CATAPULT
Offshore Renewable Energy

Framework for the Categorisation of Losses and Uncertainty

Wave and Tidal Energy Yield Uncertainty

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Contents

List of Tables

1 Introduction

As the wave and tidal industries mature and commercial scale projects reach the point of financial investment decision (FID), it is important that energy yield and uncertainty assessments are presented clearly and consistently to all parties involved.

It is likely that for each wave or tidal energy project reaching FID, more than one energy yield and uncertainty assessment will be prepared. Given the range of methodologies available for both wave and tidal, assessments for a single project may have material differences. These may include assumptions regarding technical losses used to derive net energy generation from gross energy generation. When both the definition of a loss and the value of the loss differ, direct comparisons are difficult to make. Compounding this challenge may be the use of different uncertainty categories and their definitions, making it difficult to interpret and compare the results of different reports at the various probability levels (P90, P95, etc.).

Energy yield and uncertainty assessment methodologies in wave and tidal are distinct in a number of ways; however, they do share a similar same fundamental approach. Both derive gross generation from a site's long term resource and a marine energy convertor's power performance data. Technical loss factors are then applied to derive expected net energy generation. An uncertainty analysis is then conducted to determine the probability distribution of net energy production.

However, without standard definitions for such loss factors and uncertainty categories, there is a risk that it will be difficult to compare studies prepared by different developers and consultants, even when using the same fundamental assessment methodologies. Standardised definitions are therefore proposed to facilitate direct comparison among different studies. In addition, these will lead to more productive dialogue and ultimately improved understanding of technical losses and uncertainties.

This document has been developed in collaboration with a wide range of industry stakeholders. These include independent consultancies, technology developers and project developers.

It should be noted that the use of sub-categories, or addition of further sub-categories is at the users' discretion. The definitions described in this document have been assembled based on consolidation of loss and uncertainty categories derived from input from the Marine Farm Accelerator's Yield Technical Working Group, as well as industry input since circulating the first draft in July 2014.

Note that every project is unique and requires specific consideration, so not every item listed in this document will apply to every project being analysed or reviewed. The definitions are *not an attempt to standardise the values of losses and uncertainties used in an assessment*, but instead aim to provide a framework for the definitions.

2 Definitions – Loss Categories

The following main categories represent the first level of the proposed standard definitions of energy losses. Even if the sub-categories are not used, reporting loss factors using these main categories will facilitate better understanding of loss definitions and comparison between assessments. The term “loss” has been used here but in some instances this may in fact be a gain.

1. Availability;
2. Resource Array Interactions;
3. Marine Energy Convertor Performance;
4. Electrical;
5. Curtailment;
6. Other.

Each main category has sub-categories. Losses and efficiencies are reported as a percent of the gross energy. Gross energy includes the effects of temporal and spatial variation in resource. Where appropriate, temporal variation includes deterministic long term resource variation (i.e. tidal cycles). Spatial variation in the “natural” resource across a site would already be factored into the gross energy and is generally not included as a line item loss (or gain). In this document gross energy yield is defined as being the energy yield calculation made assuming that there are no resource-array interactions [blockage (tidal), shadowing (wave) and wake effects]. Water density effects are also generally included in the gross energy yield.

The gross energy yield is based on “reference” marine energy convertor power performance data. This “reference” performance data is supplied by the technology original equipment manufacturer and is only valid for a defined range of environmental parameters. The source and applicability of the performance data should be clearly stated (i.e. type test curve, warranted matrix etc).

Net energy is the energy production as measured at the project revenue meter (or “point of metering”). The recommended sub-categories and comments on the definitions are shown in Table 1.

Table 1: Recommended Loss Sub-categories, Definitions, and Comments

Standard Loss Category	Description	#	Recommended Sub-categories	Definition/Comments
1. Availability[1]	Accounts for periods of time, and associated foregone energy conversion, when the marine energy convertor is not available for normal operation (excluding project curtailment).	1a	Marine energy converter	Includes lost energy due to maintenance, faults, and component failures over a project's lifetime, planned and unplanned.
		1b	Environmental	Losses due to ad hoc marine energy converter shutdown, whether by the local device controller, project-wide control system, or by an operator (which include, but are not limited to, marine vessel proximity, marine life proximity and significant accumulation of biofouling on the reacting surfaces). Note, environmental curtailment is considered separately in 5d.
		1c	Balance of plant	Losses due to planned and unplanned downtime in components between the marine energy converter circuit breakers up to and including project substation transformer and project-specific transmission line to the point of metering.
		1d	Grid	Losses due to planned or unplanned downtime of power grid to the marine energy convertor array, to the point of metering.
		1e	Site access and other force majeure events	Losses due to restricted site access (which may include, but is not limited to, high sea state and high wind conditions) and other force majeure events. Force majeure events should be applied as defined in the relevant contract.
		1f	Other	Other relevant availability losses not accounted for above or in other categories.

