22nd International Conference on Sustainable Energy Technologies
Kuala Lumpur, Malaysia, 13 to 15 August 2026 · ISBN 978-1-995850-00-9 · ISSN 2978-4387

CONFERENCE PAPER · LOW-CARBON BUILDINGS

The storm-season shadow of wave energy converters on an eroding Indian coast: Repurposing wave-energy absorption technologies for coastal erosion adaptation at Kanyakumari

Vijayamohan Mankayakarasi Brathikan[1]*, Janarthanan Venkatachalam[2]

[1] Kumaraguru College of Technology, Coimbatore 641049, Tamil Nadu, India
[2] Kinowave, Kanyakumari, Tamil Nadu, India

RECEIVED 1 July 2026 · REVISED 12 July 2026 · ACCEPTED 19 July 2026
PRESENTED 13 to 15 August 2026 · PUBLISHED 23 November 2026

ABSTRACT

Coasts that erode and coasts that hold a wave energy resource are often the same coasts, so a wave farm that also shelters the shore would serve two needs with one investment. European studies show that wave farms can reduce wave height and beach erosion behind them, but they hold the device type fixed, although the largest waves, which erode beaches, can differ in period and direction from those that supply most of the power. This paper asks which kinds of wave energy converter keep absorbing energy when the sea becomes erosive, and how many rows of each would be needed to shelter an eroding coast. Four device types were compared at Kanyakumari, southern India, where about a fifth of the coast is eroding: a heaving buoy, an oscillating water column, a bottom-hinged surge flap and a twin-float liquid-column device. Each was modelled with boundary element hydrodynamics, a tuned power take-off, stroke limits and drag, driven by ten years of wave reanalysis (2015 to 2024) with wind sea and swell kept separate. Erosive sea states, the top 5% by height, fall 81% in the south-west monsoon and carry a westerly wind sea whose share of energy rises from 23% to 38%. Devices that absorb from any direction keep their capture width in these seas (ratio of erosive to all-year capture width 1.02 for the buoy, 1.10 for the water column), while devices aligned to the southerly swell lose 30 to 42% of it (0.70 for the flap, 0.58 for the twin float). One row at twice the device footprint lowers the significant wave height by 3 to 4.5% for the first three types; three to four rows reach a 10% reduction, using 83 to 200 devices per kilometre of coast and producing 14 to 27 GWh a year, enough for about 13,000 to 25,000 Indian households. The twin float would need about 16 rows and is better used for energy. The estimates ignore reflection, diffraction and currents, so they guide device choice and array size before a coupled coastal model is built.

KEYWORDS Wave energy converter, Coastal erosion, Capture width, Wave farm layout, Kanyakumari

1. Introduction

Coastal erosion and the search for clean electricity meet on the same shorelines. The Kanyakumari coast at the southern tip of India retreats by an average of 1.26 m a year, and significant erosion affects 19.5% of its length against 1.3% in accretion (Daswin and Kumar 2023). Earlier shoreline studies link this erosion to the high wave energy and littoral currents that reach the south-west coast of the district (Kaliraj *et al.* 2014). The same waves form a predictable renewable resource: wave energy is forecast more accurately than wind or solar power over hours to days (Reikard *et al.* 2011), and mixing wave power with wind reduces the variability of supply (Fusco *et al.* 2010). A device that turned part of this energy into electricity and sheltered the beach behind it would serve two needs with one structure.

