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Waves of innovation: The role of sustainability in driving impact in the blue economy – A PLS-SEM approach

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A R T I C L E I N F O

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A B S T R A C T

The Blue Economy, with its emphasis on ocean-based industries, is critical for achieving sustainable development. This study investigates the intricate relationship between sustainability, innovation, and their economic, environmental, and social impacts within Portugal's Blue Economy. Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to test the hypothesized relationships between sustainability, innovation, and triple bottom line (TBL) outcomes based on survey data from firms operating in the sector. The findings confirm that innovation acts as both a direct outcome of sustainability efforts and a mechanism for mediating its impacts on economic and environmental performance. However, no significant direct or mediating effects were observed for social outcomes, highlighting a persistent gap in this dimension that requires further research. The study contributes to both theory and practice by highlighting the strategic integration of sustainability into organizational innovation processes and its role in enhancing multidimensional performance. By identifying critical pathways and barriers, this study offers valuable guidance for policymakers and industry leaders striving to enhance the long-term sustainability of the Blue Economy.

1. Introduction

The Blue Economy represents a critical intersection of economic development and environmental stewardship, encompassing ocean-based industries such as fisheries, aquaculture, maritime transport, and renewable marine energy. The European Union's Blue Growth strategy emphasizes its pivotal role in fostering sustainable economic development while addressing pressing environmental challenges [31].

Sustainability, a cornerstone of the Blue Economy, is increasingly recognized as a driver of innovation. In this study, Sustainability-Oriented Innovation (SOI) positions innovation as the enabling response to tackle environmental and social challenges. Highlighting the transformative potential of aligning environmental and social challenges with business opportunities, fostering pathways for eco-efficient practices, such as resource optimization and renewable energy adoption [13,54,59]. For example, sustainable business model archetypes, such as "creating value from waste" and "substituting with renewables", have demonstrated the capacity to align competitive advantages with environmental objectives [12].

In resource-intensive industries such as the Blue Economy, these shifts are particularly critical. The sector's dependency on finite marine resources and fragile ecosystems demands solutions that align economic growth with environmental sustainability and social equity [22,41]. A number of challenges demonstrate this point: overfishing, habitat destruction, and marine pollution require firms to develop adaptive capabilities and integrate sustainability into their innovation strategies to not only mitigate ecological risks but also foster competitiveness and long-term value creation [17].

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Institutional theory provides a relevant framework to understand how the formal and informal rules, as well as the pressures exerted by the institutional environment, shape the strategic decisions of firms in this sector [58]. This perspective helps explain how regulations, societal expectations, and industry norms push organizations toward SOI, particularly in sectors exposed to high environmental scrutiny [16,69].

Despite growing recognition of SOI's potential, limited research has empirically examined how sustainability influences innovation and how such innovation mediates outcomes across the economic, environmental, and social dimensions in Blue Economy contexts [9]. This study addresses that gap by applying the Tripple Bottom Line (TBL) lens to evaluate how SOI affects multidimensional performance outcomes in Portugal's Blue Economy.

The TBL approach, which evaluates firms' performance across economic, environmental, and social dimensions, is particularly relevant in ocean-based sectors where long-term viability depends on maintaining both ecosystem health and community resilience [16]. Prior studies suggest that firms operating in rapidly evolving sectors, such as the Blue Economy, must develop adaptive strategies that balance immediate competitiveness with long-term sustainability [48]. In this context, the TBL provides a comprehensive framework to understand how firms can create value beyond traditional economic metrics [28]

In Portugal, the Blue Economy plays a vital role in national economic development and environmental stewardship, contributing to employment, regional cohesion, and the sustainable use of marine resources [32,62]. As a coastal nation with a long maritime tradition [78], Portugal's Blue Economy encompasses key sectors such as fisheries, aquaculture, maritime transport, and renewable marine energy. These sectors reflect both historically important industries and emerging innovation-intensive domains, making them representative of the diverse trajectories within Portugal's maritime economy [14,2]. They are also explicitly recognized in EU Blue Growth policy priorities and national strategic agendas as focal points for sustainable development and technological investment [2,32]. These industries are vital for achieving EU sustainability targets while addressing environmental challenges such as overfishing, habitat degradation, and climate change impacts on coastal communities.

