# Adapt-ORE: A Simulation Tool for Adaptive Operation and Maintenance of Offshore Renewable Energy Farms

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## I. INTRODUCTION

OPERATION and maintenance (O&M) are a fundamental aspect to study in ORE projects, due to the high economic costs involved and challenging sea conditions restricting the completion of maintenance tasks. Reference [1] shows that O&M costs exceed 20% of overall costs of offshore wind projects and according to [2] it could reach 31% in floating wind farms.

Chile is considered one of the countries with the greatest potential for the development of offshore renewable energy (ORE), particularly wave, tidal and offshore floating wind power. These three types of generation, with different characteristics and maturity levels, present scientific and technological challenges that must be addressed by industrial innovation processes, together with research and development. To accelerate the implementation of ORE in Chile, it is necessary to analyse different scenarios and local capabilities, proposing innovative technical solutions, identifying risks, and increasing economic competitiveness.

In order to have a tool that supports strategic decisions through the calculation of key performance indicators and life-cycle cost analysis of an ORE project, a discrete-event simulation (DES) model is being developed. This tool, called Adapt-ORE, allows to compare different sites, technologies, vessels, and maintenance strategies for identifying risks and opportunities in our country and Latin America.

This paper presents the first advances achieved to date, which focus on the operational stage of an ORE project.

Several models related to O&M have been developed in recent years, for example [3] shows an extensive review of models mainly focused on fixed-bottom wind. But the challenges involved in the maintenance of floating structures require adapted strategies and specific adjustments [4]. This issue has been addressed in earlier works such as [2], [5], [6] and [7].

The differentiating factor of Adapt-ORE is that it considers vessel response-based operational criteria. That is, to know the response of the vessels (e.g., motion amplitudes and accelerations) at different sea states and to define thresholds that ensure the completion of tasks safely and reliably.

This methodology is widely used in the maritime industry during the design stage of a vessel to evaluate its operability, and it is possible to find studies where it is applied in a DES (discrete-event simulation) model for marine operations [8] and fish farming [9].

## II. METHODS

### A. Adapt-ORE tool

Adapt-ORE uses a series of input data to obtain the performance indicators. Among them are site and port metocean data, power performance of the devices, vessel operational thresholds, corrective and preventive maintenance schedule and its characteristics, and environmental limits for port closure and operability.

To evaluate the feasibility of maintenance, i.e., the occurrence of suitable weather windows, the DES model is used to minimize downtime costs. Fig. 1 shows a flowchart of the method. If there is a corrective or preventive maintenance to be performed, the operation cycle is started assessing feasibility of vessel departures, in other words, assessing whether the environmental conditions in the port exceed the allowable limits for departure (input data). To avoid false starts, i.e., the vessel departs, and operations cannot be carried out due to adverse weather conditions, an assessment of the environmental conditions at the site is also performed.

If weather conditions exceed predefined limits, the vessel will wait in port and the maintenance will be postponed until suitable weather conditions occur. Otherwise, the vessel will depart and transit to the site to perform the required task.

At site, the feasibility of carrying out the operation is evaluated (see next section for details). If operational limits are exceeded, the vessel must return to port and the maintenance will be rescheduled, starting a new cycle. If the conditions are met, the operation will be performed.