* Corresponding author. Email address: brathiakan@kct.ac.in (Vijayamohan Mankayakarasi Brathikan)

© 2026 The Author(s).
Published by Caravel Press.

doi.org/10.65582/set.2026.027

The coastal engineering literature supports the idea in principle. A wave farm 7 km off Perranporth in the United Kingdom reduced the eroded area of the beach face by up to 35% one to three months into a storm season (Abanades *et al.* 2014), and among four farm-to-coast distances the closest farm gave the most protection, up to 20% less erosion, while lowering the available resource by about 10% (Abanades *et al.* 2015). At the Guadalfeo delta in Spain, a farm reduced significant wave height at 10 m depth by 18.3% and beach erosion by 44.5% on the most exposed beach (Bergillos *et al.* 2018). Two recent studies add a warning and an encouragement: an array can drive rip currents in its lee as strong as natural ones (Cao *et al.* 2025), and the arrays best at protecting a beach can also generate well (Cui *et al.* 2026).

These studies share one simplification. Each holds the device type fixed and describes it by a single transmission coefficient or by its response in typical sea states. Erosion, however, is driven by the largest waves of the year, and on many coasts these differ in period and direction from the waves that deliver most of the annual energy. A device tuned for the average sea may absorb little when it matters for the shore. No study has compared device types at one site on the sea states that erode it.

We propose that the coastal value of a wave energy converter depends on whether it keeps absorbing in the erosive part of the wave climate, and that this can be measured before any coastal model is built. The test is simple: compare the capture width of each device type in all sea states with its capture width in the erosive ones, then count the rows needed to reach a useful reduction in wave height. Kanyakumari is a sharp case because its storm season mixes a southerly swell with a strong westerly wind sea. The rest of the paper gives a simple estimate first, then the data and models, the results for four device types, the limitations and the concluding remarks.

2. A simple estimate

Consider one row of devices across the incoming waves. A device with capture width w removes the energy carried by a strip of wave front w metres wide. If devices are spaced s metres apart along the row, the row removes a fraction w/s of the energy flux that crosses it. Because energy flux scales with the square of wave height, the height behind the row falls by the factor in Equation 1, and behind N identical rows by that factor raised to the power N.

$$\frac{H_{\text{behind}}}{H_{\text{incident}}} = \left(1 - \frac{w}{s}\right)^{N/2} \tag{1}$$

Where:

- H = significant wave height (m)
- w = capture width of one device in the sea states of interest (m)
- s = spacing between device centres along a row (m)
- N = number of rows

A heaving buoy 10 m across with a capture width of 1.2 m, spaced at 20 m, removes 6% of the flux and lowers wave height by 3%. Ten per cent needs four rows. The arithmetic shows two things. Device spacing cannot fall much below twice the footprint without the devices interfering and blocking access for maintenance, so wave height falls only by a few per cent per row. And what matters for the coast is w in the erosive sea states, which is the quantity the rest of the paper measures.

3. Site, data and devices

The site is the deep-water grid point at 8.0° N, 77.6° E off Kanyakumari. Sea states came from the WAVERYS reanalysis (Law-Chune *et al.* 2021) every three hours from 2015 to 2024, which separates each sea state into a wind sea and two swell systems, each with its own height, mean period and

direction. ERA5 (Hersbach *et al.* 2020) was used as a check on the total wave power. Each partition was represented by a JONSWAP spectrum (Hasselmann *et al.* 1973) with peak period equal to the mean period divided by 0.835, and shoaled linearly from deep water to the depth of each device. Mean wave power in deep water is 8.0 kW/m from WAVERYS and 9.3 kW/m from ERA5. Every second record was used, giving 14,610 sea states.

Erosive sea states were defined as the 5% with the highest offshore significant wave height, at or above 2.11 m; the 1% at or above 2.49 m were used as a second threshold. The value choice is stated here because it defines the measure: the threshold separates the seas that move sand on the beach face from the rest, and the paper reports both thresholds to show how the result depends on it.

Four device types were modelled at representative scale (Table 1). The heaving buoy and the oscillating water column were placed at 28 m depth, the surge flap at 15 m depth where surge motion is amplified (Whittaker and Folley 2012), and the twin-float device at 28 m. Hydrodynamic coefficients were computed with the boundary element code Capytaine (Ancellin and Dias 2019) over 41 frequencies from 0.2 to 2.2 rad/s. The water column was represented by a thin floating piston inside a fixed open-bottomed chamber, a standard approximation for the internal free surface (Falcão and Henriques 2016). The flap pitches about a hinge 1 m above the bed. Its excitation was computed for headings from 0° to 90°, and its facing direction was optimised for annual energy.

