



Design analysis of a wave energy converter for hydrogen generation near shoreline of Black Sea

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ABSTRACT

The generation of electricity from waves has attracted a lot of attention from researchers lately. Despite the vastness and accessibility of wave energy across the majority of the planet, there is a dearth of literature on the production of electricity and hydrogen from wave power. In this paper, a comprehensive simulation related to hydrogen production with an oscillating wave surge converter (OWSC) system was employed for the Black Sea region. The simulations were performed by means of Homer-Pro software and the data were provided thanks to European Marine Observation and Data Network (EMODnet) as well as a novel web-based tool with regards to wave resources. Initial results of web-based tool showed that the hydrogen generation was directly impacted by considerable wave height and wave energy period. As a result, it may change based on the days and months. May had the lowest monthly energy production (3 MWh), while December had the highest monthly energy production (27 MWh). Moreover, the electrolyzers with different efficiencies were investigated with Homer-Pro. The electrolyzer with an efficiency of 85% at 100 kW produced 3301 kg annually, whereas the electrolyzers with 90% and 95% efficiency at 100 kW produced 3419 kg annually and 3422 kg annually, respectively. Apart from those findings, when more efficient electrolyzers were employed in the system, both the capital and replacement costs dropped at the same time.

1. Introduction

In this part, the overview and literature studies will be handled. Also, the novelty of paper and its contribution to the literature will be highlighted in detail. Then, the paper organization will be mentioned to clearly understand at the rest of study.

1.1. Overview and literature studies

The biggest threats to environmental sustainability are carbon and greenhouse gas emissions, which are mostly caused by fossil fuels (Bashir et al., 2022; Bashir et al., 2023). In order to mitigate some of the effects of global pollution through the development of innovative technologies, researchers have begun comparing renewable low-reactivity fuel (LRF) with conventional fuels (Dalha et al., 2024a; Dalha et al., 2024b). Besides, in spite of obstacles like pandemic issues, economic downturns, etc., research and development of renewable energy technologies and ways to maximize the benefits of renewable

energy alternatives should continue to accelerate (Koca and Genc, 2020; Hüner and Telli, 2023). By the end of 2050, an estimated 7% of the world's electrical output will come from renewable energies including wave, wind, and tide power. This is in response to the unsustainable use of fossil fuels and the environmental damage that results from their widespread usage (Esteban and Leary, 2012). Wave energy is a highly appealing choice because of its favorable climatic conditions and high energy density. It is one of these renewable energies and a vast, largely unexplored ocean energy potential. The nearshore wave energy resource is frequently much lower than the deepwater resource. This notion, however, is frequently predicated on the omnidirectional or gross wave energy resource, which is only suitable for a small number of isolated heaving buoys that are axisymmetric. A more practical metric is actually the mean value of the directionally resolved incident wave energy, which is described as the exploitable wave energy resource (Whittaker and Folley, 2012). There are only 10–15% energy losses from the offshore to the nearshore according to this new definition. Because nearshore is located closer to the coast, installation and maintenance

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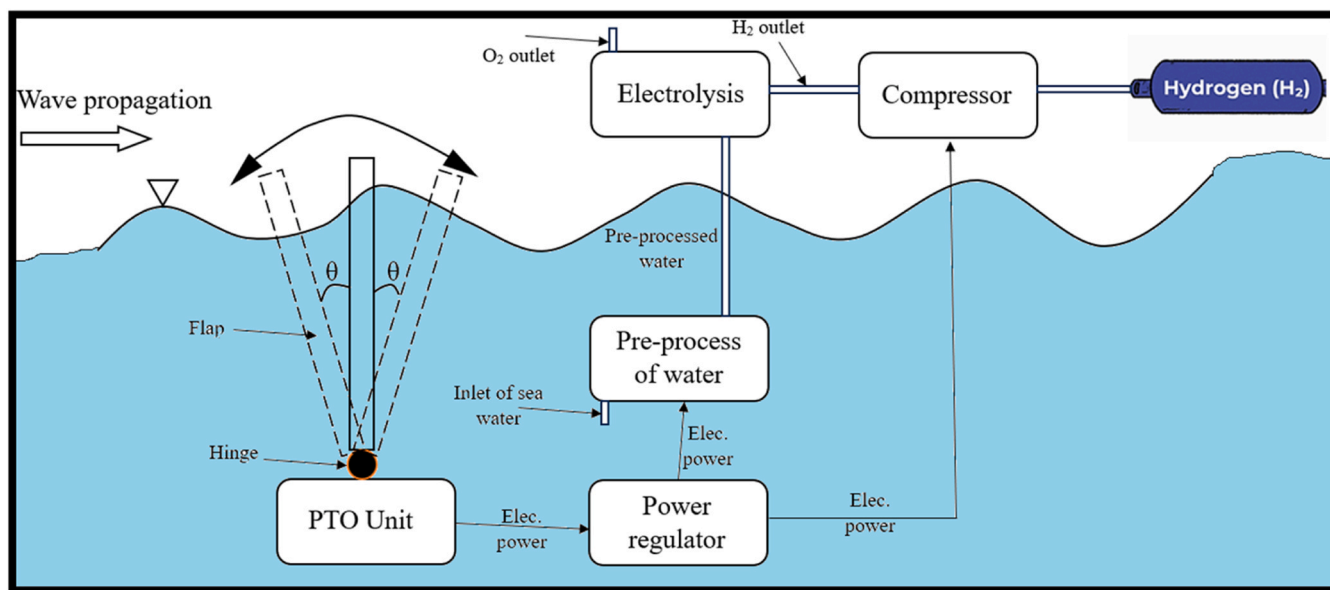


Fig. 1. Proposed OWSC system for both electricity and hydrogen production.

expenses are also lower there. Due to their straightforward mechanical and structural construction, The Oscillatory Wave Surge Converters (OWSCs) are quickly gaining popularity among the several wave energy converters (WECs) intended for coastal applications (Simonetti et al., 2018; Wang et al., 2018).