[1] Where possible, availability should be expressed in a manner consistent with IEC/TS 61400-26-1 ed1.0 and IEC/TS 61400-26-2 ed1.0 (as appropriate).

Standard Loss Category	Description	#	Recommended Sub-categories	Definition/Comments
2. Resource Array Interactions	Accounts for the effect of dynamic interactions between the marine energy convertor array and the resource.	2a	Internal resource array interactions	Losses attributable to resource array interactions [which may include, but are not limited to, blockage (tidal), shadowing (wave) and wake effects] within the marine energy converter array that is the subject of the energy yield assessment.
		2b	External resource array interactions	Losses attributable to resource array interactions [which may include, but are not limited to, blockage (tidal), shadowing (wave) and wake effects)] from the marine energy converter array that is the subject of the energy assessment and from identified marine energy converter arrays that are not the subject of the energy yield assessment but which are already operational.
		2c	Future external resource array interactions	Losses attributable to resource array interactions [which may include, but are not limited to, blockage (tidal), shadowing (wave) and wake effects] from additional development in the vicinity of the marine energy converter array being studied, but which are not yet operational.
3. Marine Energy Converter Performance	Accounts for the marine energy converters' reference power performance and site specific power performance.	3a	Power performance	Losses due to a marine energy converter not producing relative to its reference power performance within test specifications and conditions.
		3b	Local resource characteristics	Losses due to differences in resource flow conditions i.e. actual flow conditions outside reference conditions (which may include, but are not limited to, high turbulence, high shear, off-yaw axis currents and inclined flow).
		3c	Hysteresis	Losses due to period of shutdown of marine energy converter between cut-out conditions and cut-back-in (within the control system hysteresis loop).
		3d	Performance degradation	Losses due to degradation of marine energy converter performance over time (which may include, but is not limited to, biofouling, corrosion and erosion of reacting surfaces).

Standard Loss Category	Description	#	Recommended Sub-categories	Definition/Comments
		3e	Other	Other marine energy converter performance losses not accounted for above.
4. Electrical	Accounts for electrical system efficiency and internal consumption.	4a	Electrical losses	Losses to the point of metering, including, as applicable, transformers, collection cabling, substation and transmission.
		4b	Facility parasitic consumption	Losses due to parasitic consumption (which may include, but are not limited to, heaters and transformer no-load losses) within the marine energy convertor array which are not already accounted for in the power performance data. This factor is not intended to cover facility power purchase costs, but does include the reduction of sold energy due to consumption "behind the meter."
5. Curtailment[2]	Accounts for site specific marine energy converter array operational curtailment (partial or complete).	5a	Operational management	Losses due to the marine energy convertor being curtailed due to the ambient environmental conditions being outwith the devices' operational performance limits but which are not accounted for in the device's reference power performance data (for example, tidal devices being curtailed in high wave conditions).
		5b	Grid curtailment / constraint and ramp-rate	Losses due to limitations on the grid external to the marine energy convertor device array, both due to limitations on the amount of power delivered at a given time, as well as limitations on the rate of change of power deliveries. This can be the ongoing control of output over the project lifetime or temporary constraint / curtailment until grid reinforcements are carried out early in the project.
		5c	Offtaker curtailment	Losses due to the power purchaser electing not to take power generated by the facility.

[2] Where possible, curtailment (reduced availability) should be expressed in a manner consistent with IEC/TS 61400-26-1 ed1.0 and IEC/TS 61400-26-2 ed1.0 (as appropriate).

Standard Loss Category	Description	#	Recommended Sub-categories	Definition/Comments
		5d	Environmental curtailment	Losses due to planned shutdowns or altered operations due to external environmental factors (for example, for seasonal marine life migration).
6. Other	Accounts for other loss factors relevant to convert a gross energy yield to a net energy yield.	6a	Resource metric - energy relationship	Any loss due to the non-linear relationship of resource metric and energy and its impact over the long term for a cyclic resource (for example, water current speed and energy).
		6b	Water density	Water density correction due to seasonal and other variations in temperature and salinity, if not considered in the gross energy calculation.
		6c	Other	Any other losses not considered in the above categories.

