Record-breaking 2023 marine heatwaves raise alarms for ocean energy infrastructure

Tianyun Dong,[1,2,3] Yuntian Chen,[1,*] and Zhenzhong Zeng[2,4,5,*]

[1]Zhejiang Key Laboratory of Industrial Intelligence and Digital Twin, Eastern Institute of Technology, Ningbo 315200, China
[2]School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China
[3]Department of Electronic Engineer and Information Science, University of Science and Technology of China, Hefei 230026, China
[4]State Key Laboratory of Soil Pollution Control and Safety, Southern University of Science and Technology, Shenzhen 518055, China
[5]SUSTech Energy Institute for Carbon Neutrality, Southern University of Science and Technology, Shenzhen 518055, China
*Correspondence: ychen@eitech.edu.cn (Y. C.); zengzz@sustech.edu.cn (Z. Z.)

Received: July 6, 2025; Accepted: September 19, 2025; Published Online: October 10, 2025; https://doi.org/10.59717/j.xinn-energy.2025.100120

Citation: Dong T., Chen Y. and Zeng Z. (2025). Record-breaking 2023 marine heatwaves raise alarms for ocean energy infrastructure. *The Innovation Energy* 2:100120.

Marine heatwaves (MHWs) pose escalating threats to offshore renewable energy infrastructure by intensifying thermal stress on floating photovoltaic systems and disrupting wind energy generation through altered atmospheric conditions. The unprecedented severity of global MHWs in 2023, far exceeding historical norms, highlights critical vulnerabilities in ocean-based energy systems. Integrating MHWs forecasting into infrastructure planning will be essential to ensure energy reliability and resilience against future climate extremes.

Marine heatwaves (MHWs), defined as prolonged periods of unusually warm ocean temperature, are emerging not only as a threat to marine ecosystems but also as a growing risk to global energy infrastructure. These extreme events can strain floating photovoltaic systems, offshore wind farms, and coastal energy facilities by intensifying thermal loads, altering wind regimes, and increasing maintenance demands. As the world accelerates its transition to ocean-based renewable energy, the mounting frequency and severity of MHWs expose a critical frontier in climate vulnerability, where environmental extremes collide with energy resilience.

The year 2023 was officially declared the warmest on record "by a huge margin" according to the World Meteorological Organization (WMO),[1] with both global sea surface temperature (SST) and ocean heat content reaching unprecedented highs.[2] Reports from European Centre for Medium-Range Weather Forecasts (ECMWF)[3] and the UK Met Office[4] confirmed that the North Atlantic experienced its hottest June on record, with SST warming reaching 1.3 °C above average. NASA climate director Gavin Schmidt emphasized that the urgent need to understand why 2023 became the warmest year on record by such a large margin.[5] A new study published in *Science* by Dong *et al.*[6] reveals that Global MHWs activity in 2023 reached an extraordinary 53.6 billion °C·days·km^2, which is hypothetically equivalent to boiling the entire global ocean for two full days. This value is more than three standard deviations above the 1982–2022 average of 15.1 billion °C·days·km^2, and significantly exceeds the previous record set in 2016 (37.3 billion °C·days·km^2). These MHWs shattered previous records in global average intensity, duration, and spatial extent, while exhibiting pronounced regional differences. Events in the North Atlantic and Southwest Pacific were particularly extreme, with estimated return periods of 276 (less than 0.36% probability) and 141 (less than 0.71% probability) years, respectively. These climate extremes are not just harbingers of oceanic disruption—they are a critical test of how well our energy systems can adapt.

MHWs are increasingly recognized as a threat to offshore renewable energy infrastructure. High cloud cover reduces incoming solar radiation and limits energy output, while elevated SST can overheat photovoltaic (PV) panels, lowering conversion efficiency and accelerating material degradation.[7] Dong *et al.*[6] demonstrated that in the North Atlantic, reduced cloud cover and weakened winds enhanced solar shortwave radiation and shallowed the ocean mixed layer, amplifying surface warming. Similarly, in the Southwest Pacific, decreased cloudiness and intensified meridional heat transport contributed to persistent heat accumulation. These physical drivers not only sustained extreme SST anomalies but also heightened thermal and operational stress on floating PV systems (Figure 1). Prolonged MHWs exacerbate these risks, increasing maintenance needs, shortening system lifespan, and reducing energy reliability.

Moreover, extreme ocean warming may disrupt offshore wind energy production by altering atmospheric circulation and shifting wind regimes,[7] further exposing marine energy systems to climate-driven volatility. Dong *et al.*[6] showed that wind fields in the North Atlantic and North Pacific weakened significantly during the 2023 marine heatwaves. This reduction in surface winds not only suppressed latent heat release, contributing to further surface warming, but also reduced ocean mixing and circulation. Such changes in wind strength and structure may compromise wind farm efficiency and complicate future site selection,[8] highlighting the need to integrate coupled ocean–atmosphere dynamics into offshore energy planning.

Intensifying marine heatwaves pose growing risks to offshore energy infrastructure. On the one hand, marine heatwaves, i.e., extreme SST anomalies may compromise the structural stability of offshore oil and gas platforms, placing additional strain on safety mechanisms and cooling systems.[9] On the other hand, SST significantly influences the dispersion pathways and extent of oil spills, potentially causing severe ecological damage to coastal ecosystems.[9] Moreover, warming oceans contribute to more frequent and intense extreme weather events, such as hurricanes and storm surges, which further increase the risk of platform damage and operational disruptions.[10] Despite these escalating threats, most existing energy system models lack integration of marine heatwaves and other extreme oceanic climate variables. Incorporating MHW forecasts and conducting climate sensitivity analyses will be critical for improving the reliability and resilience of energy infrastructure, especially as offshore development expands.