The OWSCs are the most practical WEC device yet created; they are capable of converting wave movements into a structural rotation. Given their versatility in operating under a wide range of wave conditions, the OWSC devices represent a potential option (Babarit et al., 2012; Babarit, 2015). Additionally, unlike most other WECs, this kind of WEC does not need to be tuned in resonance with the incident wave field in order to provide meaningful estimations of the power capture width (Renzi and Dias, 2013). When it comes to their yearly energy absorption estimations, they are said to be among the most efficient because of their design and operating mechanism, which effectively harness a significant quantity of hydrodynamic power (Zheng et al., 2023). It makes use of the sea wave's oscillating motion to produce power. In deep water, it is placed all the way to the ocean floor. Typically, a pumping system produces a high-pressure water flow using an oscillating wave surge converter. A turbine generator, which resembles a hydroelectric power conversion device, is struck by water. As a result, the turbine turns, producing power.

However, wave energy technologies have not yet attained the same degree of popular adoption with respectable power capacities. While significant efforts have been made to construct WEC systems like Pelamis (Henderson, 2006; Dalton et al., 2010), technical challenges seem to be standing in the way of achieving the desired outcomes. Few problems are as follows: (i) the necessity of situating the WEC system well out to sea, away from the coast, (ii) Long power cable that must be utilized to transport the generated electricity all the way to the coast, (iii) Because of the erratic power potential of the waves, a wave energy converter produces irregular power. The generated power is a dynamic function of the wave's period and amplitude, (iv) Regular maintenance of the WEC system is difficult to do because of the remote location of the offshore site, (v) The requirement for a protection mechanism to stop damages brought on by storms and other extreme situations involving the workplace.

Assuming that a system of this kind can be created, constructed, and put into operation, the WEC application would be a costly investment because to these technological challenges and associated disadvantages. But perhaps the new WEC application would become much more useful

and economical if some of these disadvantages could be overcome by bolstering the WEC system with an alternative green energy strategy. Hydrogen energy has the potential to alleviate certain issues encountered in WEC system development applications. Firstly, a lengthy power connection linking the WEC system to the main power grid on land is not necessary if the electrical power generated is utilized to manufacture hydrogen rather than transmitting it to the shore. Further, at the bottom of the deep sea, the produced hydrogen can be securely stored underwater and maintained at a low temperature. The efficiency of the system is further increased by locally storing the generated energy, which also removes the cable-based energy transfer losses.

As mentioned above, the inability of conventional WEC systems to manage the erratic level of electrical power generated is another problem. Because the acquired power is irregular, a unique kind of power regulation, conversion, and transfer technology is needed to move it to the main grid. In reality, though, the irregularly fluctuating energy form may be used to generate hydrogen with ease by turning on or running the required number of proton exchange membrane (PEM) generators at any given moment. The system may become significantly more cost-effective by producing hydrogen, which would increase its effectiveness. Consequently, by performing the maintenance and hydrogen collection chores concurrently, it could be possible to pay additional WEC system associated maintenance expenditures. To put it another way, the new strategy combines the advantages in a way that makes the weaknesses of each subsystem equal and strengthens the strong points.

1.2. Novelty of paper and study contributions

The objective of this current study is to provide both electricity and hydrogen production with a OWSC system installed in Black Sea. As illustrated in Fig. 1 belonging to the proposed OWSC system, a flap would make back and front motion with certain angles by means of existing of wave propagation. PTO unit would generate irregular electricity. The irregular electricity is then turned into the regular electricity via power regulator so as to utilize the power consumption of compressor and pre-process of water. In what follows, the pre-processed water splits up as O₂ and H₂ by means of electrolysis followed by utilizing compressor to keep H₂ into tanks. Current literature of the Black Sea wave energy lacks comprehensive investigations in conjunction with its potential, technical features, comparison of various energy resources,



Fig. 2. The study region.

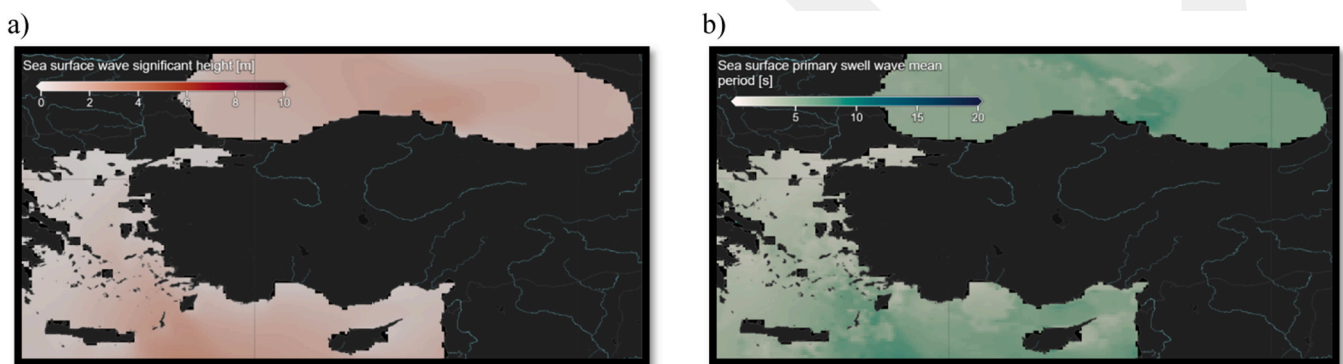


Fig. 3. Sea surface map, a) Significant wave height, b) Primary swell wave mean period.

monthly and yearly analysis, etc. In this regard, to fully grasp the potential for wave energy exploitation, it is critical to fill in these research gaps. In order to address the aforementioned drawbacks, the current work has made the following noteworthy additions and is novel:

- OWSC system among WECs will be studied and evaluated first time in the literature for Black Sea region.

- Apart from generating electricity from OWSC systems, the green-hydrogen production from those systems will be provided with its technical and financial analysis.