These characteristics of Portugal's maritime economy emphasizes the urgency of embedding sustainability into innovation strategies, not only as a compliance response but as a proactive approach to long-term resilience [38]. By leveraging sustainability as a driver of innovation, Portugal can position its Blue Economy as a model of resilience and sustainable development, contributing to the broader European Union's efforts to foster a thriving and environmentally responsible maritime sector.

This study examines how sustainability influences innovation and its subsequent impact across the TBL domains in Portugal's Blue Economy. Employing Partial Least Squares Structural Equation Modeling (PLS-SEM), the analysis addresses two key questions: 1) How does sustainability drive innovation in Blue Economy firms? and 2) How does innovation mediate the impacts of sustainability on economic, environmental, and social outcomes?

The results contributes to academic literature by clarifying the mediating role of SOI in translating sustainability practices into improved performance outcomes. From a practical perspective, the findings support the development of targeted strategies for firms and policymakers by highlighting the limited influence of innovation on social outcomes and underscoring the need to better integrate equity and inclusivity into sustainability-driven innovation efforts.

By unpacking the relationship between sustainability, innovation, and impact, the study offers a nuanced framework for operationalizing sustainability at the firm level. The conclusions respond to broader calls for a systemic shift in which sustainability is embedded as a driver of industrial transformation. In doing so, the study aims to inform the design of more effective business models and policy instruments to advance sustainable development in the maritime sector.

2. Conceptual framework and hypothesis development

2.1. Institutional theory

Institutional theory provides a framework to understand how the broader regulatory environment and institutional pressures can shape organizational behaviors and strategies within the Blue Economy [17,26]. Firms in this sector must navigate a complex regulatory landscape, comply with stringent environmental laws and international sustainability standards, and collaborate with diverse stakeholders, such as government agencies, NGOs, and local communities, to ensure the long-term sustainability of their operations and the surrounding marine ecosystem [74,95].

Institutional theory further emphasizes institutional isomorphism, where coercive (regulatory), normative (professional), and mimetic (imitative) pressures converge to shape organizational practices [26]. Particularly relevant for the Blue Economy, firms may adopt similar SOI as they respond to shared regulatory mandates and industry norms [16]. However, firms are not merely passive recipients, they actively interpret, adapt, and potentially reshape these pressures, contributing to the ongoing evolution of institutional norms [63].

The Institutional Theory framework indicates that these external pressures can lead to homogeneity in organizational behaviors, particularly in industries like the Blue Economy that face intense regulatory scrutiny [26,74,9]. In Portugal, the European Union's maritime policies, such as the Marine Strategy Framework Directive, significantly shape the business practices of firms operating in this sector [34]. These are complemented by national strategies, such as the National Ocean Strategy (*Estratégia Nacional para o Mar*), and sector-specific regulatory frameworks that further guide sustainable development in fisheries, aquaculture, maritime transport, and offshore renewables [2,23].

Importantly, the pressures exerted by institutional frameworks can foster a culture of innovation within firms, as they are required to adopt sustainable practices [22,95]. This necessity drives firms to develop new business models and solutions that are both environmentally sustainable and economically viable, aligning with institutional norms and regulatory expectations to ensure the long-term viability of the Blue Economy.

This study draws on Institutional Theory to contextualize the regulatory, normative, and cultural-cognitive environment shaping firms' sustainability practices in the Blue Economy. However, the primary analytical focus lies on firm-level responses, specifically the role of SOI as a mediating mechanism linking sustainability initiatives to performance outcomes. We do not empirically test institutional pressures directly, but we acknowledge their influence as a key driver of SOI adoption, consistent with prior research on sustainability transitions in regulated sectors [26,95].