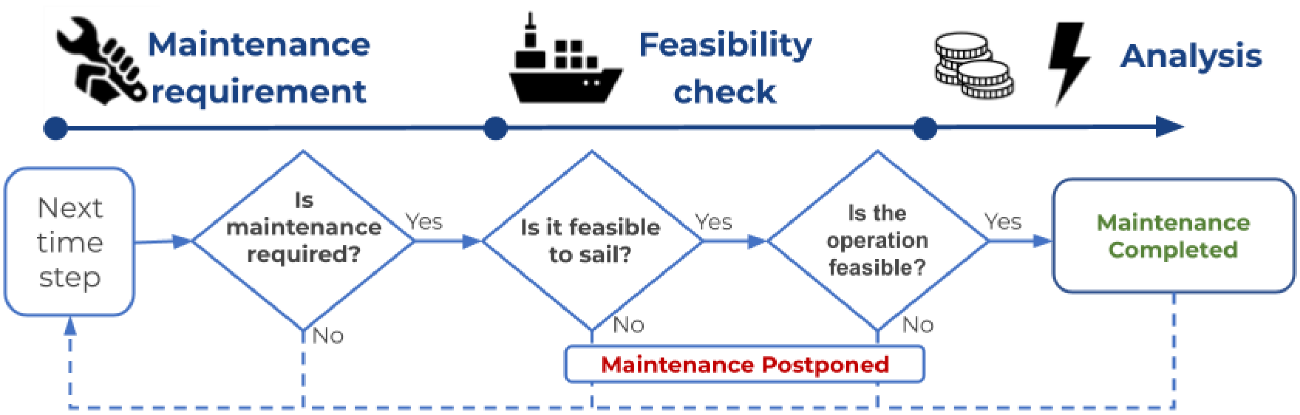


Fig. 1. Flowchart of the DES in Adapt-ORE

### B. *Feasibility of operation*

Maintenance can be performed if wind speed does not exceed a user-defined value (20 m/s by default) and the operational limits of the vessel are not exceeded. The operational limits are specific to a vessel and the activities to be performed. They depend on both its hydrodynamic characteristics and on the environmental conditions.

Harmonic vessel motions when interacting with regular waves (hydrodynamic response) can be determined experimentally or with numerical analysis tools [10], e.g., the open source code NEMOH, which is based on a 3-D boundary element method (BEM, well-known as panel method) and potential theory [11]. NEMOH is used to estimate Response Amplitude Operators (RAOs), which are ratios between the maximum amplitude of the object motions and the maximum amplitude of the incident regular wave in six degrees of freedom (surge, sway, heave, roll, pitch and yaw). The response of the vessel to a sea state, that is, the response spectrum, is obtained by multiplying a representative wave spectrum by the square of the RAO.

For a specific operation, e.g, staff transfer or work on deck, acceptable vessel motions and accelerations for a safe and reliable operation may vary. A widely used criteria for maximum motions and accelerations is proposed by NORDFORSK [12], providing limiting criteria for specific tasks such as light, heavy and intellectual work, among others.

Considering the response spectrum and limiting criteria for a specific task, it is possible to determine the maximum allowable wave height as a function of wave period. This is shown in Fig. 2 by the limiting sea state curves for transit passengers with different wave heading [13].

### C. *Case study*

To show the capabilities of Adapt-ORE, a fictional case is created to compare two floating offshore wind projects in Central Chile. Two sites located at the west and east side of Santa María Island (37.05°S - 73.52°W) have been chosen to assess the impact on accessibility on the overall energy generation. The western site (site 1 in Fig. 3) is more exposed because it faces ocean waves and winds (greater resource and difficult access), whereas the eastern site (site 2) is protected by the island (less resource and easy access).

Both projects consider a wind turbine with a hub height of 90 meters, a rated power of 5 MW and a nominal wind speed of 10.4 m/s. Wind data were extracted from ECMWF

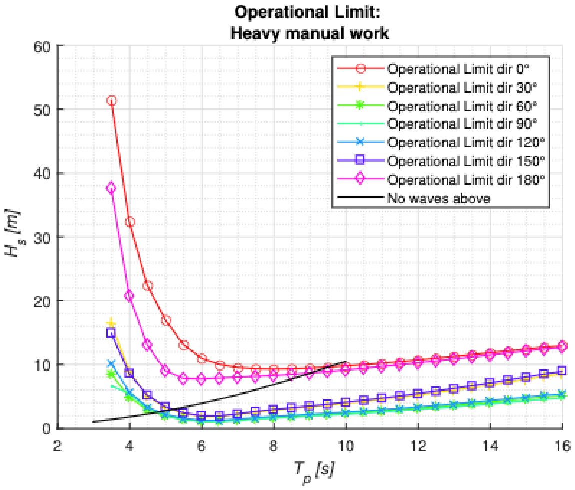


Fig. 2. Limiting sea states curves for transit passenger with different wave heading