1.3. Paper organization

To encapsulate the paper’s structure: The methodological framework, comprising the study area and system description, is described in Section 2. Section 3 contains a record of the primary findings and

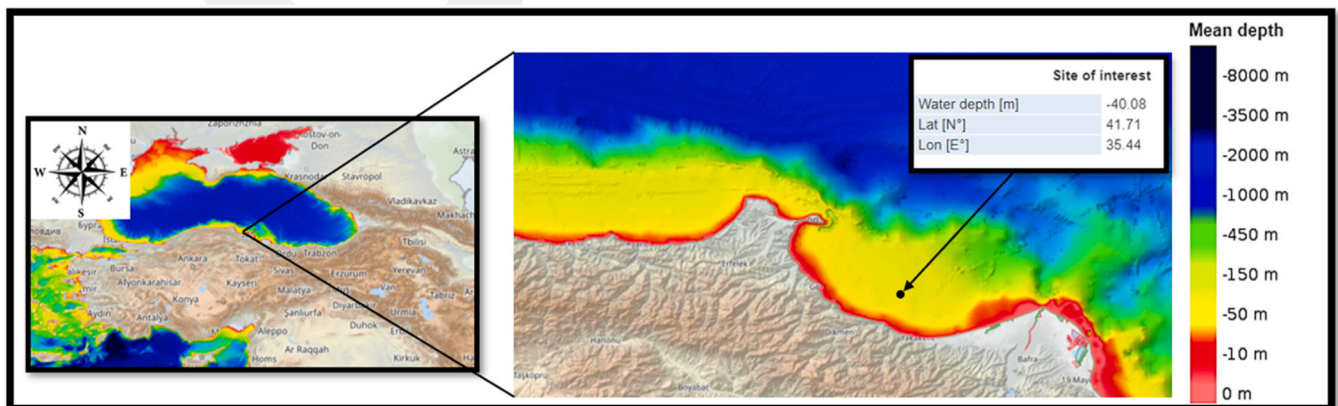


Fig. 4. Bathymetry map.

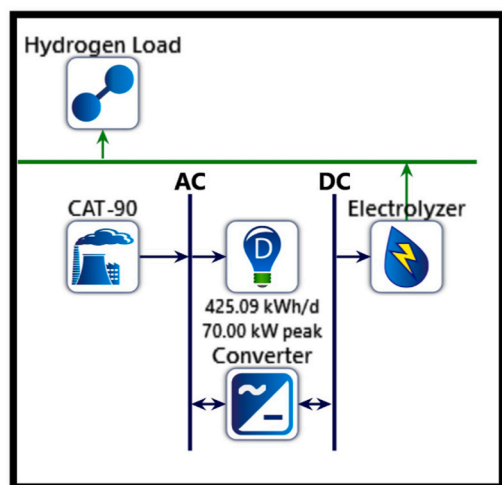


Fig. 5. System configuration.

conversations. In Section 4, the key conclusions are summarized.

2. Methodological framework

2.1. Study region

In the current study, the proposed OWSC system was designed close to Sinop province where it was Türkiye's northern tip, having coordinates of $41^{\circ}42'41.7''N$ and $35^{\circ}25'14.4''E$ as demonstrated in Fig. 2. According to the study performed by Görmüş et al. (Görmüş et al., 2024), there was a potential in terms of generating electricity from offshore renewable energy sources with wind and wave energy in Black Sea region. However, their findings did not have deep and technical information.

Secondly, the features of sea surface and bathymetric distribution would also provide information related to the study area of installation of wave power (Jadidoleslam et al., 2016). In this respect, sea surface and bathymetry maps were ensured as demonstrated in Fig. 3 and Fig. 4, respectively. Those graphs were obtained from Copernicus Marine Service (Official website of Copernicus Marine Service, 2024). According to the study related to the wave energy flux (Guillou, 2020), significant wave height and swell wave mean period play critical role in terms of the suitable locations of wave energy hot spot. It was clearly pointed out from Fig. 3 that the significant wave height was between 4 m and 6 m, while the swell mean period was distributed between 10 s and 15 s. In particular, higher swell wave mean period clearly demonstrated that there was higher energy wave potential close to Sinop province. Additionally, the value of water depth obtained from Fig. 4 seemed to be suitable for installation OWSC. Apart from those results, the findings of a research study (Acar et al., 2023) clearly matched well with the findings of current study. Therefore, this hot spot close to Sinop province was selected as study area to understand which scale both electricity and greener hydrogen production were provided.

2.2. System descriptions

This section included comprehensive details and descriptions of the HOMER-Pro program and data analysis.

2.2.1. HOMER-Pro configuration

Hybrid Optimization of Multiple Energy Resources (HOMER) is a simulation and modeling application that is widely used to provide guidelines for the optimal design and assessment of independent (Elmaadawy et al., 2020) and grid-connected energy systems (Jahangiri et al., 2019). These systems, which include any arrangement of various

components including fuel cells (FC), hydrogen storage, wind turbines (WT), generators (GEN), electrolyzers, battery energy storage (BAT), and solar photovoltaic (PV) modules, commonly supply hourly heat and electrical needs. HOMER has been used in a number of energy studies because of its dependability, consistent programming structure, and aesthetically pleasing user interface (Bahramara et al., 2016; Weinand et al., 2020). The KOCA Research Group has a licensed version of the HOMER-Pro software package available.

The system comprises, Hydrogen Load, different efficient Electrolyzers, converter as depicted in Fig. 5. Necessary data related to electricity from wave power for the electrolyzers was provided via a novel web-based tool. Those data were then imported to Homer-Pro software in order to analyze hydrogen production under 3 different the electrolyzers' efficiencies.

The values of hydrogen load for daily profile and monthly average were illustrated in Fig. 6. Related to the daily profile, it was noticed that the curve fluctuated during day. The curve reached the peak position when time was 18:00 all year round, meaning that hydrogen demand was the highest in this time. Also, it was seen that peak value was around at 0.31 kg/hr. For monthly averages, the highest average hydrogen load was seen in November with peak value of approximately 0.6 kg/hr. However, the community exhibited less demand in February, May and June.