Table 1. Devices compared and their tuned settings.

Device	Size and depth	Motion	Natural period	Tuned facing
Heaving buoy	cylinder 10 m diameter, 5 m draft; 28 m depth	heave	5.7 s	any direction
Oscillating water column	chamber 10 m by 10 m, walls 5 m deep; 28 m depth	internal surface	5.5 s	any direction
Surge flap	18 m wide, 2 m thick, hinge 1 m above bed; 15 m depth	pitch	27 s	normal towards 165°
Twin float	two floats 7.5 m diameter, 17.25 m draft, 21 m apart, liquid column and air turbines; 28 m depth	relative heave	opposed modes tuned by air volume	line axis at 165°

Each of the first three devices has a linear power take-off whose damping was chosen once to maximise annual energy over 300 random sea states, then held fixed for the year. In each sea state the response was computed from the frequency-domain equation of motion. Quadratic drag was linearised statistically (drag coefficient 1 on the buoy bottom and 2 on the flap). If the significant amplitude exceeded a stroke limit (3 m for the buoy, 2.5 m for the water column, 0.5 rad for the flap), the damping was raised until it did not. The twin float was computed with the model of a companion study, which includes its float drag, the measured loss of its connector and two tuned air chambers (Brathikan and Venkatachalam 2026). Capture width is the mean absorbed power divided by the mean incident energy flux per metre at the device depth, both summed over the sea states considered.

4. Results

4.1. Which devices keep absorbing in erosive seas

The erosive seas at Kanyakumari belong to the south-west monsoon (81% of them, against 15% in the inter-monsoon months and 4% in the north-east monsoon). In these seas the westerly wind sea grows: its share of wave energy rises from 23% over the year to 38%, its mean direction is 271° and its mean period 4.5 s, while the swell keeps coming from 179° with a mean period of 11.4 s. Figure 1

shows the effect on wave periods. In the erosive seas a second energy peak appears between 5 and 7 s, where the buoy, the water column and the flap respond well, beside the swell peak at 12 to 15 s.