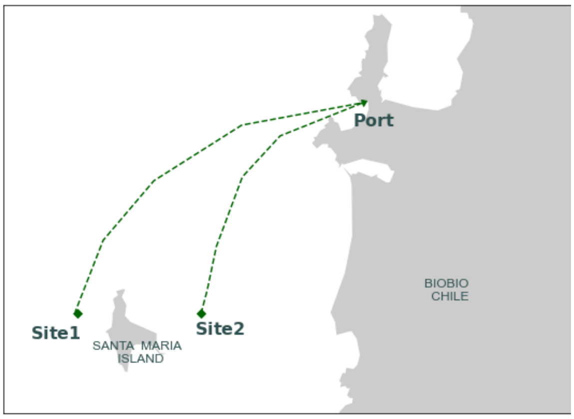


Fig. 3. Location of wind energy projects and port for case study in Central Chile

TABLE I
PERFORMANCE INDICATORS OBTAINED FOR EXPOSED (SITE 1) AND PROTECTED (SITE 2) SITE USING ADAPT-ORE

| | Site 1 | Site 2 |
|---|---|---|
| Annual energy delivered [GWh] | 21.9 | 11.0 |
| Annual energy lost [GWh] | 0.42 | 0.097 |
| Capacity factor [%] | 49.9 | 25.1 |
| Total waiting time [hours] | 631 | 139 |

ERA5 reanalysis dataset and wave data are from Waverys dataset by the Copernicus program. A period of 5 years was analysed (2017-2021) with hourly resolution.

The chosen port is located 25 km north of the island (~46 km from the protected site and ~50 km from the exposed site). Wind data at port location were extracted from a nearby weather station at Carriel Sur Airport [14].

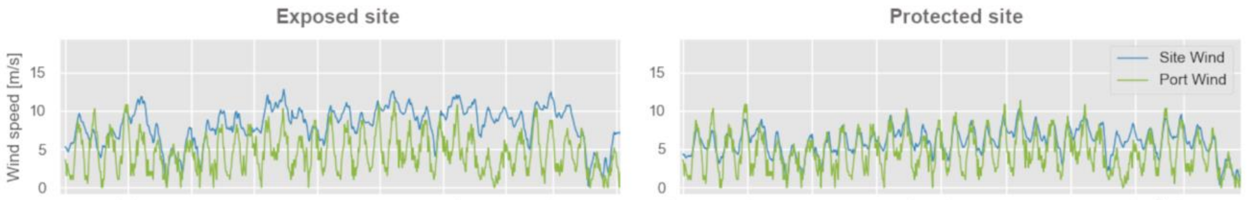
A wind speed of 10 m/s was used as the environmental limit for departing and it was determined by port closure records obtained from DIRECTEMAR [15].

To compare both sites under the same parameters, the maintenance configuration was the same in both cases. The most limiting NORDFORSK 1987 criterion ("Transit passengers") was chosen for corrective maintenance, which allows a maximum vessel roll motion of 2.5 degrees. Whereas the most permissive criterion was used for preventive maintenance ("Light manual work" with a roll motion of 6 degrees).

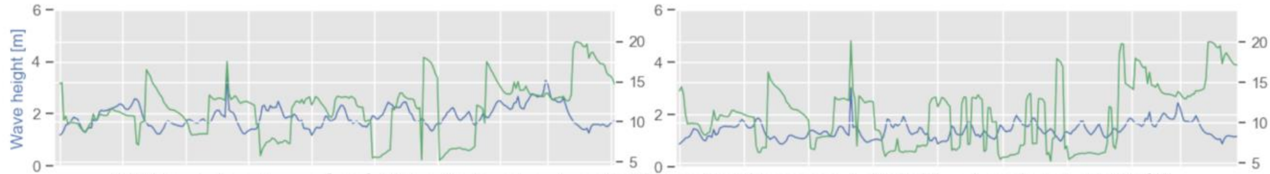
## III. RESULTS

Adapt-ORE generates a series of plots showing the performance of the analysed project, e.g., Fig. 4 shows metocean parameters (Fig. 4a-b), power (Fig. 4c) and maintenance (Fig. 4d) for both sites during one month. In the bottom row the performance of two maintenance activities is shown. Note that for the exposed site (left panel), a significant waiting period is observed, whereas the protected site could make these maintenance operations with no delay. This leads to a higher energy loss during downtime (black line in 4c) at the exposed site. This pattern is consistent during the five years of study, reaching 26.3 days of waiting time for suitable weather windows at the western site, compared to 5.8 days at the eastern site (see Table I). Despite this, energy delivered at the exposed site was almost three times higher than the energy generated at the protected site.