Thus, Institutional Theory offers a valuable analytical lens, capturing not only compliance-driven behavior but also the strategic adaptations through which firms navigate and respond to sustainability transitions. These include efforts to align with institutional expectations in ways that enhance both resilience and innovation [1,74,94,77].

2.2. Sustainability-oriented innovation (SOI)

SOI refers to the process of developing new or improved products, services, or business models that explicitly integrate environmental and social considerations into the innovation process [37,69]. This approach aims to create solutions that contribute to sustainable development by addressing both operational impacts and the long-term sustainability of resource use. In the Blue Economy, SOI is particularly relevant due to firms' reliance on marine ecosystems and their exposure to increasingly stringent environmental regulations [1,54].

Firms that adopt SOI are better equipped to meet regulatory pressures, address environmental risks, and sustain competitive advantages, conditions that are especially salient in Portugal's maritime sectors [64,93]. For example, the adoption of renewable energy solutions for maritime transport, as seen in Portugal's investment in research and development, has allowed firms to reduce their carbon footprint and meet strict emissions standards [65,101]. Similarly, the implementation of innovative aquaculture techniques, such as closed-loop systems and integrated multi-trophic aquaculture, has helped firms minimize environmental impact while maintaining productivity, as demonstrated by Portugal's national Integrated Multi-Trophic Aquaculture (IMTA) pilot (XtremeAquaCrops) funded through the Fundo Azul and implemented by CCMAR and IPMA [15,84].

Through the adoption of such innovations, firms in the Blue Economy can align compliance with long-term ecological goals, thereby reinforcing both sustainability and competitiveness. Integrating SOI within organizational strategies can foster dynamic capabilities, enabling firms not only to respond reactively but to anticipate environmental and social shifts proactively, thereby enhancing long-term resilience and competitiveness [41,106].

To address the research objectives, we propose the following hypothesis:

H1. : **Sustainability orientation within firms operating in the Blue Economy positively influences innovation**.

The hypothesis is rooted in the concept of SOI, which posits that firms' sustainability initiatives spur them to innovate and create new solutions that incorporate environmental and social factors. By embracing SOI, companies operating in the Blue Economy can bolster their competitiveness, adhere to strict regulations, and contribute to the long-term sustainability of the maritime industry [1,4].

2.3. Triple bottom line (TBL)

The TBL framework compels organizations to comprehensively evaluate and balance their performance across three key dimensions: social, environmental, and financial [28,104]. This holistic approach goes beyond the traditional focus on financial profits, recognizing that businesses have a responsibility to create positive impacts in their communities and on the natural environment in which they operate [105].

In dynamic and resource-sensitive contexts like the Blue Economy, applying the TBL can reveal trade-offs and synergies between economic profitability, environmental stewardship, and social equity, guiding firms toward integrated sustainability strategies that mitigate risks and leverage emerging opportunities [17]. The social dimension of the TBL encompasses the firm's contributions to and relationships with its stakeholders, including employees, local communities, and society at large. This can include measures such as workforce diversity, employee satisfaction, fair labor practices, and the company's role in supporting community development and well-being [28].

The environmental dimension examines the firm's impact on natural resources, energy usage, waste management, emissions, and its overall environmental footprint [29]. Sustainable practices, such as the adoption of renewable energy, resource efficiency, and ecosystem conservation, are essential for achieving positive environmental outcomes.

The financial dimension represents the organization's economic performance and profitability, ensuring the long-term viability and competitiveness of the business. This component is crucial for enabling the firm to invest in and sustain its social and environmental initiatives, creating a virtuous cycle of value creation [28,103,104].

This comprehensive approach supports the long-term sustainability of the Blue Economy, fostering economic prosperity while mitigating environmental degradation and promoting social equity [16]. This holistic approach to assessing the impacts of business activities ensures that the economic benefits of innovation do not overshadow the necessary environmental and social considerations, which is vital for the long-term.

