OECONOMIA
COPERNICANA

VOLUME 17 ISSUE 1 2026

p-ISSN 2083-1277, e-ISSN 2353-1827
https://oeconomiacopernicana.com/

Received: 29.01.2026; Revised: 13.02.2026, Accepted: 29.03.2026, Published Online: 14.04.2026

UNLEASHING THE POTENTIAL OF OFFSHORE SOLAR POWER AND THE AQUACULTURE SECTOR FOR A SUSTAINABLE MARINE ECONOMY

Mohd Alsaleh[a]* and A.S. Abdul-Rahim[b,c]
a College of Economics and Management, Shanghai Ocean University, Shanghai, China
[b] School of Business and Economics, Universiti Putra Malaysia, Malaysia
[c] Institute of Tropical Agriculture & Food Security (ITAFoS), Universiti Putra Malaysia, Malaysia
*Corresponding Author: Mohd Alsaleh (moe_saleh222@hotmail.com)

Abstract

In 2014, the European Union (EU) policy panel launched the Marine Action Plan (MAP), aiming to promote the development of marine energy and provide a clear development direction and policy support for blue growth and marine sustainability. It is of great significance to objectively evaluate the effects of the policies on the implementation and improvement of the policy itself. Based on the panel data of 27 members of the European Union from 1990 to 2023, this study uses the policies to construct the heterogeneous timing difference-in-difference model to evaluate the impacts of transformation policies on the offshore solar power and aquaculture integrating projects development in the European Union members. This study found that the policies have a significant role in promoting offshore solar panel production among Western European Union members but not Central and Eastern European Union members. Moreover, the policies have a significant impact on offshore solar power and aquaculture integration projects in Western European countries in comparison to the Central and Eastern European countries. These outcomes were verified by a placebo test, showing that the policy is effective, and put forward some suggestions for the further promotion of the transformation of offshore solar power projects.

Keywords: Offshore solar power; aquaculture; Marine action plan; marine environment; regulation quality

1- Introduction

In the European Union (EU27), there is a growing trend of integrating offshore solar energy and aquaculture, with some ongoing projects and initiatives demonstrating the potential for synergy between the two sectors. Offshore renewable energy, including offshore solar, is crucial for the EU's 2050 energy strategy and the European Green Deal. The EU has set ambitious goals for the marine renewables industry, planning to scale it up five-fold by 2030 and 25-fold by 2050. Although offshore wind power is the most developed, research and testing on other technologies, such as solar power, are also advancing. The EU aims to have at least 42.5% of renewable energy by 2030 (Magkouris et al., 2023). Specifically, for ocean energy, the goal is to have at least 1 GW of installed capacity by 2030 and 40 GW by 2050. While the EU aquaculture sector is growing steadily. In 2021, it ranked 11th globally, accounting for 0.9% of the global output. It encompasses various forms such as fish farming, shellfish farming, algaculture, and the algae sector (Magkouris et al., 2023).

Directives such as the Renewable Energy Directive 2009/28/EC, the Offshore Safety Directive 2013/30/EU, the Marine Strategy Framework Directive 2008/56/EC, Marine Spatial Planning Directive 2014/89/EU have been issued. These directives set standards, licensing requirements, and operational policies for the development of offshore renewable energy projects, covering aspects such as promoting renewable energy sources, ensuring offshore operation safety, and protecting the marine environment, providing a legal guarantee for the development of offshore solar power.

In the EU27, many projects combined the two sectors, for example, (1) Blue Growth Farm Project; (2) AQUAWIND; and (3) OLAMUR Project. These combined projects come with significant advantages but not without serious challenges for the EU27 members. Advantages of offshore solar power integration with aquaculture projects (Costoya et al., 2022): (1) The shared use of infrastructure can reduce the costs of both offshore solar energy and aquaculture projects. For example, the power generated by offshore solar panels can be used to power aquaculture equipment, reducing the need for separate power supply facilities. (2) The synergetic development of the two sectors enables more efficient use of marine space, addressing the issue of limited marine space. It also helps to reduce the conflict between different marine industries over space. (3) Offshore solar energy is a clean and renewable energy source, and its combination with aquaculture helps to reduce the carbon footprint of the aquaculture industry.

The main challenges of offshore solar power integration with aquaculture projects in the EU27 members (Nguyen and Wang, 2024): (1) Technical challenges, there are technical difficulties in integrating offshore solar energy equipment with aquaculture facilities. For example, the stability of solar panels in the marine environment and their impact on the growth of aquaculture species need to be further studied and optimized. The solution requires continuous research, development, and testing to improve the technical level of integration. (2) Regulatory and policy issues, the development of offshore solar-aquaculture projects needs to comply with relevant marine regulations and policies, including those related to marine space planning, environmental protection, and fishing rights. Coordination among different departments and the formulation of an efficient roadmap are required to ensure the smooth activation of projects. (3) Economic viability, the initial investment in offshore solar-aquaculture projects is relatively high, and there are certain risks.

To overcome these main challenges, the EU27 has proposed a series of policies to integrate aquaculture with marine energy, aiming to promote the sustainable development of the aquaculture and marine energy industries while reducing their impact on the marine ecosystem. The main policies are as follows (Vlaswinkel et al., 2023): (1) the "Energy Transition Partnership for EU Fisheries and

Aquaculture" will be established to bring together stakeholders and regional authorities to jointly address the challenges of the sector's energy transition. (2) The EU supports the sector in accelerating its energy transition by improving fuel efficiency and switching to renewable, low-carbon power sources, to achieve climate-neutral aquaculture by 2050, in line with the European Green Deal's ambition to reach climate neutrality in the EU by 2050. (3) The EU27 policy has provided financial support for relevant projects. For example, it has funded the OLAMUR project with 8.2 million euros.

Therefore, this research questions as following question: (1) To what extent does the policy implementation of offshore solar power projects in the aquaculture sector in the EU affect the blue economy in the EU during the period between 1990 and 2023? (2) To what extent do different EU27 member states benefit in terms of blue growth from the integration of offshore solar power and aquaculture practices policy? Accordingly, this research objective can be stated as follows: (1) To explore how offshore solar power deployment policy in the EU27 is being integrated with aquaculture activities for the period between 1990-2023, and to what extent this integration policy of 2014 impacts blue growth. (2) To compare the experiences of different EU27 member states in implementing offshore solar power projects in aquaculture, and assess which models and policies are most effective in blue growth. (3) To analyze the social, economic, and environmental dimensions of offshore solar power integration policy with aquaculture, and understand how these dimensions interact to influence blue energy and marine energy during the same period.

By segregating the EU27 members into two groups based on economic structure and development, this research can identify the differences and characteristics of different economies within the EU. Group 1 is the European Union industrial countries (Western EU14) and consists of economically developed and diversified economies with high GDP per capita, advanced service-oriented structures, and strong innovation capacities. The EU14 members, such as Belgium, Spain, and the Netherlands, are notable for their proactive approach to aquaculture offshore solar-powered policy, while these nations have been developing 2014 regulatory frameworks, implementing support schemes, and hosting pilot projects (see Figure 1).

Group 2 is European Union emerging countries (Central and Eastern EU13), which includes economies in transition or with underdevelopment economies, which have lower GDP per capita, industrial structures in the process of transformation, and relatively lower innovation capacities. EU27 policies like the European Green Deal and the Common Agricultural Policy (CAP) strongly influence EU13's newer economies. These policies push for renewable energy adoption and sustainable aquaculture, creating a framework for the Marine Action Plan (MAP). Therefore, the increase of EU-wide policies regarding marine action plans has greatly increased the adoption of aquaculture offshore solar-powered projects in EU13 economies. For example, countries within the Central and Eastern European region are beginning to implement aquaculture offshore solar-powered projects and are creating legislation to support the growth of this sector.

The significance and novelty of offshore solar power and aquaculture-related research using the difference-in-difference method lie in the following aspects: (1) Through the applied difference-in-difference method, this research can effectively evaluate the impact of offshore solar power and aquaculture-related policies in 2014 by assessing the implementation effect of a policy that promotes the construction of offshore photovoltaic–aquaculture complexes. The research results can provide a scientific basis for formulating relevant policies, optimizing policy design, and improving policy-making accuracy and effectiveness. (2) By applying the difference-in-difference method, this research accurately analyzes the changes in the utilization efficiency of marine resources, renewable sources, and other resources before and after the implementation of offshore solar power and aquaculture integrated policies in 2014. (3) The difference-in-difference method in this research can evaluate the long-term impact of offshore solar power and aquaculture integrated policy on the marine ecological environment, economic development, and social welfare. It helps to identify potential problems and challenges in the development process and provides solutions to promote the healthy and sustainable development of the offshore solar power and aquaculture industry.