2.2.2. Data analysis

All data were obtained from a novel web-based tool. This platform is a new web application that makes it easy to analyze wave resources and WEC productivity in European waters. Its objective is to assist the many parties involved in the wave energy industry, specifically: (i) WEC developers, with initial identification the qualities of potential locations for installation in the future, (ii) Energy planners, by incorporating WECs into medium- to long-term energy plans, (iii) Decision-makers and investors, with the purpose of determining viable locations for upcoming wave farms and for the investigation of the most suitable WEC typologies across various oceans.

In this regard, data analysis results for significant wave height and wave energy periods of selected region were provided in Fig. 7 and Fig. 8, respectively. Data were obtained between 2010 and 2019. According to monthly data of the significant wave height, the lowest value with nearly 2 m was observed in May, while it reached its maximum point with nearly 5 m in February. It was also noticed that there was a remarkable fluctuation at the transition months especially including April and May. In graph belonging to the yearly data, the lowest value was seen in 2015. Unlike the monthly data, there was no significant fluctuation for yearly data. Furthermore, the yellow line indicated the mean value of significant wave height. This value was approximately 1 m for both monthly and yearly data. Related to the values of wave energy period, the lowest value was seen with nearly 7 s in May. In particular, the period exceeded at 10 s in February for both graphs. For the mean value of wave energy period, it was generally observed between 4 s and 6 s except for February.

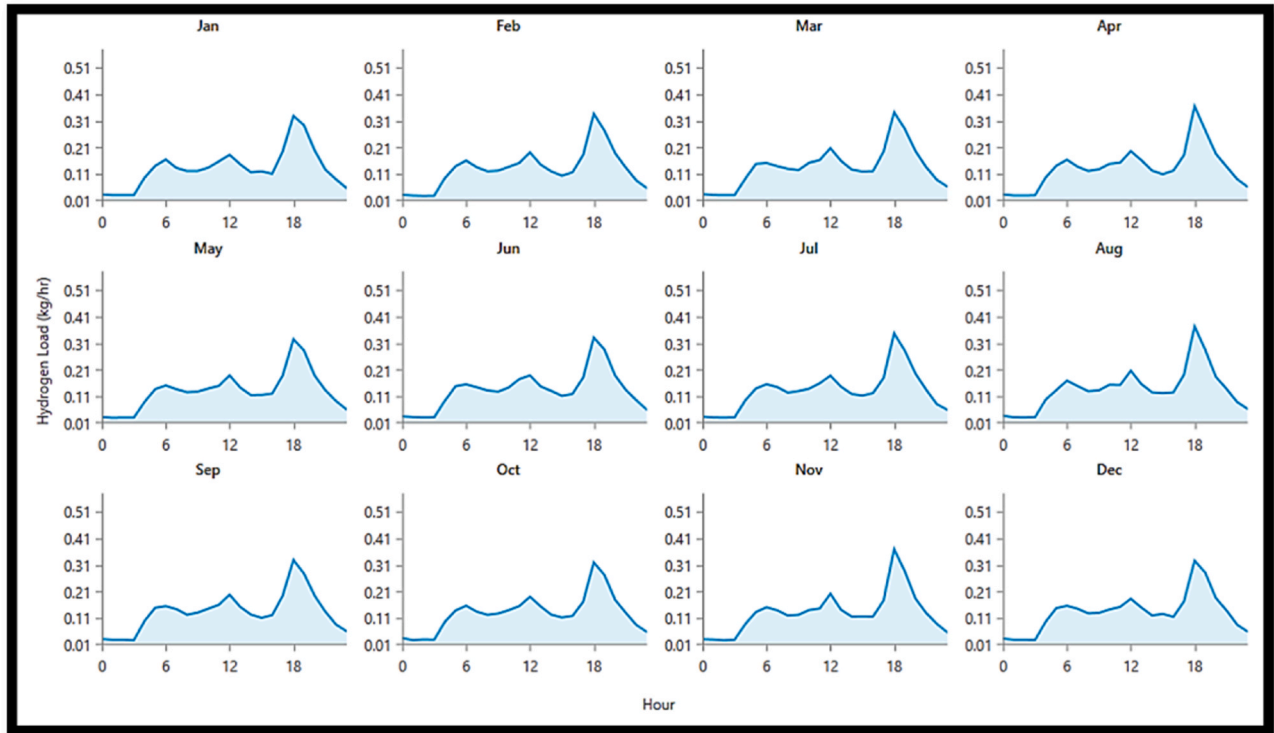
2.2.3. Research scenarios

In terms of better understanding of impact of electrolyzer efficiency on cost of total system, the optimization was performed by utilizing Homer-Pro. Concerning the research scenarios, 3 different scenarios by investigating different electrolyzer efficiency were fulfilled according to the criteria as follows: Electrolyzer at 100 kW with (i) 85% efficiency, (ii) 90% efficiency and (iii) 95% efficiency. At the rest of current study, 100 kW with 85%, 90% and 95% efficiencies were abbreviated and symbolized as C(1), C(2) and C(3), respectively.