As marine heatwaves become more frequent and intense, integrating MHW research into offshore energy planning offers a vital pathway to enhance the adaptive capacity of energy systems. At the decision-making level, this includes integrating MHW early warning systems into operational risk management frameworks, dynamically adjusting maintenance schedules during high-risk periods, and optimizing the siting of floating photovoltaic and offshore wind systems based on historical and projected thermal stress exposure. On the supply and operations side, a range of adaptive measures can be implemented, such as enhancing the resilience of cooling systems, using heat-resistant materials, deploying thermal buffering technologies, and reinforcing structural components to withstand the compound stress of extreme sea surface temperatures and intensified storms. A comprehensive understanding of how extreme ocean conditions affect energy system performance is essential for developing future energy strategies that are robust, flexible, and climate-resilient.

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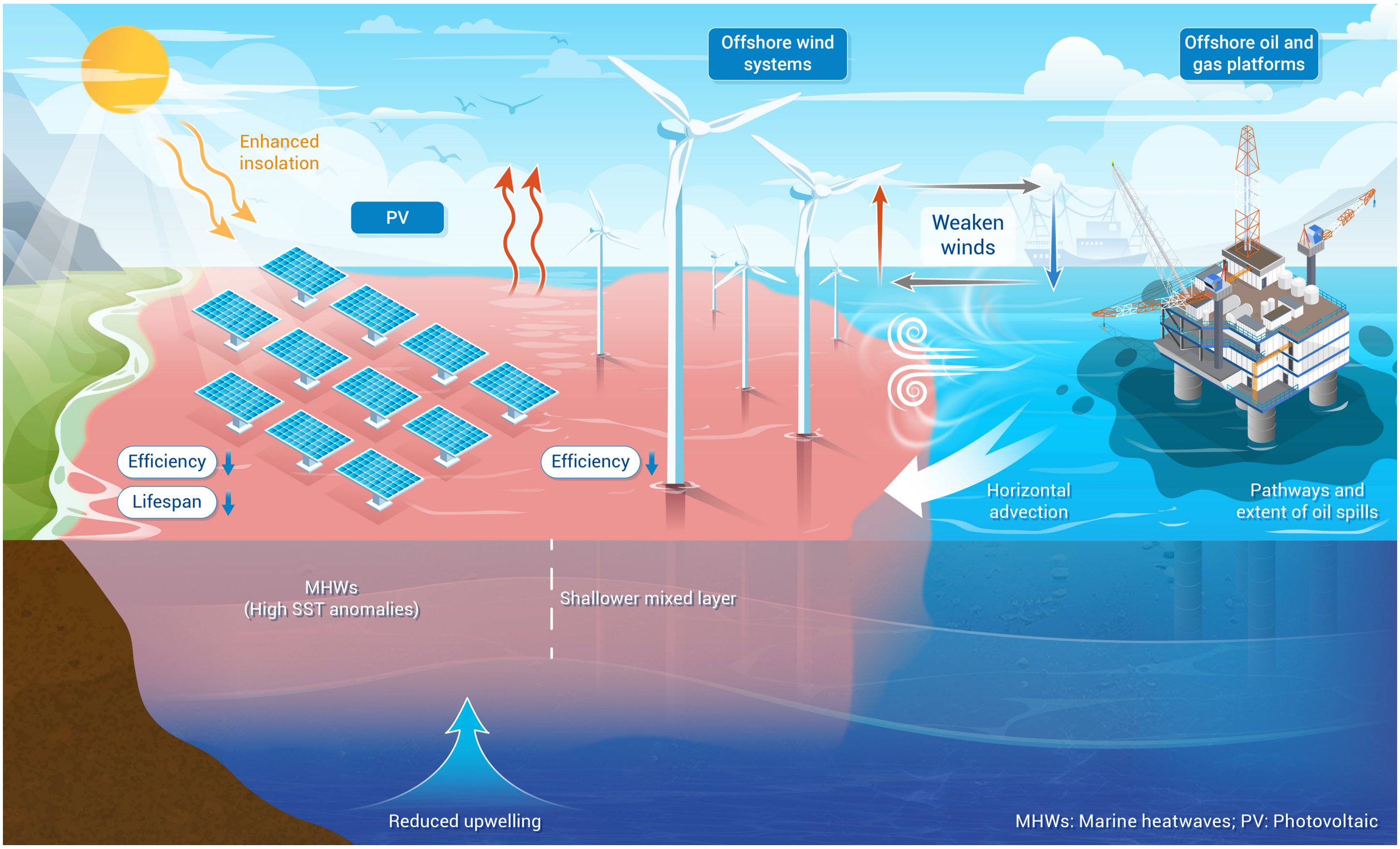

Figure 1. Schematic illustration of marine heatwave (MHW) impacts on offshore energy infrastructure. MHWs lead to shallower mixed layers and reduced upwelling, weakening winds and reducing efficiency of offshore wind systems. Enhanced MHWs decrease photovoltaic (PV) efficiency and shorten system lifespan, while offshore oil and gas platforms are exposed to additional thermal stress.

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FUNDING AND ACKNOWLEDGMENTS

This study was supported by Guangdong Basic and Applied Basic Research Fund (2022A1515240070), Shenzhen Science and Technology Project for Sustainable Development in Special Innovation (KCXFZ20230731093403008), the National Natural Science Foundation of China (12572266), SUSTech High Level of Special Funds (G03034K001, G030290001). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.