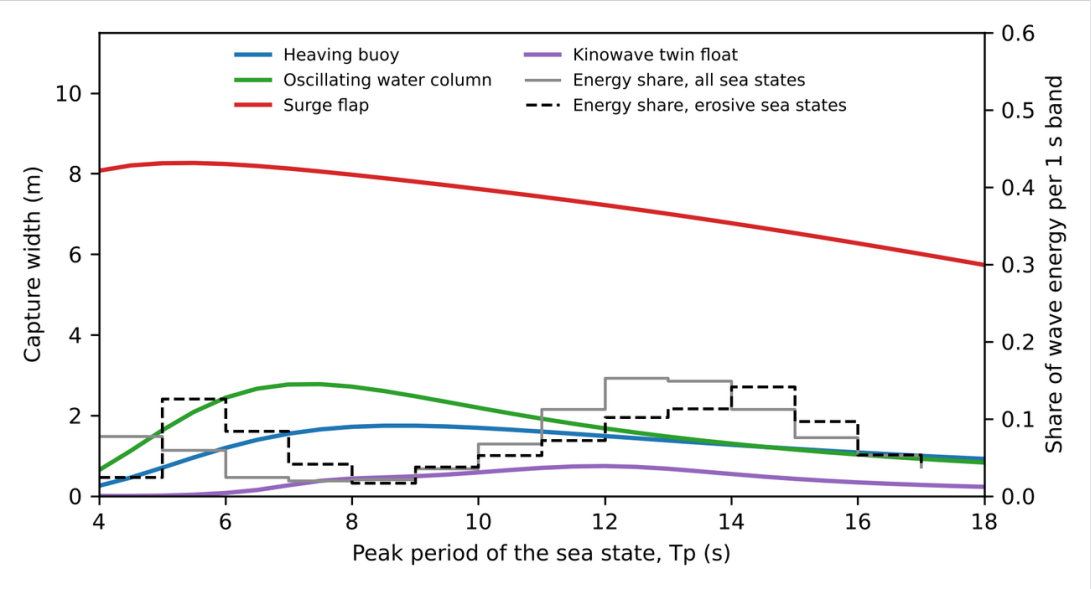

Figure 1. Capture width of each device against the peak period of a single sea state of height 1 m arriving head-on (lines, left axis), with the share of wave energy in each 1 s band of peak period over all sea states and over the erosive sea states (steps, right axis). Kanyakumari, WAVERYS partitions 2015 to 2024.

Table 2 gives the measured result. The buoy and the water column absorb from any direction, and their capture width in erosive seas equals or exceeds their all-year value (ratios of 1.02 and 1.10 at the 5% threshold, 1.09 and 1.26 at the 1% threshold). The flap and the twin float are aligned to the southerly swell that carries most of the annual energy. In erosive seas the flap keeps 70% of its capture width and the twin float 58%, falling to 59% and 47% in the top 1%. The flap still has the largest capture width of the four in absolute terms, because its 18 m width intercepts more wave front, but it loses its advantage in the seas that matter for the shore. None of the devices reached its stroke limit in any sea state, since the largest offshore significant wave height in the record is moderate for an open coast.

Table 2. Annual energy and capture width in all sea states and in erosive sea states.

Device	Annual energy (MWh)	Capture width, all (m)	Capture width, top 5% (m)	Capture width, top 1% (m)	Ratio, top 5% to all	Ratio, top 1% to all
Heaving buoy	84	1.21	1.23	1.32	1.02	1.09
Oscillating water column	101	1.46	1.60	1.83	1.10	1.26
Surge flap	320	4.49	3.14	2.67	0.70	0.59
Twin float	25	0.36	0.21	0.17	0.58	0.47

4.2. How many rows a shelter needs

Figure 2 applies Equation 1 with the erosive-sea capture width and a spacing of twice the device footprint across the waves (20 m for the buoy, 22 m for the water column, 36 m for the flap and 15 m for the twin float, whose line runs nearly along the swell). One row lowers the significant wave height by 3.1% (buoy), 3.7% (water column), 4.5% (flap) and 0.7% (twin float). A 10% reduction, a little over half the reduction in wave height reported at Guadalfeo, needs three rows of flaps or water columns

or four rows of buoys. Per kilometre of coast this means 83 flaps, 136 water columns or 200 buoys. Over a year these arrays would produce 26.6, 13.8 and 16.8 GWh per kilometre. At about 90 kWh a month per electrified Indian household (Prayas Energy Group 2017) this is enough for 13,000 to 25,000 households. The twin float would need about 16 rows and more than 1,000 devices per kilometre for the same shelter.