Structure of the study, the remainder of this study is organized as follows: (1) Literature Review, this section examines recent research in the field, considering both empirical and theoretical perspectives. (2) Data and Methodology, this section outlines the model specification and details the panel data estimators employed in the analysis. (3) Empirical Results, this section presents the estimation results obtained from the panel data estimators. (4) Discussion and Conclusion: This section discusses the key findings, explores their implications, and provides concluding remarks.

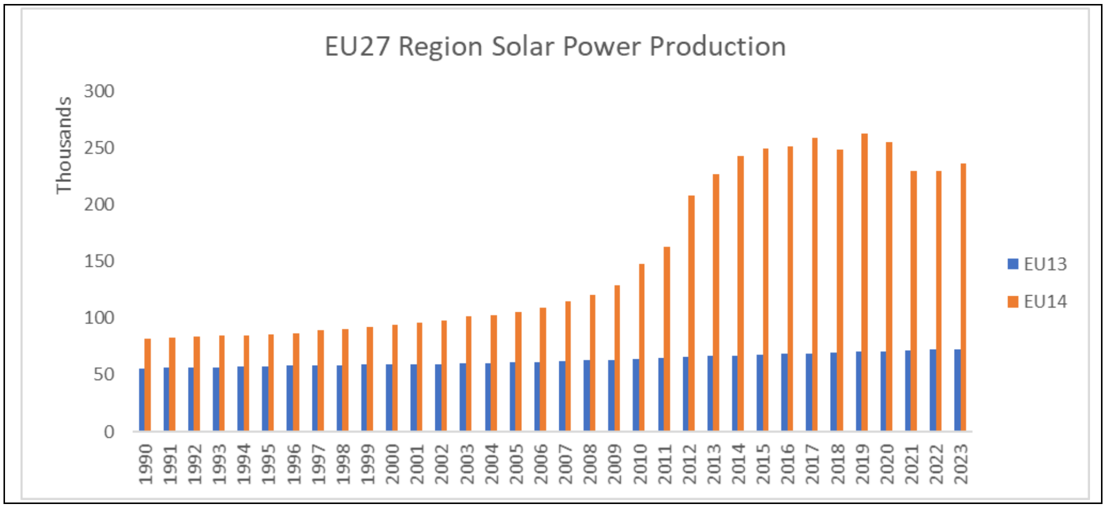

Figure 1 Offshore Solar power in the EU27 states (EU13 and EU14) during the period 1990-2023

2- Literature Review

In the EU, there are relevant plans and measures for offshore solar power and the marine action plan for blue energy, aiming to promote the development of renewable energy and achieve the goals of energy transformation and carbon neutrality (Magkouris et al., 2023). Many other nations such as China as per earlier research such as; Wen and Lin (2024) and Cui et al. (2024) proposed a framework to identify dust on photovoltaic panels in offshore floating solar power stations, claiming that the political framework is designed to be compatible with existing image recognition models and incorporates specialized enhancement modules to further improve recognition accuracy and efficiency of offshore solar panel. Similar findings were observed in the Western Iberian Peninsula by Costoya et al. (2022) and in India by Agarwala (2021).

The installation of solar panels on the sea surface does not occupy additional land resources, and at the same time, it can make use of the space above the aquaculture area to achieve the two-way utilization of marine space. For example, Nguyen and Wang (2024) searched advances in offshore aquaculture and renewable energy production, stating that modifications and innovations in infrastructure are needed for offshore fish farming in higher-energy sea states. Recent studies by Stockbridge et al. (2025) and Manolache and Andrei (2024) have examined the current landscape of marine energy projects that incorporate either a single form of renewable energy or multiple types of marine renewable energy sources alongside aquaculture operations. Their findings indicate that integrating offshore renewable energy with aquaculture can result in significant cost reductions and increased income. Furthermore, this approach supports the advancement of sustainable development, as highlighted by Wang and Lund (2022).

Recent studies have examined the environmental effects of emerging offshore renewable energy systems in various regions. In the Dutch North Sea, Vlaswinkel et al. (2023) investigated the environmental impacts associated with offshore solar installations, particularly as initial pilot projects are being implemented. Their findings indicate that factors such as water quality, bird populations, bio-deposition, biofouling, and the effects related to Fish Aggregating Devices are influenced by the scale of the offshore solar project. In the Mediterranean Sea, Keller Jr et al. (2022) analyzed the relationship between the efficiency of floating photovoltaic (PV) systems and carbon dioxide (CO2) emissions. Their research suggests that floating PV systems contribute significantly to the removal of CO2 from the ocean. By operating efficiently, these systems help mitigate ocean acidification and support marine biology by shifting the carbonate balance toward a more basic state. Conversely, Hofmann et al. (2025), Xu et al. (2024), and Ning et al. (2023) reviewed recent advancements in the decarbonization of marine and offshore engineering systems. They concluded that ocean-based negative emission technologies remain in the early stages of development within the European region, primarily due to high costs and ongoing environmental concerns.

The EU aims to achieve ambitious energy and climate targets. Offshore solar power, as a clean and renewable energy source, can help the EU reduce its dependence on fossil fuels, increase the proportion of renewable energy in the energy mix, and thus promote the realization of the goal of energy transition. In Spain, Filgueira-Vizoso et al. (2025) and Vaca-Cabrero et al. (2025) studied the economic feasibility of floating offshore solar farms of the Levantine-Balearic region, suggesting the importance of incorporating spatial constraints when assessing the economic viability of marine solar farms, where floating solar farms show the greatest viability. Recent studies by Zaiter et al. (2025) and González-Cancelas et al. (2025) have examined the levies and barriers associated with developing offshore multi-use platforms in various European regions. Their research highlights several significant challenges facing the advancement of offshore solar panel projects. These challenges include high investment costs, complex regulatory environments, and difficulties in coordinating among stakeholders. Despite these obstacles, the studies also identify important opportunities for growth in this sector. Key opportunities include ongoing technological innovation, the introduction of policy incentives, and the potential for synergies between different marine industries.

In 2020, the European Commission released the "EU Strategy on Offshore Renewable Energy", which proposed specific measures to support the long-term sustainable development of the offshore renewable energy sector. It set a target of at least 1 GW of ocean energy installed capacity by 2030, which includes offshore solar power (Dahlström et al., 2025). For example, Barrett et al. (2024) and Barrett and Crowley (2025) provide evidence of a positive relationship between external knowledge linkages and innovative activity, adding novel insights into the relationship between open innovation strategies, research, and innovation outcomes for offshore renewable energy firms predominantly in the introductory stages of the technological life cycle with limited commercialization experience. In the same manner, Pasimeni et al. (2024) explored macro patenting trends as a key technological component in offshore renewable energy, referring to a surge in global patent filings from 2006 to 2012, followed by a period of stagnation until 2017, when patent activity experienced a resurgence.

The EU has set clear strategic goals for the development of solar energy. The Solar Strategy for the EU aims to increase the installed capacity of solar photovoltaics to more than 320 GW by 2025 and nearly 600 GW by 2030. These goals provide a clear direction for the development of offshore solar power and help guide the allocation of resources and the formulation of specific development plans (Salvador and Ribeiro, 2023). In the North Sea, Rentier et al. (2023) studied the institutional constellations and policy instruments for offshore renewable power, confirming that the EU is witnessing an overall convergence in the use of policy instruments, which we attribute to the liberalization of the offshore renewable energy sector as well as to policy-learning effects. More specifically, in Denmark and Spain, Harguindéguy and Wokuri (2024) applied a comparison of offshore renewable energy policy, showing that stressing the relevance of public funding instability, federal architecture, intertwined political interests, and policy discourse has a significant impact on the rise of offshore renewable energy.

Chomać-Pierzecka (2024) analyzed the role of offshore renewable energy systems in Poland, focusing on their significance within the national energy mix. The study also examined public perception regarding recent developments in this sector. Findings highlight that offshore renewable energy is considered a key component in shaping Poland’s future energy landscape. However, public attitudes toward the construction of such systems vary, influenced by factors including investment considerations, environmental impact, ecosystem effects, and changes to the landscape. These observations are consistent with earlier research by Declerck et al. (2023) and Salvador and Ribeiro (2023), which emphasized the cumulative effects of offshore renewable projects. Their work underscores the importance of integrating pragmatic policy approaches with comprehensive marine spatial planning tools to address the complexities associated with offshore renewable energy development.

H1: The treated policies of promoting the integration of offshore solar power with aquaculture will lead to an increase in the share of blue energy and the blue economy.

H2: The controlled policies of promoting the integration of offshore solar power with aquaculture will lead to a decrease in the share of blue energy in the blue economy.