3. Results and discussions

In this part, the results of monthly and yearly electricity generation from OWSC were discussed. Then, net present cost and total cost were

a)



b)

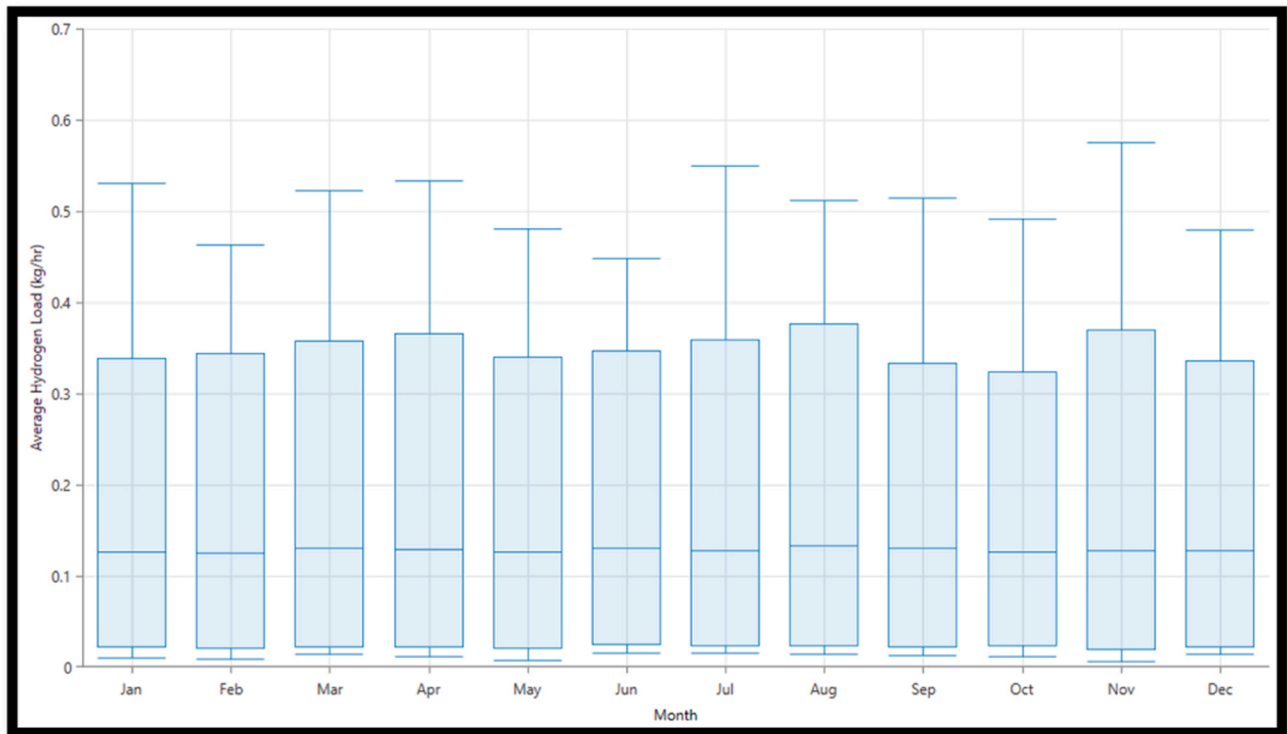


Fig. 6. Values of hydrogen load, a) Daily profile, b) Monthly averages.

highlighted by utilizing HOMER-Pro software. The total input energy as well as H₂ production were finally interpreted.

The power rose for OWSC was denoted in Fig. 9. This result was found by utilizing web page tool. It was pronouncedly pointed out that wave power was dominantly seen in North-West (NW) part and at 300°

and 300° with approximate value of 9 kW/m. Additionally, other strong part of wave energy was observed in North-East (NE) part and at 15° and 30°. Those values indicated that wave energy potentials at those locations were higher than other parts, referring suitable positions of OWSCs.

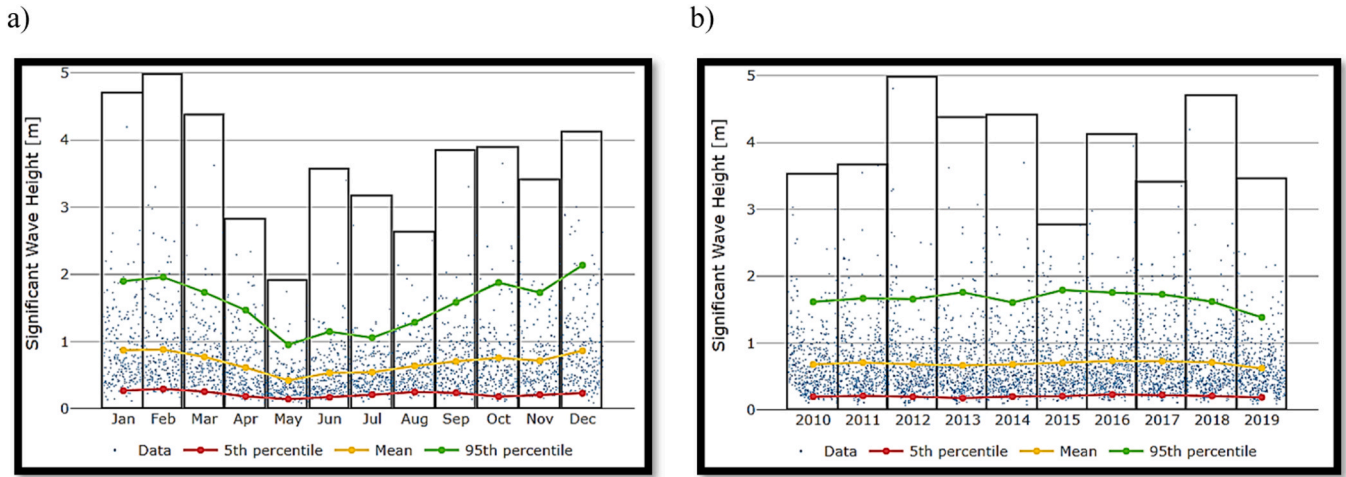


Fig. 7. Data analysis for significant wave height, a) monthly data, b) yearly data.