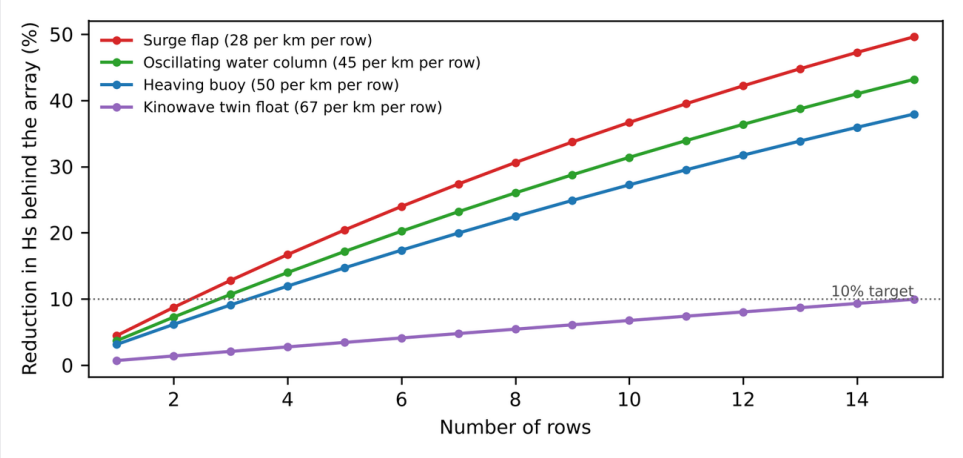

Figure 2. Reduction in significant wave height behind an array in the erosive sea states (top 5%), against the number of rows, for devices spaced at twice their footprint across the waves. The legend gives the number of devices per kilometre in each row.

The comparison changes the ranking that energy alone would give. By energy the flap leads by a factor of three, and the water column and buoy follow. For shelter in erosive seas, the flap's lead per row shrinks to about 20%, and the water column, which absorbs more in storms than over the year, comes close to the flap with under a third of its annual output per device.

4.3. What this means for the twin-float device

The twin-float device absorbs through the difference in heave between its floats, so it needs waves whose length is comparable with the float spacing and that run along its line. It is oriented to the long southerly swell, and the westerly wind sea of the monsoon storms reaches it from the side, where the floats rise and fall together. As a coastal shelter it is the weakest of the four. Its value lies in energy from the swell, and any coastal benefit would need a different layout, such as a second set of lines facing the westerly wind sea.

5. Limitations

1. The arrays are treated as rows of independent absorbers. Diffraction around devices refills the shadow with distance, so the reduction at a shore several kilometres away is smaller than at the array; this biases the shelter estimates upwards.
2. Reflection is ignored. A flap and the walls of a water column reflect part of the incident energy, which also reduces transmission; this biases the shelter of these two devices downwards, and their advantage over the buoy may be larger than shown.
3. Hydrodynamic interaction between devices in a row is ignored. At twice the footprint spacing it can raise or lower capture width by tens of per cent depending on period and heading, so the row counts carry an uncertainty of about one row.
4. The power take-off is linear and tuned once for the year. Control that adapts to each sea state would raise absorption in all seas; it would change the absolute numbers more than the ratio between erosive and all-year capture width.

5. Erosion is represented by wave height alone. Nearshore currents can turn a reduction in wave height into erosion elsewhere (Cao *et al.* 2025; Cui *et al.* 2026), and sediment transport, beach slope and storm duration are not modelled. The shelter figures are therefore necessary conditions for protection, not predictions of shoreline change.
6. Devices were sized at representative scale and placed at typical depths, and other sizes were not tested. A different size changes the capture width and the number of devices per kilometre; because the loss in erosive seas comes mainly from direction, the ratio between erosive and all-year capture width is expected to change less, but this remains to be shown.

6. Concluding remarks

The coastal value of a wave energy converter at Kanyakumari depends on whether it absorbs from the direction and in the periods of the monsoon storms. Devices that absorb from any direction keep or raise their capture width in erosive seas; devices aligned to the swell lose a third to a half of it. The result does not depend on the exact storm threshold, since it holds at both the top 5% and the top 1%, and it follows from a feature of the wave climate that is common on monsoon coasts: storm seas that combine a long swell with a strong, short wind sea from another direction.

For coastal planners the numbers give a first sizing rule. Three to four rows of water columns, flaps or buoys at twice their footprint can lower wave height by about 10% in erosive seas while producing 14 to 27 GWh a year per kilometre. For device developers the lesson is to report capture width in the erosive part of the climate as well as the annual energy, because the two can rank devices differently. For the twin-float device studied by the authors, the result sets its role as an energy converter for the swell rather than a coastal shelter.