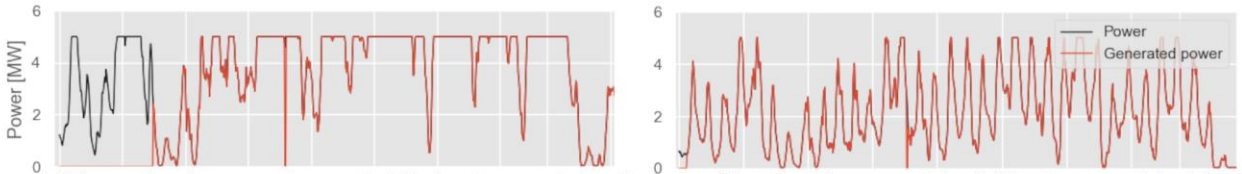
This can also be seen in Fig. 5 which shows the monthly energy delivered (line) and lost (colored areas) at both sites. Evidently, the energy at the exposed site is higher than the protected site, especially during summer season, when the losses are also greater. Whereas the protected site has minor power production it has minor power losses than the exposed site.



(a) Time series of wind speed at port (green line) and on site (blue line) for exposed site (left) and protected site (right).



(b) Time series of wave height (blue line) and peak period (green line) for exposed site (left) and protected site (right).



(c) Time series of generated power (red line) and power during downtime (black line) for exposed site (left) and protected site (right).

(d) Sequence of operation execution for a corrective and a preventive maintenance: waiting at port (red line), waiting at site (blue line) and operation (green line), for exposed site (left) and protected site (right).

Fig. 4. Example of a corrective and a preventive maintenance for exposed site (left) and protected site (right).

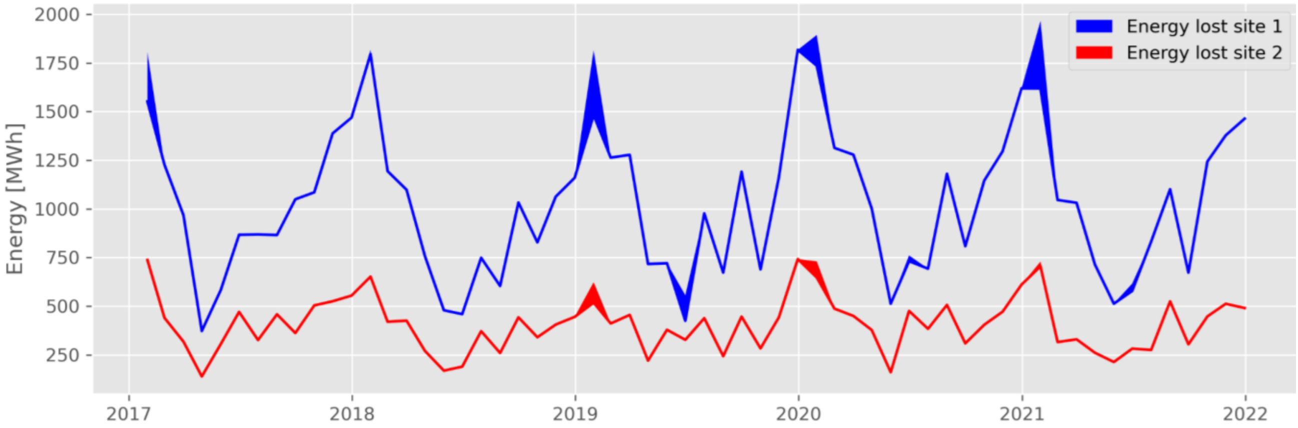


Fig. 5. Monthly energy delivered for exposed (blue line) and protected (red line) sites. Colored areas show energy lost during downtime.