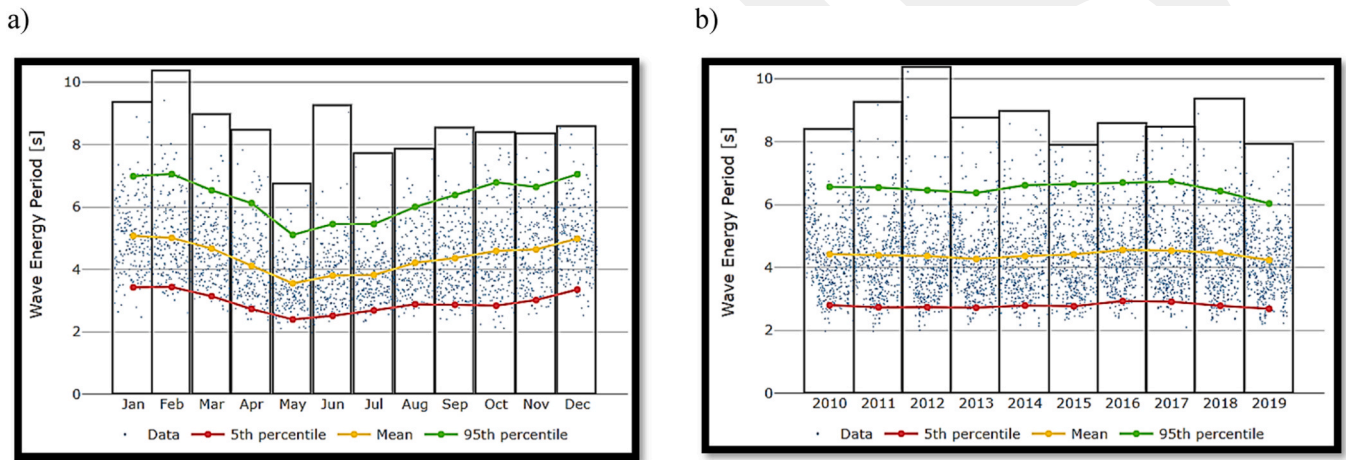


Fig. 8. Data analysis for wave energy period, a) monthly data, b) yearly data.

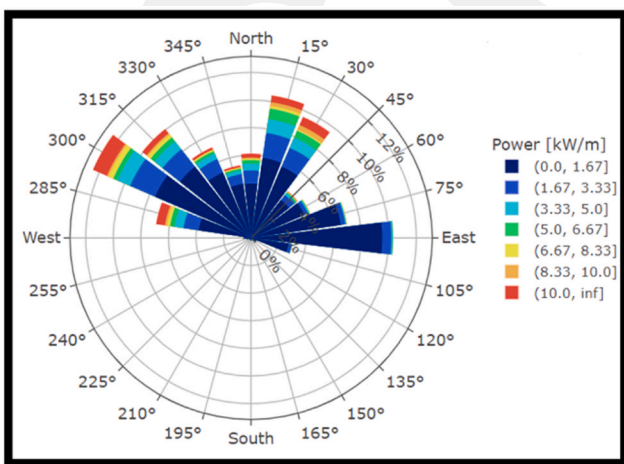


Fig. 9. Power rose of the selected hot point location.

The results of monthly energy production from OWSC were provided in Fig. 10. The maximum and minimum values were indicated with green and red lines, respectively, while the means values were demonstrated with the bars. The maximum values were nearly 43 MWh/month

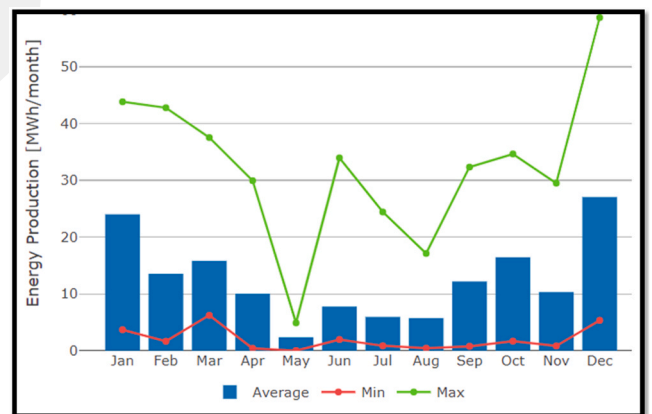


Fig. 10. Monthly energy production.

in January, and it decreased until May which was the deepest point. Between May and November, the maximum curve was fluctuated because of most probably existing unsteady wave behavior. It then reached with peak point with 60 MWh/month in December. Concerning mean energy production values, minimum and maximum values with 3 MWh/month and 27 MWh/month were observed in May and December, respectively. About the results of yearly energy production between

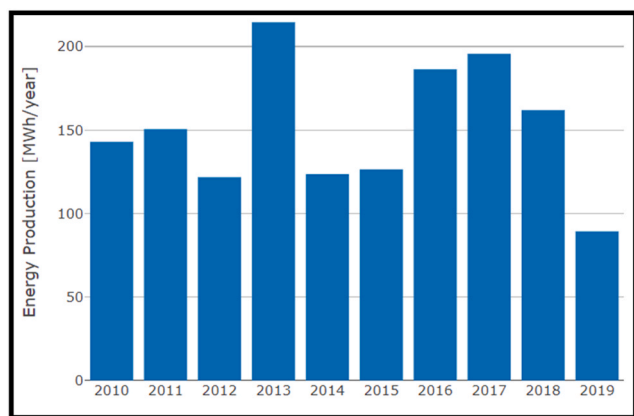


Fig. 11. Yearly energy production.

2010 and 2019 as denoted in Fig. 11, it was clearly observed that higher values were in 2013, 2016, 2017 and 2018. Unlike the monthly energy production, the fluctuation values were not seen on the bar since they were lumped values. Additionally, energy production from wave power decreased about 90% between 2017 and 2019.

The comprehensive findings related to the cost analysis including net present and total costs were provided for different electrolyzer efficiency scenarios in Fig. 12 and Fig. 13, respectively. Initial values of capital and replacement costs were \$6856 and \$2951, respectively. It was obviously noticed that those cost values decreased through different scenarios. Hydrogen production naturally increased with a 95% electrolyzer efficiency, requiring fewer capital and replacement expenditures. About the total cost, it demonstrated as pie graph. Yellow slice indicated the C(1), while purple and gray ones stand for C(2) and C(3) cases, respectively. C(1) part makes up 34% of the total, whereas the remaining sections are evenly distributed among themselves and make up 33% of the entire piece. Once more, this finding demonstrates that a decrease in net cost values is accompanied by a rise in electrolyzer efficiency.