The next study should couple these device responses, including reflection, to a spectral wave model and a morphodynamic model of the Kanyakumari coast, test arrays that combine swell-facing energy lines with omnidirectional devices facing the westerly storm sea, and compare the cost per kilometre of such dual-use arrays with conventional coastal defences.

Declarations

Author contributions. Vijayamohan Mankayakarasi Brathikan: Writing (original draft), Data curation, Formal analysis, Investigation, Methodology, Conceptualization. Janarthanan Venkatachalam: Writing (review and editing).

Funding. This research received no specific funding.

Conflicts of interest. The authors declare no competing interests.

Data availability. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgements. The authors thank Copernicus Marine Service for the WAVERYS reanalysis and ECMWF for ERA5. Analysis and drafting were assisted by an AI model (Claude, Anthropic); the authors checked every number against the analysis outputs and every reference against its source and take full responsibility for the content.

References

Abanades, J.; Greaves, D.; Iglesias, G. (2014) 'Wave farm impact on the beach profile: A case study', *Coastal Engineering*, 86, pp. 36-44. Available at: https://doi.org/10.1016/j.coastaleng.2014.01.008

Abanades, J.; Greaves, D.; Iglesias, G. (2015) 'Coastal defence using wave farms: The role of farm-to-coast distance', *Renewable Energy*, 75, pp. 572-582. Available at: https://doi.org/10.1016/j.renene.2014.10.048

Ancellin, Matthieu; Dias, Frédéric (2019) 'Capytaine: a Python-based linear potential flow solver', *Journal of Open Source Software*, 4(36), pp. 1341. Available at: https://doi.org/10.21105/joss.01341

Bergillos, Rafael J.; López-Ruiz, Alejandro; Medina-López, Encarnación; Moñino, Antonio; Ortega-Sánchez, Miguel (2018) 'The role of wave energy converter farms on coastal protection in eroding deltas, Guadalfeo, southern Spain', *Journal of Cleaner Production*, 171, pp. 356-367. Available at: https://doi.org/10.1016/j.jclepro.2017.10.018

Brathikan, V.M.; Venkatachalam, J. (2026) 'Parametric CFD investigation of a differential heave wave energy converter for distributed coastal energy access', *Prototypes for Humanity 2026 Short Papers*. Dubai.

Cao, Xiangming; Shi, Jian; Zheng, Jinhai; Zhang, Chi; Pan, Junning (2025) 'Offshore wave energy converter array poses threat to coasts causing significant rip currents', *Physics of Fluids*, 37(8), pp. 086627. Available at: https://doi.org/10.1063/5.0279511

Cui, Lidong; Sergiienko, Nataliia Y.; Cohen, Nadav; Leontini, Justin S.; Cazzolato, Benjamin S.; Flocard, Francois; Manasseh, Richard (2026) 'Coastal response to wave energy converter arrays: A semi-analytical model for control of nearshore currents and beach morphology', *Renewable Energy*, 263, pp. 125497. Available at: https://doi.org/10.1016/j.renene.2026.125497

Daswin, E.; Kumar, M. (2023) 'Coastline change rate estimation on the southern coastal districts of Tamil Nadu, India using the multi temporal Google Earth images and GIS based statistical approach', *Global NEST Journal*, 25(4), pp. 95-103. Available at: https://doi.org/10.30955/gnj.004482

Falcão, António F.O.; Henriques, João C.C. (2016) 'Oscillating-water-column wave energy converters and air turbines: A review', *Renewable Energy*, 85, pp. 1391-1424. Available at: https://doi.org/10.1016/j.renene.2015.07.086

Fusco, Francesco; Nolan, Gary; Ringwood, John V. (2010) 'Variability reduction through optimal combination of wind/wave resources – An Irish case study', *Energy*, 35(1), pp. 314-325. Available at: https://doi.org/10.1016/j.energy.2009.09.023

Hasselmann, K. et al. (1973) 'Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP)', *Ergänzungsheft zur Deutschen Hydrographischen Zeitschrift*, A8(12).