The EU and some member states have introduced Marine policies and Marine action plans related to offshore solar power integration with aquaculture, such as France, Belgium, and the Netherlands. However, there is a lack of in-depth research using the Difference-in-differences (DID) approach to assess the impact of these policies. The current literature did not precisely measure how these policies affect the development of offshore solar power integration with the aquaculture sector in the EU27 region. Without this evaluation, it is difficult to provide an empirical basis for marine energy policy optimization. Moreover, there is no research applying the DID method to compare EU27 members that have adopted specific offshore photovoltaic technologies with those that have not. Without such research, it is impossible to determine the actual effects of these technologies in practice. This restricts the further promotion and improvement of these technologies in the field of the offshore solar power market in the EU. Lastly, offshore solar power aquaculture technology involves the interests of multiple parties, including energy developers, landowners, and farmers. Although it is theoretically possible to create new value, the actual value-distribution mechanism remains unclear. Existing studies have not used the DID method to analyze the changes in the benefits of each party under different economic models and policies at the EU member level.

3- Method and Data

3.1. Data collection

To identify the key factors influencing offshore solar power generation and the sustainability of aquaculture hybrid projects within EU27 countries, the difference-in-differences (DID) analytical approach was employed. This method was applied to data spanning from 1990 to 2023. The designated treatment period for the countries under study was from 2014 to 2023. This timeframe was selected due to the implementation of the Marine Action Plan (MAP) and the promotion of blue energy policies across the region. The empirical analysis utilized data from EU24 countries over the period 1990 to 2023. The selection of this estimation approach was based on the suitability of the difference-in-differences methodology for the research objectives.

Offshore Solar Power (OSP): The surface area of offshore solar thermal collectors, measured in thousands of square meters. Aquaculture Production (AQU): Production and operational activities, measured in metric tons. Gross Domestic Product (GDP): Economic growth, measured in current US dollars. Innovation (INN): Research and development innovation, measured by R&D expenditure as a percentage of GDP. Carbon Dioxide Emissions (CO2): Emissions resulting from the combustion of fossil fuels and cement production, including emissions from the consumption of solid, liquid, and gaseous fuels, as well as gas flaring in marine activities. Regulatory Quality (REQ): An assessment of government effectiveness in formulating and implementing policies and regulations that support private sector development. All variables were sourced from the World Development Indicators and Eurostat. Further details are provided in Table 1.

Table 1. Variable explanation list

Variable	Symbol	Source	Variable	Unit of Measurement
Aquaculture Output	AQU	Eurostat	Independent	Metric Tons
Dummy Variable	Intercept	WBD	Independent	Treated = 1, Controlled = 0
Offshore Solar Power Output	OSP	Eurostat	Dependent	Thousand Square Meters

Innovation	INN	WBD	Independent	R&D Expenditure % of GDP
Carbon Dioxide Emission	CO2	Eurostat	Independent	Metric tons per capita
Regulator Quality	REG	WBD	Independent	% Confidence governance interval
Economic Growth	GDP	Eurostat	Independent	Current US dollars

3.2. Theoretical background

Externalities theory refers to the impact of an economic activity on third parties that is not reflected in market prices. In the case of the integration of offshore solar power and aquaculture, there may be positive externalities. For example, the shade provided by solar panels can reduce water temperature, which is beneficial to the growth of some aquatic organisms, and the installation of solar panels can also reduce the evaporation of water, saving water and marine resources. These positive externalities are difficult to fully reflect in the market price, and the DID method can be used to estimate the impact of the integration model on these externalities.

For this analysis, the Difference-in-Differences (DID) approach is employed, following the methodologies outlined by Upton and Snyder (2017), Abadie (2018), and Xu (2017). This method is suitable for both cross-sectional and panel data and is applied to EU14 and EU13 countries across two distinct periods: 1990–2010 and 2011–2023. The DID model is selected because it provides unbiased estimates of the effect of solar power adoption within the EU27 region, thereby ensuring the reliability of the results. In this context, let y(i, t) represent the outcome of interest for country i at time t. Observations are made for each country before the treatment period (t = 0) and after the treatment period (t = 1). Countries exposed to the treatment during the specified period are identified by the indicator D(i, t) = 1. Conversely, countries not exposed to the treatment are denoted by D(i, t) = 0. In this study, the EU14 countries constitute the treated group (D(i, t) = 1), while the remaining countries serve as the control group (D(i, t) = 0), as described by Abadie (2018). The primary DID estimator is typically implemented using a linear parametric model. The estimation procedure follows the approaches established by Card (1985) and Abadie (2018). It is assumed that the outcome variable is generated according to the variance process specified in the following equation.

$Y_{i,t} = \mu_{i,t} = \delta(t) + \alpha \cdot D_{i,t} + \eta(i) + v_{i,t}$ (1)

Interpretation of model components and estimation approach, in Equation (1), δ(t) denotes a component that varies over time, while α captures the effect of the treatment. The term η(i) refers to a country-specific factor, and v(i, t) represents country-specific shocks, which are required to have a mean of zero within each period (t = 0, 1) and are directly correlated over time. The variables y(i, t) and D(i, t) are observable.

$P(D_{i,t} = 1 | -\mu_{i,t}) = P(D_{i,1}) = 1$ (2)

t =0,1. By applying addition and multiplication to the conditional expectation E[η(i)|D(i,1) in Eq. (1), the equation can be reformulated accordingly.

$Y_{i,t} = \delta(t) + \alpha D_{i,t} + E[\eta(i) | D_{i,1}] + \varepsilon_{i,t}$ (3)

From Eq. (3); $(i,t)=\eta(i)- E[\eta(i)]|\ D(i,1)]+v(i,\ t)$. It should be noted that $\delta\ (t)=\delta\ (0) + (\delta(1)-\delta\ (o)t$,
And; $E[\eta(i)]|\ D(i,1)]=E[\eta(i)]|\ D(i,1)=0]+E[\eta(i)]\ |\ D(i,\ 1)\ =1]-\ E[\eta(i)]\ |\ D(i,1)=0]D(i,1)$.
Let $\mu= E[\eta(i)]|\ D(i,1)=0]\ +\delta(0)$, $\tau= E[\eta(i)]|\ D(i,\ 1) = 1]-\ E[\eta(i)]|\ D(i,1)=0]$, and $\delta=(\delta(1) - \delta\ (o)$.
Equation (4) is derived below:
$Yi,t = \mu + \tau Di,1 + \delta t + \delta Di,t + \varepsilon i,t$ (4)

The constraints imposed in Equation (2), which specify $t = 0, 1$, indicate that $E[1, D(i, 1), t, D(i, t), \varepsilon(i, t)] = 0$. The variables in Equation (4), as well as δ, can be estimated using the ordinary least squares (OLS) method. This formulation allows for the identification of treated countries based on the dependence structure, specifically when $D(i, 1) = 1$ and considering the country-specific component $\eta(i)$. Furthermore, Equation (4) can be simplified as shown below.

$Yit = \delta\ + \delta_i \times TREAT_i + \delta_{it}\times POST_t + \beta^{2\times 2}{}_t TREAT_i \times POST_t + U_{it}$ (5)

Y_{it} denotes the observed outcomes for several indicators, including offshore solar power (OSP), aquaculture (AQU), gross domestic product (GDP), innovation (INN), carbon dioxide emissions (CO2), and regional factors (REG). The term $\delta_i TREAT_i$ identifies countries that have been exposed to the treatment at time i. Similarly, $\delta_{it} POST_t$ refers to countries that have experienced the treatment after its implementation. The interaction term, $\beta_{2\times 2t} TREAT_i \times POST_t + U_{it}$, captures the combined effect of the treatment dummy for a group of countries and the post-treatment dummy within the regression model. This section incorporates both EU13 and EU14 member states that have been exposed to the treatment before and after its implementation. The objective is to identify the factors influencing the sustainability of the offshore solar power and aquaculture sectors. Uit represents the country-specific, serially uncorrelated transitional component related to green energy investments in each nation. The methodology applied here is known as the difference-in-differences (DID) approach. Given the condition specified in Equation (2), the resulting model is presented in Equation (6) below.

$\delta = \{E[Yi,1|Di,1=1]-E[Yi,1|Di,1=0]\} - \{E[Yi,0|Di,1=1]-E[Yi,0|Di,1=0]\}$ (6)
Model formulation and estimation approach, in this context, Y_{it} denotes the outcomes for variables such as OSP, AQU, GDP, INN, CO2, and REG. The term $\delta_i TREAT_i$ is used to represent the countries included in the analysis.