## IV. DISCUSSION & CONCLUSION

The objective of this work is to show the capabilities of the first version of Adapt-ORE. Although this was a simple comparison using simplified assumptions, it gives a first approach of the advantages of such simulations as decision-making support tool at early project stages. Future work will be focused on integrating the main costs involved in the operating stage of an ORE project into the assessment.

The future of ORE in Chile, especially floating offshore wind, is promising, and tools such as Adapt-ORE can provide important insights for the development of this industry in our country.

## V. REFERENCES

[1] C. J. Crabtree, D. Zappalá, and S. I. Hogg, “Wind energy: UK experiences and offshore operational challenges,” *Proc. Inst. Mech. Eng. Part J. Power Energy*, vol. 229, no. 7, pp. 727–746, 2015, DOI: 10.1177/0957650915597560.

[2] L. Castro-Santos and V. Diaz-Casas, “Life-cycle cost analysis of floating offshore wind farms,” *Renew. Energy*, vol. 66, pp. 41–48, 2014, DOI: 10.1016/j.renene.2013.12.002.

[3] M. I. H. Tusar and B. R. Sarker, “Maintenance cost minimization models for offshore wind farms: A systematic and critical review,” *Int. J. Energy Res.*, vol. 46, no. 4, pp. 3739–3765, 2022, DOI: 10.1002/er.7425.

[4] K. Saeed, J. McMorland, M. Collu, A. Coraddu, J. Carroll, and D. McMillan, “Adaptations of offshore wind operation and maintenance models for floating wind,” *J. Phys. Conf. Ser.*, vol. 2362, no. 1, p. 012036, 2022, DOI: 10.1088/1742-6596/2362/1/012036.

[5] G. Rinaldi, P. R. Thies, and L. Johanning, “Improvements in the O&M modelling of floating offshore wind farms,” in *Developments in Renewable Energies Offshore*, 1st ed., CRC Press, 2020, pp. 481–487. DOI: 10.1201/9781003134572-54.

[6] N. Avanessova, A. Gray, I. Lazakis, R. C. Thomson, and G. Rinaldi, “Analysing the effectiveness of different offshore maintenance base options for floating wind farms,” *Wind Energy Sci.*, vol. 7, no. 2, pp. 887–901, 2022, DOI: 10.5194/wes-7-887-2022.

[7] A. Dewan, and M. Asgarpour, “Reference O&M concepts for near and far offshore wind farms”. Petten: ECN, 2016.

[8] E. Sandvik, M. Gutsch, and B. E. Asbjørnslett, “A simulation-based ship design methodology for evaluating susceptibility to weather-induced delays during marine operations,” *Ship Technol. Res.*, vol. 65, no. 3, pp. 137–152, 2018, DOI: 10.1080/09377255.2018.1473236.

[9] E. L. Nørgaard, “Defining and evaluating long-term operability of service vessels in exposed aquaculture,” M.Sc. thesis, Dept. Marine Technology, NTNU, Trondheim, NOR, 2019.

[10] P. Matamala, Á. Gallardo, C. Parra, J. M. Ahumada, C. Cifuentes, F. González and G. Tampier, “Numerical and experimental assessment of the hydrodynamic behavior of an attenuator wave energy converter device,” *Trends Renew. Energ. Offshore*, pp. 241–249, 2022.

[11] A. Babarit and G. Delhommeau, “Theoretical and numerical aspects of the open source BEM solver NEMOH”, presented at the *11th EWTEC*, Nantes, France, 2015.

[12] NORDFORSK, *Assessment of ship performance in a seaway*. Copenhage, Denmark, 1987.

[13] N. Jara, “Numerical derivation of operational limits using open source BEM-solver NEMOH”, “Obtención numérica de límites operacionales mediante uso del open source BEM-solver NEMOH,” M.Sc. thesis, Inst. of Naval Arch. And Oc. Engineering, UACh, Valdivia, CL, 2023.

[14] “Dirección Meteorológica de Chile.” 2023. [Online]. Available: https://www.meteochile.gob.cl/PortalDMC-web/

[15] “Sistema de Visualización de Instalaciones Portuarias - DIRECTEMAR website.” 2023. [Online]. Available: https://svip.directemar.cl/