Hydrogen production and total input energy data, which constituted the main framework of this study, were tabulated as illustrated in Table 1 and Table 2. For the total hydrogen production, 3301 kg/yr was obtained when the electrolyzer with 85% efficiency was utilized in the system. It was clearly observed that when electrolyzer efficiency rose at the same time, so did the overall amount of produced hydrogen. In contrast to hydrogen generation, the total input energy exhibited different scenarios. It was 153206 kWh/yr when C(1) was employed in the system. However, it slightly decreased when electrolyzer efficiency increased. All detailed information were demonstrated in the Tables.

4. Conclusion

A wave power system for hydrogen production was proposed in the present study. As wave energy conversion system, OWSC was installed at the Black Sea region. In what follows, yielding power was utilized hydrogen production via electrolyzer which had different efficiency with Homer-Pro software. Initial findings demonstrated that significant wave height and wave energy period directly affected the hydrogen generation. Therefore, it might vary depending on the months and days. The lowest monthly energy production of 3 MWh was recorded in May, and the highest monthly energy production of 27 MWh was recorded in December. About yearly energy production, higher values were recorded in 2013, 2016, 2017 and 2018. In the light of yielding energy production from OWSC, electrolyzers with 3 different efficiencies exhibited 3 different cases. Electrolyzer at 100 kW with 85% efficiency (C(1)) produced 3301 kg/yr, while electrolyzers at 100 kW with 90% and 95% efficiency (C(2) and C(3)) generated 3419 kg/yr and 3422 kg/yr, respectively. Apart from hydrogen production analysis, the detailed costs analysis was employed in the study. The replacement and capital expenses of the electrolyzer with the lowest efficiency were \$2951 and \$6856, respectively. Also, it was observed that those values simultaneously decreased when electrolyzers with higher efficiencies were employed in the system.



Fig. 12. Net present costs of different scenarios (Unit is \$).

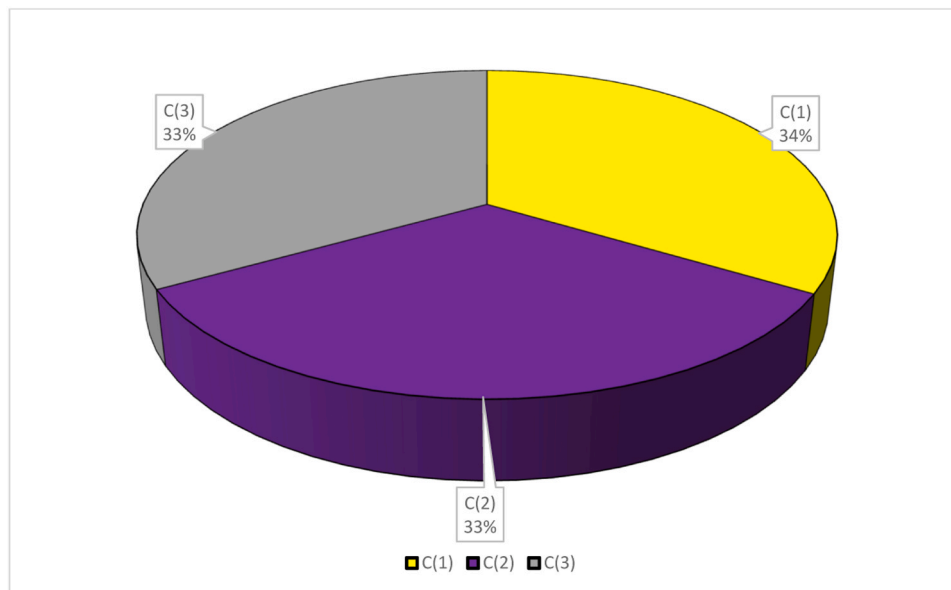


Fig. 13. Total cost of different scenarios (Unit is \$).

Table 1

Summary of H₂ production for different scenarios.

Quantity	C(1)	C(2)	C(3)
Mean output (kg/hr)	0.377	0.39	0.39
Minimum output (kg/hr)	0.00571	0.00571	0.00571
Maximum output (kg/hr)	0.5	0.479	0.479
Specific consumption (kWh/kg)	46.4	43.8	41.5
Total H₂ production (kg/yr)	3301	3419	3420

Table 2

Statistics of input energies for different scenarios.

Quantity	C(1)	C(2)	C(3)
Rated capacity (kW)	100	100	100
Mean input (kW)	17.5	17.1	16.2
Minimum input (kW)	0.265	0.25	0.237
Maximum input (kW)	23.2	21	19.9
Capacity factor (%)	17.5	17.1	16.2
Hours of operation (hr/yr)	8760	8760	8760
Total input energy (kWh/yr)	153206	149865	141984

CRedit authorship contribution statement

Muhammad Farhan Bashir: Formal analysis, Software, Writing – original draft. **Kemal Koca:** Supervision, Validation, Writing – original draft, Writing – review & editing. **Eyüp Bekçi:** Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Acar, E., Akpinar, A., Kankal, M., Amarouche, K., 2023. Increasing trends in spectral peak energy and period in a semi-closed sea. *Renew. Energy* 205, 1092–1104. <https://doi.org/10.1016/j.renene.2023.02.007>.
- Babarit, A., 2015. A database of capture width ratio of wave energy converters. *Renew. Energy* 80, 610–628. <https://doi.org/10.1016/j.renene.2015.02.049>.