To address the research questions, we propose the following hypothesis:

H2. : ***Innovation positively influences organizational performance across the triple bottom line dimensions***.

- **H2a**: Innovation positively influences economic outcomes.
- **H2b**: Innovation positively influences environmental outcomes.
- **H2c***: Innovation positively influences social outcomes.*

This set of hypotheses examines the direct effect of innovation on firm performance. It reflects the premise that innovation, regardless of its origin, can improve outcomes across economic, environmental, and social dimensions. While sustainability initiatives may influence the type or direction of innovation, H2 focuses solely on innovation's impact on performance, independent of what drives it.

In contrast, the next set of hypotheses explores how sustainability orientation leads to performance improvements through the mediating role of SOI. In the intricate interplay of sustainability practices within the Blue Economy, innovation emerges not merely as an outcome but as a pivotal mediator that bridges the gap between sustainability initiatives and their multifaceted impacts. The TBL framework compels organizations to simultaneously pursue advancements across economic, environmental, and social dimensions [96]. In this context, innovation acts as the linchpin that translates sustainability efforts into tangible outcomes that can be quantitatively and qualitatively assessed.

By embedding innovative practices at the core of sustainability strategies, firms are equipped to not only respond adaptively to environmental challenges but also to capitalize on economic opportunities and enhance social well-being [67,113]. This mediation is critical, as it underscores the capacity of innovative processes to amplify and extend the benefits of sustainability initiatives, making them more comprehensive and impactful. Consequently, understanding the mediating role of innovation helps clarify the mechanisms through which sustainable practices influence broader organizational performance and contribute to sectorial advancements.

To address the research questions, we propose the following hypothesis:

H3. **: *Innovation mediates the relationship between sustainability initiatives and organizational performance across the triple bottom line.***

- **H3a**: *Innovation mediates the relationship between sustainability and economic outcomes*.
- **H3b**: *Innovation mediates the relationship between sustainability and environmental outcomes*.
- **H3c**: *Innovation mediates the relationship between sustainability and social outcomes*.

By examining the mediating role of SOI, this study aims to uncover the nuanced mechanisms through which sustainability initiatives translate into multidimensional impacts within the Blue Economy. Focusing on firm-level dynamics, this analysis contributes to a systems-level understanding of how innovation practices triggered by sustainability orientation influence performance across economic, environmental, and social domains. Such insights are critical to informing integrated strategies that reflect the interconnected nature of these dimensions and support the Blue Economy's long-term transformation.

By synthesizing SOI, Institutional Theory, and the TBL within the context of Portugal's Blue Economy, this research aims to provide detailed comprehension. into the multifaceted impacts of SOI. This theoretical grounding not only frames our empirical investigation but also enriches the academic discourse on sustainable practices in maritime industries. Each hypothesis is crafted to evaluate the relationships dictated by these frameworks, ensuring a comprehensive understanding of the interplay between innovation and sustainability within this vital sector.

3. Methodology

3.1. Contextualizing Portugal's blue economy

Portugal is a coastal nation located in southwestern Europe, with a long and storied maritime history [38]. As a member of the European Union Portugal's economy has a significant focus on the Blue Economy, which encompasses a range of ocean-based industries. The country's extensive coastline, which stretches for 2500 km, has played a vital role in shaping its economic and cultural identity [2,62].

Portugal's Blue Economy is a critical component of its overall economic landscape, contributing significantly to the country's GVA and employment, in 2021 representing 1.8 % of the national GVA and 3.2 % of the national employment [32]. The sector includes resource-intensive industries that are closely tied to the health of the marine ecosystem, such as fishing and maritime transportation [62].

At the same time, Portugal's coastal communities are increasingly vulnerable to the impacts of climate change, such as rising sea levels and more frequent extreme weather events [66]. Addressing these complex challenges requires a comprehensive approach that integrates sustainability into the innovation strategies of businesses operating in the Blue Economy [6].