Hersbach, Hans; Bell, Bill; Berrisford, Paul; Hirahara, Shoji; Horányi, András; Muñoz-Sabater, Joaquín; Nicolas, Julien; Peubey, Carole; Radu, Raluca; Schepers, Dinand; Simmons, Adrian; Soci, Cornel; Abdalla, Saleh; Abellan, Xavier; Balsamo, Gianpaolo; Bechtold, Peter; Biavati, Gionata; Bidlot, Jean; Bonavita, Massimo; De Chiara, Giovanna; Dahlgren, Per; Dee, Dick; Diamantakis, Michail; Dragani, Rossana; Flemming, Johannes; Forbes, Richard; Fuentes, Manuel; Geer, Alan; Haimberger, Leo; Healy, Sean; Hogan, Robin J.; Hólm, Elías; Janisková, Marta; Keeley, Sarah; Laloyaux, Patrick; Lopez, Philippe; Lupu, Cristina; Radnoti, Gabor; de Rosnay, Patricia; Rozum, Iryna; Vamborg, Freja; Villaume, Sebastien; Thépaut, Jean-Noël (2020) 'The ERA5 global reanalysis', *Quarterly Journal of the Royal Meteorological Society*, 146(730), pp. 1999-2049. Available at: https://doi.org/10.1002/qj.3803

Kaliraj, S.; Chandrasekar, N.; Magesh, N. S. (2014) 'Impacts of wave energy and littoral currents on shoreline erosion/accretion along the south-west coast of Kanyakumari, Tamil Nadu using DSAS and geospatial technology', *Environmental Earth Sciences*, 71(10), pp. 4523-4542. Available at: https://doi.org/10.1007/s12665-013-2845-6

Law-Chune, Stéphane; Aouf, Lotfi; Dalphinet, Alice; Levier, Bruno; Drillet, Yann; Drevillon, Marie (2021) 'WAVERYS: a CMEMS global wave reanalysis during the altimetry period', *Ocean Dynamics*, 71(3), pp. 357-378. Available at: https://doi.org/10.1007/s10236-020-01433-w

Prayas Energy Group (2017) 'Trends in India's residential electricity consumption', *Plugging In: Electricity Consumption in Indian Homes*. Pune: Prayas (Energy Group) and Centre for Policy Research.

Reikard, Gordon; Pinson, Pierre; Bidlot, Jean-Raymond (2011) 'Forecasting ocean wave energy: The ECMWF wave model and time series methods', *Ocean Engineering*, 38(10), pp. 1089-1099. Available at: https://doi.org/10.1016/j.oceaneng.2011.04.009

Whittaker, Trevor; Folley, Matt (2012) 'Nearshore oscillating wave surge converters and the development of Oyster', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 370(1959), pp. 345-364. Available at: https://doi.org/10.1098/rsta.2011.0152

HOW TO CITE THIS PAPER

Brathikan, V. M. and Venkatachalam, J. (2026). The storm-season shadow of wave energy converters on an eroding Indian coast: Repurposing wave-energy absorption technologies for coastal erosion adaptation at Kanyakumari. In: *Proceedings of the 22nd International Conference on Sustainable Energy Technologies (SET2026)*, Kuala Lumpur, Malaysia, 13 to 15 August 2026. Caravel Press, pp. 308–315. ISBN 978-1-995850-00-9. ISSN 2978-4387. https://doi.org/10.65582/set.2026.027

COPYRIGHT AND LICENCE

© 2026 The Author(s). This is an open access paper distributed under the terms of the Creative Commons Attribution (CC BY 4.0) licence, which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

WSSET World Society of Sustainable Energy Technologies Organised by the World Society of Sustainable Energy Technologies. Published by Caravel Press.