3 Definitions – Uncertainty Categories

The following main categories represent the first level of the proposed framework uncertainty definitions. Even if the sub-categories are not used, reporting uncertainties using these main categories will facilitate better understanding of uncertainty definitions and comparison among assessments. The aim is to allow comparisons between assessments prepared by different parties. The first three categories are based on resource parameters (mean current speed for tidal and significant wave height and energy period for wave), rather than energy yield. These uncertainties are converted to energy (for example, MWh/annum) by a sensitivity study and are then combined with the uncertainties associated with the device performance to give the overall uncertainty in terms of energy.

1. Site measurement;
2. Temporal variation;
3. Spatial variation;
4. Plant performance and losses;
5. Other.

Each main category has sub-categories. Comments on the definitions are shown in Table 2.

Table 2: Recommended Uncertainty Sub-categories, Definitions, and Comments

Uncertainty Category	Description	#	Example Sub-categories	Sub-category Definition/Comments
1. Site measurement	Uncertainty associated with site measurements and quality of project data	1a	Instrument uncertainty	Uncertainty associated with measurements of wave and tidal flow, including derivatives such as turbulence, by individual instruments (for example, ADCP, wave buoy). Includes instrument calibration uncertainty.
		1b	Measurement interference	Uncertainty associated with effects on measurements as a result of interference from physical instrument support/mooring structure, gross movement, rocking or environmental interference [for example, ADCP's may include proximity to ferrous materials or mounting issues. For wave buoys, may include sudden impacts (slamming) beyond the calibration threshold of the instrument's accelerometers or any mooring issues].
		1c	Short term site data synthesis	Uncertainty associated with synthesising data to "fill in" the short term site data.
		1d	Data quality and metadata	Uncertainty associated with possible bias as a result of removed or missing data, or lack of quality metadata associated with the measurement campaign. Includes uncertainty due to non-encrypted data or non-traceable data sources, or for inconsistencies/contradictory metadata.
2. Temporal variation	Uncertainty associated with estimating the long term resource frequency distribution at the site. Either through statistical adjustment of measured site data or through other methods (including modelling).	2a	Historic resource estimation	For tidal this is the quality of fitting harmonics to measurement data and non-deterministic effects which occurred during the measurement campaign. For wave this is the inter-annual variability within the measurement data and the quality of the long-term reference data and correlation between measurement and long-term data (MCP method only).
		2b	Future resource variability	For tidal, this is how a project with an as yet unfixed commissioning date may be affected by future (known) astronomical variations and the impact of non-deterministic variations during the period of the project.

Uncertainty Category	Description	#	Example Sub-categories	Sub-category Definition/Comments
				For wave, this is the inter-annual variability of the resource during the period of the project.
		2c	Climate change	Uncertainty associated with local impacts of long term global climate patterns.
3. Spatial variation	Uncertainty associated with extrapolating (modelling) from measurement points to individual marine energy converter locations	3a	Model inputs	Uncertainty of all data inputs in hydrodynamic or other model (which may include, but is not limited to, accuracy and resolution of bathymetry data and assigned boundary conditions).
		3b	Horizontal and vertical extrapolation (as appropriate).	Uncertainty associated with hydrodynamic or other modelling between "known" measurement points and marine energy convertor device locations (vertical and horizontal plane). This may be associated with model mesh resolution and other factors.
		3c	Other uncertainty	Uncertainty which may include, but is not limited to, potential model bias and model quality (model sophistication and quality of calibration and validation).
4. Plant performance and losses[3]	Uncertainty associated with estimating marine energy converter production, efficiencies with respect to subsea conditions, and all plant losses including wake losses.	4a	Availability	Uncertainty associated with estimating marine energy converter, environmental, balance of plant, grid, site access or force majeure events and other availability over project lifetime.
		4b	Resource array interactions	Uncertainty associated with marine energy convertor and resource interactions (single and compound device interactions) which may include, but is not limited to, uncertainty in the wake model inputs (including ambient turbulence, flow direction, device thrust curve), wake model performance and "appropriateness" for site. Includes uncertainty related to any proposed neighbouring sites (construction timing, layout, device type).

[3] These are consistent with the categories given in Table 1.

Uncertainty Category	Description	#	Example Sub-categories	Sub-category Definition/Comments
		4c	Power performance	Uncertainty associated with device power performance which may include, but is not limited to, performance under operational conditions outwith reference power performance conditions (for example, turbulence, yawed flow, tidal height, wave spectral shape).
		4d	Electrical losses	Uncertainty associated with transmission line loss (to the point of metering) estimation and electrical metering.
		4e	Performance degradation	Uncertainty associated with estimating the impact of marine energy convertor performance degradation.
		4f	Curtailment	Uncertainty associated with estimating the impact of any form of curtailment at the project.
		4g	Other losses	Includes uncertainties associated with other project specific losses.
5. Other	Other uncertainties	5a	Other	Includes other uncertainties that do not fit into the above categories.

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