Portugal has implemented several initiatives to promote a more sustainable Blue Economy. The country has strengthened regulations and enforcement measures to address issues like overfishing, habitat degradation, and marine pollution [2]. For example, Portugal has adopted stricter quotas and monitoring systems for fishing activities, as well as implemented ecosystem-based management approaches in aquaculture [60,73]. Additionally, the government has invested in research and development to support the adoption of innovative, eco-friendly technologies across maritime sectors, such as renewable energy solutions for maritime transport [35].

Portugal has also worked to enhance the resilience of its coastal communities by implementing climate change adaptation strategies, including measures to protect against rising sea levels and extreme weather events [66]. These efforts demonstrate Portugal's commitment to balancing economic growth, environmental preservation, and social equity within its vital Blue Economy.

3.2. Research design

This section introduces the quantitative study conducted to examine the role of sustainability in driving innovation and its associated impacts within the Blue Economy firms. Relying on a structured survey administered to firms operating in Portugal's maritime sectors, the research employs PLS-SEM, with full details of the method provided in Section 3.4., to explore the hypothesized relationships between SOI and economic, environmental, and social performance.

The constructs used in the questionnaire were aligned with established frameworks for measuring sustainability and innovation impacts. Specifically, items were drawn from validated studies that addressed strategic innovation practices in maritime sectors [19], environmental and social outcome indicators in marine resource management [50], and firm-level sustainability practices in resource-intensive industries [91]. This ensured theoretical alignment with the SOI and TBL frameworks and empirical relevance to the Blue Economy context.

Survey items were carefully designed to reflect each construct and ensure conceptual clarity and empirical relevance. The indicators addressed innovation strategy, performance management, and sustainability practices, as well as their perceived impacts across the three dimensions of performance. The complete list of constructs and indicators is provided in Table 1.

3.3. Data collection

This study targeted firms within Portugal's Blue Economy,

Table 1
Constructs and measurement items from questionnaire Sustainable Practices in Innovative companies of the Portuguese Blue Economy.

Dimensions/ Constructs	Observed Measurements / Variables / Indicators	Source
Innovation Strategy	INS1: To what extent is innovation important for the growth of your company?	Valdez-Juárez & Castillo-Vergara [108]; Mousavi et al. [68]; Behnam & Cagliano [9]; Teece et al. [106]; Porter & van der Linde [82].
	INS2: How much has your company invested in R&D over the past 3 years (e.g., budget proportion, ongoing projects)?	Rosário & Dias [88]; González-Álvarez & Cabeza-García [44]; OECD [72]; Adams et al. [1]; Porter & Van Der Linde [82].
	INS3: To what extent has your company adopted new technologies (e.g., AI, automation)?	Verdolini et al. [111]; Zhang *et al.* [115]; Geissdoerfer et al. [41]; Venkatesh *et al.* [110]; Teece et al. [106].
Innovation Performance Management	INP1: How often does your company conduct regular evaluations and reviews of the impact of innovation?	Alomoto et al. [3]; Amui et al. [5]; Adams et al. [1]; GRI [42]; Bossle et al. [13].
	INP2: To what extent does your company use data analytics to monitor the progress of innovation impacts?	Fontes et al. [38]; OECD[72] ; Adams et al. [1]; GRI [42]; Joung *et al.* [53].
	INP3: How frequently does your company develop sustainability reports and transparently communicate the results?	Machado de Almeida & De Portugal [62]; Villaseñor-Derbez et al. [112]; GRI [42]]; Bocken et al. [12]; Elkington [28] .
	INP4: How often does your company engage stakeholders, including local communities, in assessing the impact of innovations?	Jiang *et al.* [18]; Villaseñor-Derbez et al. [112]; Cisneros-Montemayor *et al.* [18]; GRI [42]; Porter & Kramer [81].
	INP5: To what extent does your company use internationally recognized assessment methodologies to evaluate innovation?	Rosário & Dias ; Verdolini et al. [111]; Silvestre & Ţîrcă [99]; Adams et al. [1]; GRI [42].
Sustainability	SUS1: How important is sustainability to your company's overall strategy?	Verdolini et al. [111]; OECD [72]; Amui et al. [5]; Bocken et al. [12]; Elkington [28].
	SUS2: How important is compliance with environmental regulations in your sustainability strategy?	González-Álvarez & Cabeza-García [44]; Silvestre & Ţîrcă [99]; Teece et al. [106]; Porter & Van Der Linde [82]
	SUS3: How important is social responsibility to your company's sustainability strategy?	Jiang *et al.* [51]; Villaseñor-Derbez et al. [112]; Alomoto et al. [3]; Bocken et al. [12]; Elkington [28].
	SUS4: How important is the use of renewable energy to your company's sustainability strategy?	European Commission [31]; Pudzis *et al.* [83]; Adams et al. [1]; Bocken et al. [12].
	SUS5: How important is sustainable resource management to your company's sustainability strategy?	Villaseñor-Derbez et al. [112]; Amui et al. [5]; Adams et al. [1]; Bocken et al. [12].
	SUS6: How important is circular economy practice to your company's sustainability strategy?	Rosário & Dias [88]; OECD [72]; Adams et al. [1]; Bocken et al. [12].