The formulation of the model is essential when working with cross-sectional data of the form $(Y(_{i,\ t}), D(_{i,\ 1}))$, where t takes the values 0 and 1. Since the study utilizes panel data, it captures differences before and after a specific event or intervention across the countries examined. The observed outcome is expressed as the difference between $Y(_{i,\ 1})$ and $Y(_{i,\ 0})$. The parameter δ is then estimated using the ordinary least squares (OLS) method.
$\delta = E[Yi,1-Yi,0|Di,1=1] - E[Yi,1|Yi,0,Di,1=0]$ (7)
Based on Equation (2), when considering $t = 0, 1$, the difference $v(i,1) - v(i,0)$ represents an average that does not depend on $D(i,1)$. As a result, in the absence of any treatment across countries, the mean outcomes would display the same variation as those observed in the treated countries. Abadie (2018)

notes that this modeling approach may be restrictive, particularly if the treated and untreated groups differ in terms of unbalanced explanatory variables that influence the dynamics of the outcomes. This limitation can affect the validity of the results when such differences exist. Drawing an analogy to the foundational work of Ashenfelter (1978), it is important to address these variations and account for heterogeneity among the countries under study. To manage these concerns, Ashenfelter and Card (1985) proposed a model specifically designed to accommodate such differences:

$$Di,1 = \begin{cases} 1, \text{if } yi,1 - k + ui < Y \\ 0, \text{otherwise} \end{cases} \quad (8)$$

In this context, K represents a positive integer, Y is a constant, and u(i) denotes a random variable. The scenario described considers the response of countries with relatively low levels of solar power utilization in agricultural projects. Following the treatment period, countries with limited solar power deployment in agriculture are expected to implement new policies aimed at increasing the use of solar energy within the aquaculture sector. This shift is primarily driven by the requirements of the Paris Accord and the influence of environmental advocacy groups. The Difference-in-Differences (DID) approach is applicable under the condition (i, 1−K). Under these circumstances, the effect on the group receiving the treatment is outlined below:

$$f(\theta,Di1) = \begin{cases} -Yi1, Di1 = 1 \\ \mid Yi0 \mid, Di1 = 0 \end{cases} - [E(Yi0 \mid Xi, Di1 = 1) - E(Yi0 \mid Xi, Di1 = 0)] \quad (9)$$

The equation X(i) = (i, 1-k) defines a vector, X(i), which represents the observable characteristics of each country. As outlined in this article and in Abadie (2018), these characteristics are established at the initial time point, t = 0. Equation (9) addresses the sequence in which countries are matched for analysis. Specifically, it compares each group of treated countries, denoted by i, to individual countries that have not received the treatment. In relation to the outcome variable, Y_i, for the treated countries, the analysis assigns a weight to the matched outcome, represented by the estimated value bY_i. This weighted outcome is then linked to its corresponding neighbor within the comparison group. Therefore, the matching process ensures that the outcomes for treated countries are appropriately compared to similar untreated countries, based on their observable characteristics.

$$\widehat{Y\imath} = \sum_{j \in C^0(Pi)} w_{ij}\, y_j \quad (10)$$

$C_0(P^i)$ denotes the set of treated neighbors i within the group where D = 0. The term Wij refers to the weight assigned to each untreated individual i when making a comparison with a treated individual i.

In general, the matching estimator for the Average Treatment Effect on the Treated (ATT), denoted as ATT(S_{10}), can be expressed as follows:

$$\widehat{ATT} = \frac{1}{\#[D=1\cap(S10)]}\sum_{i\in\{Di=1\}\cap S10} (Yi - \widehat{Y\imath}) \quad (11)$$

E {Y|treated on S_{10} − E {Y|weighted/untreated

4- Results and discussion

To assess the development and potential expansion of the offshore solar power sector within the EU27 countries, a normality test was performed on the relevant dataset. The Jarque-Bera normality test was employed to evaluate skewness and kurtosis. The results indicated that the data are normally distributed, as demonstrated by a statistically significant p-value of 0.00. This finding confirms that the residual errors adhere to a normal distribution. Table 2 contains the Eviews analysis results for the Jarque-Bera normality test. Based on these results, the difference-in-differences (DID) estimator was utilized to further analyze the data. The DID approach offers several advantages: it enables the comparison of similar entities, thereby ensuring valid comparisons; it accounts for both observed and unobserved differences among countries; it is straightforward to implement; and it operates under a non-parametric framework.

Table 2 also provides a summary of the descriptive statistics for covariance and the normality test. Among the variables, the mean GDP score is the highest. In contrast, the measure of innovation—defined by the number of individuals engaged in innovation activities—is relatively low, suggesting that innovation remains limited in the offshore solar power sector across the EU27. Both aquaculture and carbon dioxide emissions exhibit high mean scores, reflecting significant emissions within the aquaculture sector. The regulation quality metric underscores the importance of policy in advancing the energy sector's sustainability and addressing environmental pollution. As anticipated, the mean score for offshore solar power remains modest.

Table 2: Summary statistics and normality test

	AUQ	CO2	GDP	INN	OSP	REG
Mean	4.095	4.726	11.112	0.520	3.774	2.004
Median	4.144	4.737	11.161	0.514	3.72425	2.019
Maximum	5.638	5.981	12.648	0.773	5.055	2.147
Minimum	2.025	2.000	9.406	-1.302	3.000	-4.342
Std. Dev.	0.823	0.5632	0.735	0.112	0.247	0.101
Observations	918	918	918	918	918	918
Normality Test	Skewness	Kurtosis	Jarque-Bera	Probability		Observation
Residual	0.129	2.477	13.00	0.001		918

Table 3 presents the intercept dummy variable for both treated countries and time, as specified in Equation (5). This variable is included to offer a counterfactual perspective on the hypothesis that all countries, regardless of treatment status, would receive comparable levels of renewable and sustainable energy policies. The dummy variable is defined as follows: D = 1 for treated countries and D = 0 for untreated countries. The statistical analysis indicates that this dummy variable is significant, with a p-value of 0.000. These results suggest that both treated and untreated countries demonstrate a strong tendency to attract offshore solar power projects and to implement renewable and sustainable energy policies. Such measures are directed at mitigating the impact of energy use and supporting a transition toward sustainable development. Further details can be found in Figures 3 and 2.

Table 3 Regression with a dummy variable for the intercept (treat*post) t- t-statistic test

Variable	Coefficient	Std. Error	t-Statistic	Prob.
INTERCEPT	0.022	0.008	2.699	0.007

R-squared	0.809	Mean dependent var	3.779
Adjusted R-squared	0.795	S.D. dependent var	0.247
S.E. of regression	0.112	Akaike info criterion	-1.468
Sum squared resid	10.717	Schwarz criterion	-1.121
Log-likelihood	740.128	Hannan-Quinn criteria	-1.336
F-statistic	55.715	Durbin-Watson stat	0.054
Prob(F-statistic)	0.000		

The parallel trend test is an essential prerequisite for applying the time-varying point Difference-in-Differences (DID) methodology. In this study, the event study approach has been employed to conduct the parallel trend test within the time-varying DID framework. Figure 2 presents the dynamic effects observed in the analysis. Specifically, during the four periods preceding the implementation of the MAP policy, the coefficients associated with the dummy variables do not exhibit statistically significant deviations from zero. This outcome suggests that, before the policy intervention, the trends in MAP strategies for both the treatment and control groups remained relatively stable. Following the introduction of the MAP policy, the coefficient of the relevant variable rises above one. This result indicates that the MAP strategies in both the treatment and control groups experienced notable changes attributable to the policy's implementation.

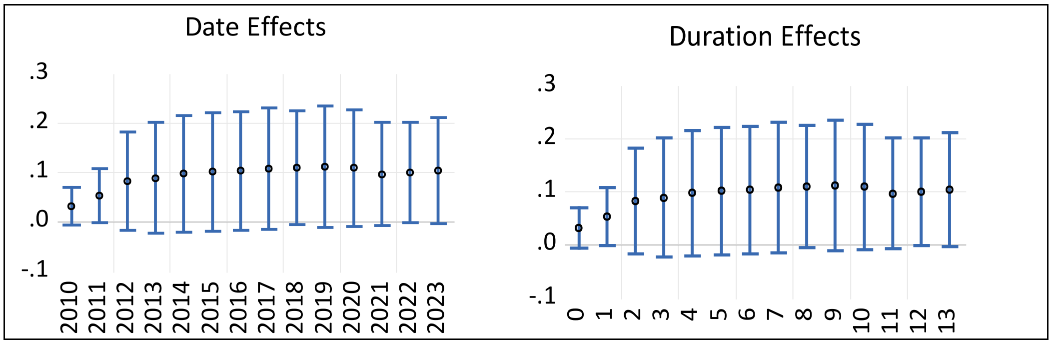

Figure 2: Parallel trend test. The vertical dashed line shows the "event year" of 2014, and the horizontal dashed line shows the zero-value axis.

