.

Using the tidal resource assessments generated down to a fine resolution at the particular regions of interest as determined in Components 1 and 2, and information such as the power curve of various tidal energy conversion technologies, the electricity generation profile at short timescales will be calculated for various tidal energy converters. This calculation will take into account mechanical losses and/or other issues associated with the converters in a real ocean situation. The information on the tidal technologies, specifically the power curve, will be obtained from technology developers. CSIRO already has an existing agreement with one developer which will allow us to access the required data.

The environment and geography of the regions that have been identified as being most suitable for tidal energy in Components 1 and 2 and the characteristics such as physical size, mooring constraints and other physical and operational characteristics of the tidal energy conversion devices will allow for the determination of the maximum tidal farm size in each location. However, factors such as demand for electricity, grid characteristics including the potential for local microgrids and economics will come into play to determine the optimal farm size and configuration for each site.

The Australian Energy Market Operator (AEMO) publishes the National Transmission Network Development Plan (NTNDP), which provides information on the current and expected demand for electricity and electricity supply required in the National Electricity Market (NEM), over the next 20 years ([15]). The information from the NTNDP is then used by transmission network providers to determine where upgrades and issues such as fringe-of-grid scenarios may occur in their own, state-based networks. The transmission network providers publish where and how much they will need to spend to resolve these issues with their network. CSIRO in partnership with the Energy Networks Association (ENA) developed the Electricity Network Transformation Roadmap (ENTR) ([16]). This roadmap examined the role increasing levels of distributed generation and energy storage i.e. so-called “disruptive” technologies, are expected to have on the grid. Outcomes of the roadmap, in combination with the NTNDP and published information on upgrades from transmission network providers, will allow for the determination of the characteristics of the current and future grid and the broader demand for electricity in the prospective areas for tidal energy. A similar process occurs in Western Australia (WA) and the Northern Territory (NT), the two states that are not included in the NEM. Currently, the two grids in WA, the South West Interconnected System (SWIS) and the North West Interconnected System (NWIS), are operated and controlled by Western power and Horizon power respectively. The networks in NT are operated and controlled by Power and Water Corporation. Information on those networks, if the tidal resource is prospective in those regions, will need to be obtained from these entities. There are also many smaller/off-grid microgrid networks in WA, NT and QLD. If the tidal resource is significant and near any small networks the potential of upgrading those networks to connect to the larger networks will be analysed as well as utilising the tidal resource within the microgrid itself.

Characteristics of the grid that are of interest for this study include the voltage, frequency, power quality, distance from the prospective tidal farm, distribution and types of loads on the local grid, existing electricity generation sources and in particular distributed intermittent generation. There may be several types of networks including microgrids near the locations identified in earlier components and it will be possible to explore the impact both in terms of economics and power quality of adding a tidal farm to these networks. In this way, it will be possible to determine the most economically-optimal tidal farm size and grid connection point. An appropriate software package such as PowerFactory will be used to model the impact of different-sized tidal farms on different networks at the locations of interest ([17]). Network costs will be included as an additional layer to determine the optimal farm size both technically and economically.

As the tides are well known in advance, the output of any tidal farm is forecastable. Because of this, tidal energy may be able to provide some grid support, such as replacing expensive electricity from gas-fired peaking plants and/or diesel engines and/or energy storage. It may also be able to provide electricity generation at fringe of grid locations, which are problematic for networks. This will increase the economic viability of tidal energy and make it an attractive investment for the network.

However, while tidal energy sources may be able to connect to the grid, generate electricity and have a positive impact on the grid, will the cost of tidal electricity be competitive with other forms of generation? An energy system model developed by the International Energy Agency (IEA) which CSIRO has adapted to the Australian context – AUS-TIMES - will be used to model the competitiveness of tidal energy with existing and potential new forms of electricity generation, in the particular regions that have been identified in Components 1 and 2, at a fine time-scale for several years ([18]). AUS-TIMES will determine the most economically-competitive generation capacity of tidal energy in Australia out to the year 2050 along with the amount of electricity generated, under various scenarios. The capital cost trajectories used in AUS-TIMES will be sourced from the CSIRO’s Global and Local Learning Model (GALLM) and associated report which has updated electricity generation technology cost projections ([19]). Up-to-date cost data will be sourced from tidal technology companies and used to update the GALLM cost database and simulations of capital cost trajectories. The scenarios used to explore the competitiveness of tidal in GALLM and AUS-TIMES will include various levels of carbon pricing, coal, biomass and gas prices and incentives such as mandatory targets for renewable energy.

The final outcome of Component 3 will be economically and technically feasible future deployment scenarios for tidal energy at various locations around Australia.