(continued on next page)

Table 1 (*continued*)

Dimensions/ Constructs	Observed Measurements / Variables / Indicators	Source
	SUS7: How important is investment in research and development (R&D) to your company's sustainability strategy?	González-Álvarez & Cabeza-García [44]; Teece et al. [106]; Porter, Van Der Linde [82].
Impacts (Economic)	EC1: Over the past 3 years, what has been the impact of your company's sustainable practices on job creation?	Villaseñor-Derbez et al. [112]; Alomoto et al. [3]; Porter & Kramer [81]; Elkington [28].
	EC2: What has been the impact of your company's sustainable practices on economic growth?	Machado de Almeida & De Portugal [62]; Fontes et al. [38]; Teece et al. [106]; Porter, Van Der Linde [82].
	EC3: What has been the impact of your company's sustainable practices on profitability?	Verdolini et al. [111]; Adams et al. [1]; GRI 42; Bocken et al. [12].
Impacts (Environmental)	ENV1: To what extent have your company's sustainable practices reduced pollution?	Pudzis *et al.* [83]; Geissdoerfer et al. [41]; Adams et al. [1]; Bocken et al. [12].
	ENV2: What has been the impact of your company's sustainable practices on biodiversity conservation?	Jiang *et al.* [51]; Villaseñor-Derbez et al. [112]; GRI [42]; Porter & Kramer [81].
	ENV3: What has been the impact of your company's sustainable practices on energy efficiency?	European Commission [31]; Verdolini et al. [111]; Bocken et al. [12]; Teece et al. [106].
Impacts (Social)	SOC1: To what extent have your company's sustainable practices engaged the community?	Jiang *et al.* [51]; Villaseñor-Derbez et al. [112]; Alomoto et al. [3]; Porter & Kramer [81]; Elkington [28].
	SOC2: What has been the impact of your company's sustainable practices on improving living conditions?	Villaseñor-Derbez et al. [112]; Cisneros-Montemayor *et al.* [18]; Adams et al. [1]; Bocken et al. [12].
	SOC3: What has been the impact of your company's sustainable practices on education and awareness?	Jiang *et al.* [51]; Villaseñor-Derbez et al. [112]; Rosário & Dias [88]; GRI [42]; Elkington [28].

Source: Own elaboration.

specifically selecting participants from the associates of *Fórum Oceano*, the managing entity of Portugal's Maritime Cluster and a key actor in fostering innovation and collaboration in ocean industries, and *Oceano Azul Foundation*, a leading non-profit organization supporting marine conservation and sustainable ocean initiatives in Portugal. These sources were chosen due to their integral roles in promoting sustainable maritime activities and innovation across national industries [40,71].