The primary hypothesis of this study was that the effectiveness of Marine Action Plans (MAP) related to offshore solar power in aquaculture projects would be reflected in distinct response patterns—both negative and positive—when compared to those observed in control countries. To examine this, the research tested two separate hypotheses: first, the impact of negative coping MAP strategies, and second, the influence of positive adaptive or transformative MAP strategies. The analysis employed the Ordinary Least Squares (OLS) model, as presented in Table 4, and used the Fixed Effect-Ordinary Least Squares (FE-OLS) model as a robustness check in Table 5. Both models controlled for Central and Eastern European countries (EU13) to ensure accurate comparisons. Given that responses to MAPs can vary significantly among EU27 member states, the study also considered the specific characteristics of these countries, particularly in the context of negative coping strategies. As a result, the authors concentrated on the three most commonly referenced models: EU27, EU14, and EU13.

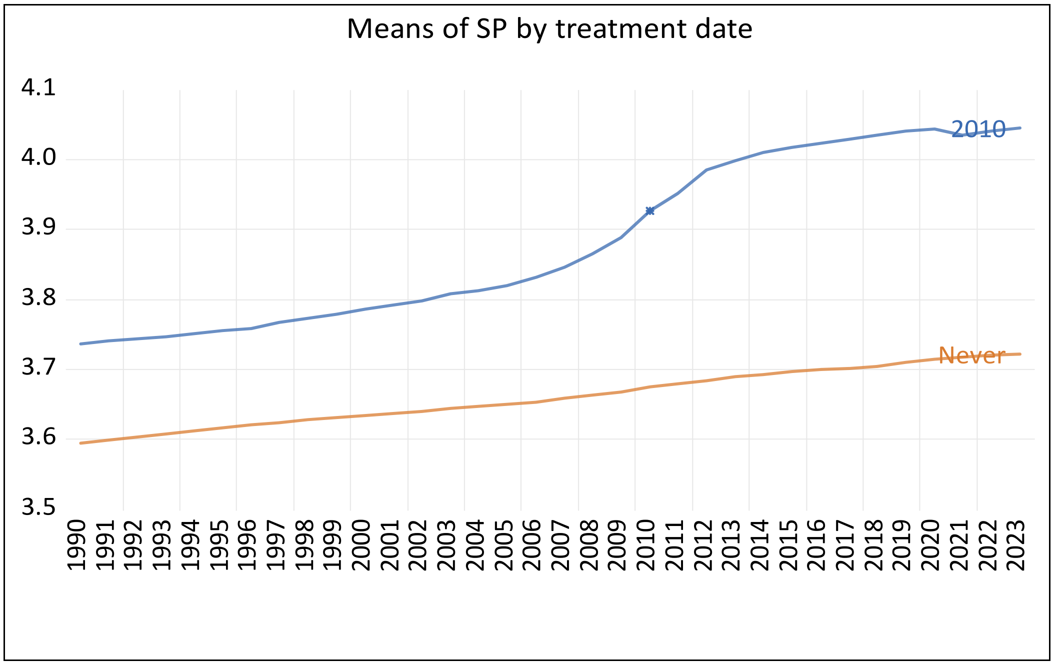

Figure 3 Policy implementation profiles showing the list of adverse events that affected the treatment (in blue) and controlled countries (in red) from 1990 to 2023, before and after the baseline date of 2014.

For each of the three principal models presented in Tables 4 and 5, this study identified the countries that reported being affected by the relevant policies at the baseline. Subsequently, the associated coping MAP strategies were examined. The Ordinary Least Squares (OLS) and Fixed Effects OLS (FE-OLS) models used to test the Difference-in-Differences (DiD) approach yielded non-conclusive results, as shown in both tables. In Table 4, the DiD (intercept) variable is statistically significant for both the EU27 and EU14 groups. This indicates a greater tendency to adopt positive, strengthening MAP strategies within these groups. In contrast, for the EU13 control group, the DiD (intercept) variable does not reach statistical significance. Similarly, Table 5 demonstrates that the DiD (intercept) variable remains statistically significant for the EU27 and EU14 groups, while for the EU13 group, the significance is weak.

Overall, these findings support the initial hypothesis regarding MAP strategies. Specifically, the implementation of MAP-related policies that encourage the integration of offshore solar power with aquaculture projects is associated with an increased share of marine renewable energy, thereby contributing to environmental sustainability within the EU27 region. The results are more definitive for positive responses, as the likelihood of adopting adaptive or transformative MAP strategies is higher among the EU27 region as a whole and among the treatment countries (EU24), compared to the control countries (EU13).

Table 4 Testing the effect of MAP on coping with offshore solar power strategies, using OLS models. Test completed for the three main models: EU27 States overall (Model1); Western European Union States EU14
(Model2) and Central and Eastern European Union States, EU13 (Model3).

Model	EU27		EU14		EU13	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
INTERCEPT	0.232***	0.018	0.256***	0.024	0.022	0.020
AQU	0.033***	0.009	0.035***	0.013	0.065***	0.017
CO2	(0.096)***	0.028	(0.328)***	0.068	(0.119)***	0.025
GDP	0.235***	0.026	0.142**	0.067	0.177	0.028
INN	0.248***	0.028	0.061	0.132	11.717	4.162
REG	0.102	0.062	0.967***	0.184	(0.014)	0.313
Constant	2.483***	0.178	5.573***	0.625	10.442	2.886
Observation	918		476		442	
Number of groups	27		14		13	
F-statistic	135.250		63.622		20.121	
Prob(F-statistic)	Prob>F=0.000		Prob>F=0.000		Prob>F=0.000	
R-squared	0.471		0.448		0.937	
Control	YES		NO		YES	
Treat	YES		YES		NO	
Intercept	YES		YES		YES	

In Table 4, there is a significant positive influence of MPA strategies on offshore solar power; an increase in MPA application by 1% will bring about an increase in offshore solar power supply by 0.25% in EU14 states and 0.23% in the EU27 states overall. In the EU14 states, this research observes that MAP policy implementation contributes to an increase in the share of AQU, GDP, and REG by 0.035, 0.142, and 0.967 for a 1% increase in offshore solar power production. Among the other variables, a 1% increase in offshore solar power was associated with a decrease in CO2 by 0.328%. The DID analysis outcomes for the changes in MAP policies are reported in Table 5. The most influential group measure is shown to be the EU14 treatment group. After its treatment, an observed change of 0.037% in AQU, 0.11% in GDP, 0.880% in INN, and 0.201% in REG was recorded in the years following the treatment for each 1% increase in offshore solar power production in the EU14.

In Table 5, among the three MAP measures considered, the EU13 controlling group is the least affected by the MPA policies. In the year following the MAPs policies boosting the EU27 region overall, there is an estimated reduction in CO2 emissions of 0.50% for a 1% increase in offshore solar power production. Moreover, an observed change of 0.106% in GDP, 0.60% in INN, and 0.014% in AQU was recorded for each 1% increase in offshore solar power production.

Table 5 Testing the effect of MAPs on coping with offshore solar power strategies, using FE-OLS models. Test completed for the three main models: EU27 States overall (Model 1); Western European Union States EU14 (Model 2); and Central and Eastern European Union States EU13 (Model 3).

Model	EU27	EU14	EU13

Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
INTERCEPT	0.132***	0.006	0.084***	0.010	0.025***	0.006
AQU	0.014***	0.005	0.037*	0.019	0.006	0.009
CO2	(0.050)***	0.009	(0.021)	0.043	(0.030)*	0.016
GDP	0.106***	0.009	0.011	0.037	0.069***	0.011
INN	0.060***	0.007	0.880***	0.074	1.550	1.614
REG	0.027	0.019	0.201**	0.093	0.673***	0.102
Constant	2.466***	0.120	3.539***	0.458	1.710***	1.122
Observation	918		476		442	
Number of groups	27		14		13	
F-statistic	483.125		140.806		352.279	
Prob(F-statistic)	Prob>F=0.000		Prob>F=0.000		Prob>F=0.000	
R-squared	0.945		0.854		0.955	
Control	YES		NO		YES	
Treat	YES		YES		NO	
Intercept	YES		YES		YES	

5- Discussion

When comparing EU14 western states (treatment group) and EU13 central and eastern states (control group), the greatest augmentation in offshore solar power production policies is achieved in EU14 states (see Table 5). For example, an average annual increase in offshore solar power production of 0.08% and 0.02% is observed in the EU14 and EU13 countries, respectively, following the implementation of the MAPs policy. The outcome is consistent with earlier studies such as; Portman (2010); O'Hagan (2011); and Apolonia et al. (2025) showing that Western EU14 members tend to have more supportive policies for marine renewable energy compared to Central and Eastern EU13 members for several reasons related to differences in economic development, energy infrastructure and geography, technical expertise and research capabilities, environmental awareness, and public support.