B. Progress

The existing electricity networks in prospective tidal locations across Australia have been examined and the characteristics of the grid in those locations have been determined. The study has also examined microgrids near Derby in WA, Flinders Island, King Island and the Torres Strait Islands. The study will be combined with information from Component I to decide on the second most promising site for further exploration through Component 2. The decision on this second site will be announced in mid to late 2018. An assessment of tidal energy converters and global tidal projects has also been completed and the suitability of converters for the ocean depth in Banks Strait has been highlighted.

V. CONCLUSION

The outcomes of this project will provide considerable benefit to the emerging tidal energy industry, the strategic-level decision makers of the Australian energy sector, and the management of Australian marine resources by helping them to understand the resource, risks and opportunities available, and overcoming current barriers to investment by increasing the competitiveness of tidal energy against other forms of ocean renewables. Detailed case studies for the two sites will be delivered, providing tidal project developers a head start in commissioning their site prior to deployment of their technology.

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REFERENCES

[1] S. Behrens, D. Griffin, J. Hayward, M. Hemer, C. Knight, S. McGarry, P. Osman, and J. Wright, "Ocean renewable energy: 2015–2050. An analysis of ocean energy in Australia," 2012.

[2] ARENA. (2017) Tidal energy in Australia – Assessing resource and feasibility to Australia’s future energy mix. [online]. Available: https://arena.gov.au/projects/tidal-energy-australia-assessing-resource-feasibility-australias-future-energy-mix/.

[3] M. A. Hemer, S. Zieger, T. Durrant, J. O'Grady, R. K. Hoeke, K. L. McInnes, and U. Rosebrock, "A revised assessment of Australia's national wave energy resource," *Renewable Energy*, vol. 114, pp. 85-107, 2017.

[4] Black and Veatch, Carbon Thrust, "Phase II: UK Tidal Stream Energy Resource Assessment," Carbon Trust London: 650 London Street, Isleworth, Middlesex TW7 4EG, UK, 2005.

[5] M. Lewis, S. Neill, P. Robins, and M. Hashemi, "Resource assessment for future generations of tidal-stream energy arrays," *Energy*, vol. 83, pp. 403-415, 2015.

[6] R. Rahimi, I. Penesis, M. Hemer, L. Mason, and G. Thomas. "Characterization of the tidal current resource in Tasmania". in *Proc. 2nd AWTEC*, 2014.

[7] C. Legrand, "Assessment of tidal energy resource: Marine renewable energy guides," European Marine Energy Centre, 2009.

[8] International Electrotechnical Commission, "Marine Energy - Wave, Tidal and Other Water Current Converters , Part 201: Tidal energy resource assessment and characterization; TS 62600-201:2015," Geneva, Switzerland, 2015.

[9] S. Green, R. Cossu, I. Penesis, and J.-R. Nader. "Tidal energy: A promising future resource for tasmania". in *Proc. Asian Wave and Tidal Energy Conference*, 2017.

[10] G. Sutherland, M. Foreman, and C. Garrett, "Tidal current energy assessment for Johnstone strait, Vancouver island," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol. 221(2), pp. 147-157, 2007.

[11] R. H. Karsten, J. McMillan, M. Lickley, and R. Haynes, "Assessment of tidal current energy in the Minas Passage, Bay of Fundy," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol. 222(5), pp. 493-507, 2008.

[12] T. A. Adcock, S. Draper, G. T. Houlsby, A. G. Borthwick, and S. Serhadlıoğlu, "The available power from tidal stream turbines in the Pentland Firth," *Proc. R. Soc. A*, vol. 469(2157), pp. 20130072, 2013.

[13] Z. Defne, K. A. Haas, and H. M. Fritz, "Numerical modeling of tidal currents and the effects of power extraction on estuarine hydrodynamics along the Georgia coast, USA," *Renewable Energy*, vol. 36(12), pp. 3461-3471, 2011.

[14] T. Roc, D. C. Conley, and D. Greaves, "Methodology for tidal turbine representation in ocean circulation model," *Renewable Energy*, vol. 51, pp. 448-464, 2013.

[15] AEMO, *National Transmission Network Development Plan*. 2015, AEMO.

[16] CSIRO and Energy Networks Australia, "Electricity Network Transformation Roadmap: Final Report," 2017.

[17] Digsilent. (2016) PowerFactory. [online]. Available: http://www.digsilent.de/index.php/products-powerfactory.html.

[18] Energy Plan, (2016) MARKAL/TIMES. [online]. Available: http://www.energyplan.eu/othertools/national/markaltimes/.

[19] J. A. Hayward and P. W. Graham, "A global and local endogenous experience curve model for projecting future uptake and cost of electricity generation technologies," *Energy Economics*, vol. 40, pp. 537-548, 2013.