- Babarit, A., Hals, J., Muliawan, M.J., Kurniawan, A., Moan, T., Krokstad, J., 2012. Numerical benchmarking study of a selection of wave energy converters. *Renew. Energy* 41, 44–63. <https://doi.org/10.1016/j.renene.2011.10.002>.
- Bahramara, S., Moghaddam, M.P., Haghifam, M.R., 2016. Optimal planning of hybrid renewable energy systems using HOMER: A review. *Renew. Sustain. Energy Rev.* 62, 609–620. <https://doi.org/10.1016/j.rser.2016.05.039>.
- Bashir, M.F., Benjiang, M.A., Hussain, H.I., Shahbaz, M., Koca, K., Shahzadi, I., 2022. Evaluating environmental commitments to COP21 and the role of economic complexity, renewable energy, financial development, urbanization, and energy innovation: empirical evidence from the RCEP countries. *Renewable Energy* 184, 541–550. <https://doi.org/10.1016/j.renene.2021.11.102>.
- Bashir, M.F., Ma, B., Sharif, A., Ao, T., Koca, K., 2023. Nuclear energy consumption, energy access and energy poverty: Policy implications for the COP27 and environmental sustainability. *Technology in Society* 75, 102385. <https://doi.org/10.1016/j.techsoc.2023.102385>.
- Dalha, I.B., Koca, K., Said, M.A., Rafindadi, A.D., 2024a. Biogas Intake Pressure and Port Air Swirl Optimization to Enhance the Diesel RCCI Engine Characteristics for Low Environmental Emissions. *Process Safety and Environmental Protection* 184, 703–719. <https://doi.org/10.1016/j.psep.2024.02.038>.
- Dalha, I.B., Koca, K., Said, M.A., Rafindadi, A.D., 2024b. Predicting the Effects of Direct-Injected Fuels Co-Powered by High-CO₂ Biogas on RCCI Engine Emissions using Kinetic Mechanisms and Multi-Objective Optimization. *Process Safety and Environmental Protection* 184, 747–765. <https://doi.org/10.1016/j.psep.2024.02.026>.
- Dalton, G.J., Alcorn, R., Lewis, T., 2010. Case study feasibility analysis of the Pelamis wave energy converter in Ireland, Portugal and North America. *Renew. Energy* 35 (2), 443–455. <https://doi.org/10.1016/j.renene.2009.07.003>.
- Elmaadawy, K., Koth, K.M., Elkadeem, M.R., Sharshir, S.W., Dán, A., Moawad, A., Liu, B., 2020. Optimal sizing and techno-enviro-economic feasibility assessment of large-scale reverse osmosis desalination powered with hybrid renewable energy sources. *Energy Convers. Manag.* 224, 113377. <https://doi.org/10.1016/j.enconman.2020.113377>.
- Esteban, M., Leary, D., 2012. Current developments and future prospects of offshore wind and ocean energy. *Appl. Energy* 90 (1), 128–136. <https://doi.org/10.1016/j.psep.2023.11.078>.
- Görmüş, T., Aydoğan, B., Ayat, B., 2024. Analysis of hybrid exploitation of wind and wave power in the Mediterranean and the Black Sea. *Energy Convers. Manag.* 299, 117820. <https://doi.org/10.1016/j.enconman.2023.117820>.
- Guillou, N., 2020. Estimating wave energy flux from significant wave height and peak period. *Renew. Energy* 155, 1383–1393. <https://doi.org/10.1016/j.renene.2020.03.124>.
- Henderson, R., 2006. Design, simulation, and testing of a novel hydraulic power take-off system for the Pelamis wave energy converter. *Renew. Energy* 31 (2), 271–283. <https://doi.org/10.1016/j.renene.2005.08.021>.
- Hüner, B., Telli, E., 2023. Design and performance analysis of a green house based on hybrid and passive energy systems: A case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45 (4), 12859–12879. <https://doi.org/10.1080/15567036.2023.2276907>.
- Jadidoleslam, N., Özger, M., Ağralıoğlu, N., 2016. Wave power potential assessment of Aegean Sea with an integrated 15-year data. *Renew. Energy* 86, 1045–1059. <https://doi.org/10.1016/j.renene.2015.09.022>.
- Jahangiri, M., Haghani, A., Shamsabadi, A.A., Mostafaeipour, A., Pomares, L.M., 2019. Feasibility study on the provision of electricity and hydrogen for domestic purposes

- in the south of Iran using grid-connected renewable energy plants. *Energy Strategy Rev.* 23, 23–32. <https://doi.org/10.1016/j.esr.2018.12.003>.
- Koca, K., Genc, M.S., 2020. Effects of 2019 novel coronavirus (COVID-19) outbreak on global energy demand and the electricity production with renewables: a comprehensive survey. *Sigma Journal of Engineering and Natural Sciences* 38 (3), 1369–1380.
- Official website of Copernicus Marine Service, (<https://marine.copernicus.eu/>), last accessed 2024/01/25.
- Renzi, E., Dias, F., 2013. Hydrodynamics of the oscillating wave surge converter in the open ocean. *Eur. J. Mech. -B/Fluids* 41, 1–10. <https://doi.org/10.1016/j.euromechflu.2013.01.007>.
- Simonetti, I., Cappiotti, L., Elsafti, H., Oumeraci, H., 2018. Evaluation of air compressibility effects on the performance of fixed OWC wave energy converters using CFD modelling. *Renew. Energy* 119, 741–753. <https://doi.org/10.1016/j.renene.2017.12.027>.
- Wang, R.Q., Ning, D.Z., Zhang, C.W., Zou, Q.P., Liu, Z., 2018. Nonlinear and viscous effects on the hydrodynamic performance of a fixed OWC wave energy converter. *Coast. Eng.* 131, 42–50. <https://doi.org/10.1016/j.coastaleng.2017.10.012>.
- Weinand, J.M., Scheller, F., McKenna, R., 2020. Reviewing energy system modelling of decentralized energy autonomy. *Energy* 203, 117817. <https://doi.org/10.1016/j.energy.2020.117817>.
- Whittaker, T., Folley, M., 2012. Nearshore oscillating wave surge converters and the development of Oyster. *Philos. Trans. R. Soc. A: Math., Phys. Eng. Sci.* 370 (1959), 345–364. <https://doi.org/10.1098/rsta.2011.0152>.
- Zheng, S., Phillips, J.W., Hann, M., Greaves, D., 2023. Mathematical modelling of a floating Clam-type wave energy converter. *Renew. Energy* 210, 280–294. <https://doi.org/10.1016/j.renene.2023.04.040>.