In the year after boosting offshore solar power under the MAP umbrella, an average annual escalation of about 0.037% and 0.00% in AQU for EU14 and EU13, respectively. For example, Weiss et al. (2020); Koričan et al (2022), and Mohammed (2024) suggest that Western EU14 members, such as Germany, the Netherlands, and France, have relatively strong economic strength and are more capable of formulating and implementing policies that are conducive to the development of integrated marine renewable energy and aquaculture projects by providing financial support, such as subsidies and investment incentives, to encourage the construction and operation of such projects. In contrast, many Central and Eastern EU13 members may have limited financial resources and are unable to provide the same level of policy support due to the need to focus on other aspects of economic development.

Unexpectedly, due to the promotion of offshore solar power under the MAP policy led to an average annual reduction of about 0.02% and 0.03% in CO2 for EU14 and EU13, respectively. This harmonized with earlier studies by Soukissian et al. (2017); Sgobbi et al. (2016); and Theodora and Piperis (2022), who referred to that EU14 Western European countries, such as the Netherlands, Germany, and France, have a long-standing maritime tradition and a highly developed maritime industry. They have a large number of ports, and Rotterdam in the Netherlands is one of the largest ports in Europe. These ports handle a large volume of cargo and passenger traffic, with numerous ships coming and going, resulting in high CO2 emissions from ship fuel combustion. In contrast, although many EU13 Eastern European countries also have a coastline, but overall maritime industry scale and activity level are relatively lower than those of Western European countries, which causes lower CO2 emissions.

Next, increasing offshore solar power showed an average annual rise of about 0.011% and 0.069% in GDP for EU14 and EU13, respectively. This is consistent with previous research by Taveira-Pinto et al. (2021), Fratila et al. (2021), and Bădîrcea et al. (2021) showing that the development of marine renewable energy provides an opportunity for EU13 Eastern European Members to catch up. It can attract a large amount of investment in related infrastructure construction, stimulate the growth of related industries such as manufacturing and installation, create a large number of jobs, and thus promote overall economic development. For example, countries like Poland and Romania can use the development of offshore solar to enhance their industrial capabilities and economic strength. In contrast, Western EU14 countries already have relatively mature economies and industrial systems, so the marginal impact of offshore solar on their economies may be relatively small.

Also, promoting offshore solar power reflects an average annual growth of about 0.88% and 1.55% (insignificant) in INN for EU14 and EU13, respectively. The outcome agrees with previous findings of Mueller and Wallace (2008); Corsatea (2014); and Cui and Zhao (2023) point to the higher innovation level of offshore solar power in Western EU14 countries compared to Eastern and Central EU13 countries can be attributed to several factors, including differences in R&D investment, technological foundation, talent pool, and industry-university - research cooperation.

On the other hand, raising offshore solar power drives an average annual increase of about 0.20% and 0.67% in REG for EU14 and EU13, respectively. In alignment with earlier research such as Soria-Rodríguez (2016); Soria-Rodríguez (2020); and Giannopoulos (2023) the relationship between regulatory quality and marine renewable energy is considered to be more significant in Eastern and Central EU13 countries than in Western EU14 countries for several reasons, however, Eastern EU13 countries have made significant progress in regulatory construction since joining the EU27, but there is still room for improvement compared to Western EU14 countries. In the development of renewable marine energy, they are more motivated to improve regulatory quality to create a better policy environment for project implementation. For example, they may need to improve regulations on project approval, grid connection, and environmental protection to ensure the healthy development of the industry. In contrast, the regulatory systems in Western EU14 countries are relatively mature, and the focus is more on optimizing and adjusting existing regulations rather than major improvements.

Table 6 presents the results of a carefully executed placebo test, in which estimated coefficients and their corresponding p-values were recorded using a random sample of 27 countries. These procedures were undertaken to promote the reproducibility of the findings and to reduce the potential impact of unobserved variables on the conclusions drawn from the regression analysis. The results of the placebo test indicate that all estimated values were consistently less than one, with the distribution centered near zero. This observation suggests that the conclusions reached in this analysis are unlikely to be driven by alternative factors that have not been directly examined. It is important to note, however, that these interpretations remain theoretical at this stage. Further research and careful examination are necessary to fully assess whether any confounding factors may affect the validity of the regression analysis results.

Table 6 Testing the effect of MAP on coping with offshore solar power strategies, using Placebo tests. Test completed for the three main models: EU27 States overall (Model 1); Western European Union States EU14 (Model 2); and Central and Eastern European Union States EU13 (Model 3).

Model	EU27		EU14		EU13	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
INTERCEPT	(0.188)***	0.013	(0.084)***	0.010	0.053***	0.005
AQU	0.010	0.020	0.037*	0.019	0.005	0.010
CO2	-0.009	0.014	-0.021	0.043	(1.455)***	0.548
GDP	-0.073	0.051	0.011	0.037	0.012	0.022
INN	0.154***	0.030	0.880***	0.074	0.007	0.016
REG	0.129***	0.046	0.201**	0.093	2.264***	0.255
Constant	3.004***	0.147	3.539***	0.458	3.116***	0.558
Observation	918		476		442	
Number of groups	27		14		13	
F-statistic	103.781		140.806		325.309	
Prob(F-statistic)	Prob>F=0.000		Prob>F=0.000		Prob>F=0.000	
R-squared	0.789		0.854		0.932	
Control	YES		NO		YES	
Treat	YES		YES		NO	
Intercept- Random	YES		YES		YES	

6- Conclusion and Implications

This study examined the integration of offshore solar power and the aquaculture sector across the EU27 countries from 1990 to 2023. To assess whether there were differences in offshore solar power commitments and Marine Action Plans (MAPs) strategies between two distinct periods, a difference-in-differences methodology was applied. This approach involved formulating a counterfactual hypothesis and analyzing the countries by grouping them into separate time periods to identify any significant differences. For this analysis, the EU27 countries were divided into two groups: the control group, EU13 (comprising Eastern and Central European Union members), and the treated group, EU14 (consisting of Western European Union members). The study accounted for time-varying factors that could influence the results. The empirical findings indicate that, after controlling for fixed effects, the regression coefficient for the difference-in-differences analysis was significantly positive at the 0.00 significance level, as shown in Tables 3, 4, and 5. Additionally, a placebo test confirmed the robustness of this effect (Table 6). These results demonstrate that the primary objectives of policies and regulations related to MAPs—namely, promoting offshore solar power production and enhancing the economic benefits of blue growth, particularly within the aquaculture sector—have been effectively achieved.

When comparing EU14 western states (treatment group) and EU13 central and eastern states (control group), the greatest augmentation in offshore solar power production is achieved in EU14 states. Leading that in the year after boosting MAPs policy implementation, an average annual escalation of offshore solar power, and the aquaculture sector, innovation is higher in the EU14 treatment group in comparison with the EU13 control group. While the year after boosting MAPs policy implementation, an average annual reduction of carbon dioxide emissions was observed more in EU13 states in comparison to those in the EU14 states. On the other hand, an average annual increase in economic growth and regulation quality is observed to be higher in the EU13 states in comparison with those in the EU14 states.

This paper examines how policy mechanisms (MAPs) contribute to the advancement of offshore solar power production within the EU27, focusing on two principal areas: (1) Implementing policies that foster marine sustainability and encourage blue growth across various sectors, including aquaculture, has a positive impact on the regional blue economy. These measures also contribute to the reduction of carbon dioxide emissions. Addressing historical shortcomings in areas such as aquaculture sustainability, green economic growth, regulatory standards, green innovation, and renewable energy adoption leads to measurable progress in green economic development. (2) Facilitating Sector Transformation and Investment.

EU27 member states are actively developing strategies tailored to the transformation and growth of their offshore solar power industries. For instance, transitioning from fossil fuel-powered aquaculture to systems powered by offshore solar energy is expected to attract significant investment in marine renewable and sustainable energy sources. The expansion of green aquaculture further encourages increased consumption of renewable energy within local industries. In summary, both investment and consumption play essential roles in supporting the growth of green GDP across the EU27. (See Chart 1.)

To further advance the transformation of the aquaculture sector and reinforce the progress achieved through current policies, this paper offers the following recommendations. (1) Support for Offshore Solar-Powered Projects in Eastern and Central EU: Governments in the eastern and central regions of the European Union have indicated that the EU13 group should increase political support for offshore solar-powered initiatives. Additionally, it is recommended that these governments assist sectors such as aquaculture in adapting their innovation strategies and industrial energy structures. This support will facilitate a smooth transition from conventional energy sources to renewable energy. (2) Implementation of Proactive Measures in Western EU: In the Western European Union states (EU14), it is advisable to adopt more proactive measures to promote offshore solar power. Furthermore, aquaculture enterprises with high pollution levels in these states should be required, through efficiency and quality regulations, to shift from traditional practices to offshore solar-powered methods. This transition will contribute to reducing CO2 emissions and support the development of the blue economy.

This study examined the effectiveness of MAP's policies in enhancing offshore solar power within the EU27 and in integrating aquaculture-powered projects. However, certain limitations must be acknowledged. The sample size selected for this research may not adequately represent the entire European continent, which restricts the generalizability of the findings. The results may reflect the specific economic characteristics of EU27 member states during the period under review and may not apply to other European countries outside the EU region. Further research is necessary to gain a more comprehensive understanding of the dynamic effects associated with these MAP upgrades. In particular, employing time series and panel data analyses could help determine whether the observed increase in offshore solar power production is immediate and sustained, or if it fluctuates over time. Additionally, adaptation to updated regulations in solar power integration projects may involve a learning curve, suggesting that the full impact of MAP upgrades on offshore solar power consumption patterns could emerge only after a significant time lag. A dynamic analytical approach would also facilitate a more detailed examination of the rebound and pre-bound effects referenced earlier, including their presence and magnitude.

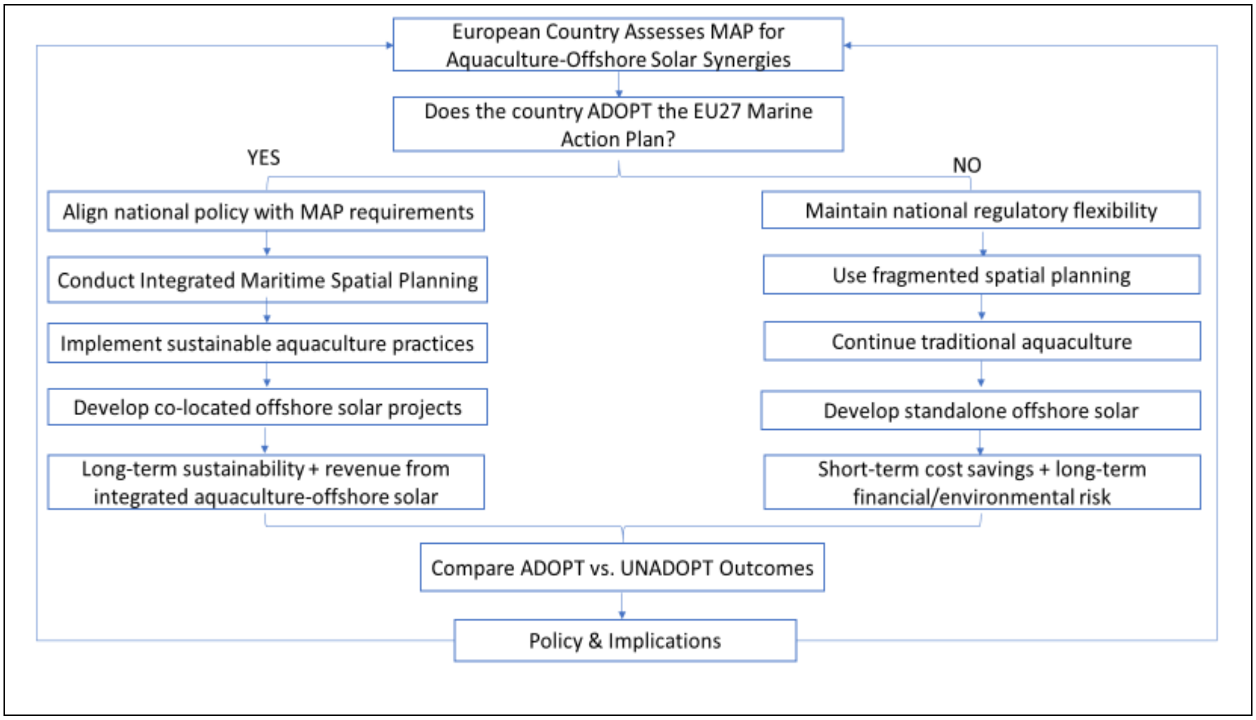

Chart 1 Impact of the Marine Action Plan (Offshore Solar Focus) on Offshore Solar-Aquaculture Synergy Projects in European Countries (Adopters vs. Non-Adopters of the Policy)

Funding sources:
No funds information.

Authors' contributions:

M.A. (Mohd Alsaleh) gathered the data and estimated the panel cointegration model and the competitive advantage of the external factors on the solar power industry in the EU27 region; M.A. presented the EU27's health environment and renewable energy sector industry and put together all the numerical results; M.A. contributed with conclusions and recommendations as well as with the limitations of the study and further research; M.A. conducted the literature review; and was responsible for the overall writing process.

Data availability:
Data is available upon request.

Competing interests:
The author declares that they have no competing interests.

Ethical approval:
The authors declare the provided manuscript has not been published before nor submitted to another journal or preprint server for consideration of publication.

Consent to participate:
The authors declare that the manuscript does not report studies involving human participants, human data, or human tissue.

Consent to publish:
The authors declare that the manuscript does not contain any individual person's data in any form (including any individual details, images or videos).

Reference

Abadie, A. (2018). Semiparametric estimators. pp. 169–196. https://doi.org/10.1002/9781119470380.ch9
Agarwala, N. (2021). Powering India's Blue Economy through ocean energy. Australian Journal of Maritime & Ocean Affairs, 14(4), 270–296. https://doi.org/10.1080/18366503.2021.1954494
Apolonia, M., Fofack-Garcia, R., Noble, D. R., Hodges, J., & Correia da Fonseca, F. X. (2021). Legal and political barriers and enablers to the deployment of marine renewable energy. Energies, 14(16), 4896. https://doi.org/10.3390/en14164896
Ashenfelter, O. (1978). Estimating the effect of training programs on earn ings. The Review of Economics and Statistics 60(1):47–57
Ashenfelter, O., and Card, D. (1985). Using the Longitudinal Structure of Earnings to Estimate the Effect of Training Programs. The Review of Economics and Statistics 67(4):648–660
Bădîrcea, R. M., Manta, A. G., Florea, N. M., Puiu, S., Manta, L. F., & Doran, M. D. (2021). Connecting blue economy and economic growth to climate change: evidence from European Union countries. Energies, 14(15), 4600.https://doi.org/10.3390/en14154600
Barrett, G., & Crowley, F. (2025). Offshore renewable energy SMEs' innovation interactions across

the triple helix: a management as practice perspective. The Journal of Technology Transfer, 1-31. https://doi.org/10.1007/s10961-024-10178-3

Barrett, S., Crowley, F., Doran, J., & O'Connor, M. (2024). Exploratory and exploitative linkages and innovative activity in the offshore renewable energy sector. International Journal of Entrepreneurial Behavior & Research, 30(11), 140-163. https://doi.org/10.1108/IJEBR-12-2022-1107

Card, D. (1985). ‘Orley Ashenfelter’ ‘China’ s emissions trading scheme’ (2020) Erdoğan S, Yıldırım DÇ, Gedikli A (2020) Natural resource abundance, financial development and economic growth: an investigation on Next-11 countries. Resourse Policy 65(November 2019). https://doi.org/ 10.1016/j.resourpol.2019.101559

Chomać-Pierzecka, E. (2024). Offshore Energy Development in Poland—Social and Economic Dimensions. Energies, 17(9), 2068. https://doi.org/10.3390/en17092068

Corsatea, T. D. (2014). Increasing synergies between institutions and technology developers: Lessons from marine energy. Energy Policy, 74, 682-696. https://doi.org/10.1016/j.enpol.2014.07.006

Costoya, X., DeCastro, M., Carvalho, D., Arguilé-Pérez, B., & Gómez-Gesteira, M. (2022). Combining offshore wind and solar photovoltaic energy to stabilize energy supply under climate change scenarios: A case study on the western Iberian Peninsula. Renewable and Sustainable Energy Reviews, 157, 112037. https://doi.org/10.1016/j.rser.2021.112037

Cui, Y., & Zhao, H. (2023). Marine renewable energy project: The environmental implication and sustainable technology. Ocean & Coastal Management, 232, 106415. https://doi.org/10.1016/j.ocecoaman.2022.106415

Cui, Y., Liu, M., Li, W., Lian, J., Yao, Y., Gao, X., ... & Yin, J. (2024). An exploratory framework to identify dust on photovoltaic panels in offshore floating solar power stations. Energy, 307, 132559. https://doi.org/10.1016/j.energy.2024.132559

Dahlström, P., Lööf, H., Sjöholm, F. et al. The EU’s comparative advantage in the “clean-energy arms race”. The annals of regional science. 74, 14 (2025). https://doi.org/10.1007/s00168-024-01343-5

Declerck, M., Trifonova, N., Hartley, J., & Scott, B. E. (2023). Cumulative effects of offshore renewables: From pragmatic policies to holistic marine spatial planning tools. Environmental impact assessment review, 101, 107153. https://doi.org/10.1016/j.eiar.2023.107153

Filgueira-Vizoso, A., Cordal-Iglesias, D., Fernández-Blanco, C., Fernández-Mira, D., García-Diez, A. I., & Castro-Santos, L. (2025). Economic feasibility of floating offshore solar farms. The case of study of the Levantine-Balearic region of Spain. Energy, 136025. https://doi.org/10.1016/j.energy.2025.136025

Fratila, A., Gavril, I. A., Nita, S. C., & Hrebenciuc, A. (2021). The importance of maritime transport for economic growth in the european union: A panel data analysis. Sustainability, 13(14), 7961. https://doi.org/10.3390/su13147961

Giannopoulos, N. (2023). The proliferation of offshore renewable energy in European seas: the regulatory challenges of emerging technologies for EU environmental law. The Future of Environmental Law, 158-177. https://doi.org/10.4337/9781035314645.00020

González-Cancelas, N., Vaca-Cabrero, J., & Camarero-Orive, A. (2025). The Role of the Fishing Sector in the Blue Economy: Prioritization, Environmental Challenges, and Sustainable Strategies in Europe, with a Focus on Spain. Journal of Marine Science and Engineering, 13(3), 621.

https://doi.org/10.3390/jmse13030621

Harguindéguy, J. B., & Wokuri, P. (2024). When politics determines policy success and failure. A comparison of offshore wind power in Denmark and Spain. Journal of Comparative Policy Analysis: Research and Practice, 26(5), 511-529. https://doi.org/10.1080/13876988.2024.2372617

Hofmann, F., Tries, C., Neumann, F., Zeyen, E., & Brown, T. (2025). H2 and CO2 Network strategies for the European energy system. Nature Energy, 1-10. https://doi.org/10.1038/s41560-025-01752-6

Keller Jr, D., Somanna, V., Drobinski, P., & Tard, C. (2022). The Offshore CO2 Capture and Utilization Using Floating Wind/PV Systems: Site Assessment and Efficiency Analysis in the Mediterranean. Energies, 15(23), 8873. https://doi.org/10.3390/en15238873

Koričan, M., Perčić, M., Vladimir, N., Soldo, V., & Jovanović, I. (2022). Environmental and economic assessment of mariculture systems using a high share of renewable energy sources. Journal of cleaner production, 333, 130072. https://doi.org/10.1016/j.jclepro.2021.130072

Magkouris, A., Rusu, E., Rusu, L., & Belibassakis, K. (2023). Floating solar systems with application to nearshore sites in the Greek Sea Region. Journal of Marine Science and Engineering, 11(4), 722. https://doi.org/10.3390/jmse11040722

Manolache, A. I., & Andrei, G. (2024). A Comprehensive Review of Multi-Use Platforms for Renewable Energy and Aquaculture Integration. Energies, 17(19), 4816. https://doi.org/10.3390/en17194816

Mohammed, K. S., Nassani, A. A., & Sarkodie, S. A. (2024). Assessing the effect of the aquaculture industry, renewable energy, blue R&D, and maritime transport on GHG emissions in Ireland and Norway. Aquaculture, 586, 740769. https://doi.org/10.1016/j.aquaculture.2024.740769

Mueller, M., & Wallace, R. (2008). Enabling science and technology for marine renewable energy. Energy policy, 36(12), 4376-4382. https://doi.org/10.1016/j.enpol.2008.09.035

Nguyen, H. P., & Wang, C. M. (2024). Advances in Offshore Aquaculture and Renewable Energy Production. Journal of Marine Science and Engineering, 12(9), 1679. https://doi.org/10.3390/jmse12091679

Ning, Y., Wang, L., Yu, X., & Li, J. (2023). Recent development in the decarbonization of marine and offshore engineering systems. Ocean Engineering, 280, 114883. https://doi.org/10.1016/j.oceaneng.2023.114883

O'Hagan, A. M. (2011). Marine spatial planning (MSP) in the European Union and its application to marine renewable energy. Global Status and Critical Developments in Ocean Energy, 118.

Pasimeni, F., Navarro, J. P. J., Boedt, G., & Schaaf, J. (2024). Exploring macro patenting trends and key technological components in offshore wind energy. World Patent Information, 78, 102300. https://doi.org/10.1016/j.wpi.2024.102300

Portman, M. E. (2010). Marine Renewable Energy Policy: Some US and International Perspectives Compared. Oceanography, 23(2), 98–105. http://www.jstor.org/stable/24860716

Rentier, G., Lelieveldt, H., & Kramer, G. J. (2023). Institutional constellations and policy instruments for offshore wind power around the North sea. Energy Policy, 173, 113344.

Salvador, S., & Ribeiro, M. C. (2023). Socio-economic, legal, and political context of offshore renewable energies. Wiley Interdisciplinary Reviews: Energy and Environment, 12(2), e462. https://doi.org/10.1002/wene.462

Sgobbi, A., Simoes, S. G., Magagna, D., & Nijs, W. (2016). Assessing the impacts of technology improvements on the deployment of marine energy in Europe with an energy system perspective. Renewable Energy, 89, 515-525. https://doi.org/10.1016/j.renene.2015.11.076

Soria-Rodríguez, C. (2016). Marine Renewable Energies and the European Regional Seas Conventions. Climate Law, 6(3-4), 314-335. https://doi.org/10.1163/18786561-00603007

Soria-Rodríguez, C. (2020). The European environmental regulation of marine renewable energies. Review of European, Comparative & International Environmental Law, 29(1), 95-106. https://doi.org/10.1111/reel.12317

Soukissian, T. H., Denaxa, D., Karathanasi, F., Prospathopoulos, A., Sarantakos, K., Iona, A., ... & Mavrakos, S. (2017). Marine renewable energy in the Mediterranean Sea: status and perspectives. Energies, 10(10), 1512. https://doi.org/10.3390/en10101512

Stockbridge, J., Brown, C. J., & Kuempel, C. D. (2025). Mapping the global co-location potential of offshore wind energy and aquaculture production. Ocean & Coastal Management, 263, 107605. https://doi.org/10.1016/j.ocecoaman.2025.107605

Taveira-Pinto, F., Rosa-Santos, P., & Fazeres-Ferradosa, T. (2020). Marine renewable energy. Renewable Energy, 150, 1160-1164. https://doi.org/10.1016/j.renene.2019.10.014

Theodora, Y., & Piperis, S. (2022). Marine renewable energy perspectives in the Mediterranean region_ planning priorities in a climate neutrality era. Ocean & Coastal Management, 229, 106307. https://doi.org/10.1016/j.ocecoaman.2022.106307

Upton, GB., and Snyder, BF. (2017). 'Funding renewable energy: an analysis of renewable portfolio standards', Energy Economic. Elsevier B.V., 66, pp. 205–216. https://doi.org/10.1016/j.eneco.2017.06.003

Vaca-Cabrero, J., González-Cancelas, N., & Camarero-Orive, A. (2025). Bayesian networks for assessing the sustainability of the Marine Renewable Energy sector in the Blue Economy of Spanish ports. Sustainable Futures, 9, 100497. https://doi.org/10.1016/j.sftr.2025.100497

Vlaswinkel, B., Roos, P., & Nelissen, M. (2023). Environmental observations at the first offshore solar farm in the North Sea. Sustainability, 15(8), 6533. https://doi.org/10.3390/su15086533

Wang, J., & Lund, P. D. (2022). Review of recent offshore photovoltaics development. Energies, 15(20), 7462. https://doi.org/10.3390/en15207462

Weiss, C. V., Menendez, M., Ondiviela, B., Guanche, R., Losada, I. J., & Juanes, J. (2020). Climate change effects on marine renewable energy resources and environmental conditions for offshore aquaculture in Europe, ICES Journal of Marine Science, Volume 77, Issue 7-8, December 2020, Pages 3168–3182, https://doi.org/10.1093/icesjms/fsaa226

Wen, Y., & Lin, P. (2024). Offshore solar photovoltaic potential in the seas around China. Applied Energy, 376, 124279. https://doi.org/10.1016/j.apenergy.2024.124279

Xu, G., Huang, Z., Jiang, M., & Rehman, H. U. (2024). "Gray" prediction of carbon neutral pathways in the G7 economies by 2050. Applied Energy, 373, 123924. https://doi.org/10.1016/j.apenergy.2024.123924

Xu, Y. (2017). Generalized synthetic control method: causal inference with interactive fixed effects models. Political Analysis 25(1):57–76. https://doi. org/10.1017/pan.2016.2

Zaiter, Y., Lago, M., Maund, J., Van Duinen, R., Chouchane, H., van den Burg, S. W., & Araujo, A.

(2025). Investigating levies and barriers for the development of offshore multi-use platforms in European regional seas. Frontiers in Ocean Sustainability, 3, 1542309. https://doi.org/10.3389/focsu.2025.1542309