Over a period of 6 months, surveys were distributed via e-mail to 147 companies identified through these networks. Participants were selected using a purposive sampling method to ensure representation across various sectors within the Blue Economy. In conducting the survey, we utilized the EU platform for surveys [33], a tool endorsed by the European Union for its robust data collection capabilities and compliance with data protection regulations. This platform facilitated a streamlined approach to distributing the survey and collecting responses, ensuring consistency and reliability across all participants.

Surveys were specifically addressed to key organizational figures, including CEOs, managers responsible for innovation and sustainability, or directors, to ensure that the responses reflected strategic visions and informed perspectives on the topics addressed. Data collection was conducted between June 2024 and November 2024. To maximize engagement and mitigate potential limitations associated with a low response rate, we implemented follow-up strategies, including reminder emails and phone calls, to encourage participation. These efforts aimed to ensure broad geographic and sectoral representation among the respondents [25].

Despite these efforts, the response rate was 27 %, with 40 companies providing complete responses. This response rate is acceptable and justifiable given the context of this research. In survey-based studies targeting senior managers or SMEs, especially in emerging policy domains like the Blue Economy, response rates typically range between 20 % and 30 %. This is well-documented in empirical management and sustainability research [7].

The methodology adhered to high ethical standards, a formal opinion was obtained from the Data Protection Officer of the University of Algarve, who confirmed that the study does not involve the processing of personal data and therefore does not require ethical approval under GDPR or national data protection law. Respondents were assured of confidentiality and anonymity to encourage honest and accurate responses. Participation was voluntary, and informed consent was obtained before beginning the survey. No incentives were offered to encourage response, maintaining the neutrality and integrity of the data collected.

To further enhance representativeness, the respondents' geographic distribution across Portugal was mapped using their postal codes. Fig. 1 illustrates the regional coverage of the sample, ensuring a comprehensive analysis of spatial patterns across the country. By depicting firm engagement across various regions in Portugal, the visualization underscores the geographic diversity of the dataset and strengthens the credibility of the study's conclusions.

The survey instrument employed a five-point Likert scale with varied response anchors tailored to the specific content of each question, and also giving an optimal balance between response sensitivity and cognitive load, as shown in psychometric research [20,86]. For questions measuring importance, the scale ranged from 1 ("Not important") to 5 ("Very important"). For questions assessing frequency or extent, the scale ranged from 1 ("Never") to 5 ("Always") or 1 ("Not at all") to 5 ("To a great extent"). For evaluative questions, the scale ranged from 1 ("Strongly disagree") to 5 ("Strongly agree"). Each scale was carefully selected based on the question's context to capture the most accurate organizational behaviors and perceptions.

The questions were also accompanied by examples to provide respondents with a clear understanding of the context and intent of the inquiry. This was crucial for ensuring that responses were based on a consistent interpretation of the questions across all participants.

A pilot test was conducted with a sample of 10 organizations from different sectors of the Blue Economy, including maritime transport, fisheries, marine biotechnology, aquaculture, and research centers. These organizations were selected for their relevance to the study context and their active involvement in sustainability or innovation-related initiatives. The pilot aimed to validate the survey's clarity, relevance, and alignment with theoretical constructs [19]. It also tested the time required for completion, which highlighted the limited availability of senior executives such as CEOs. As a result, the survey was reduced in length to ensure feasibility and minimize response fatigue. The feedback highlighted areas for improvement, leading to minor refinements in wording and question structure to enhance precision and readability.

3.4. Data analysis methods

The data analysis was conducted using the statistical software tools such as SPSS version 29 for descriptive statistics and SmartPLS version 4 for PLS-SEM, covering both measurement and structural model analyses [87]. The hypothesized relationships in the model were assessed using

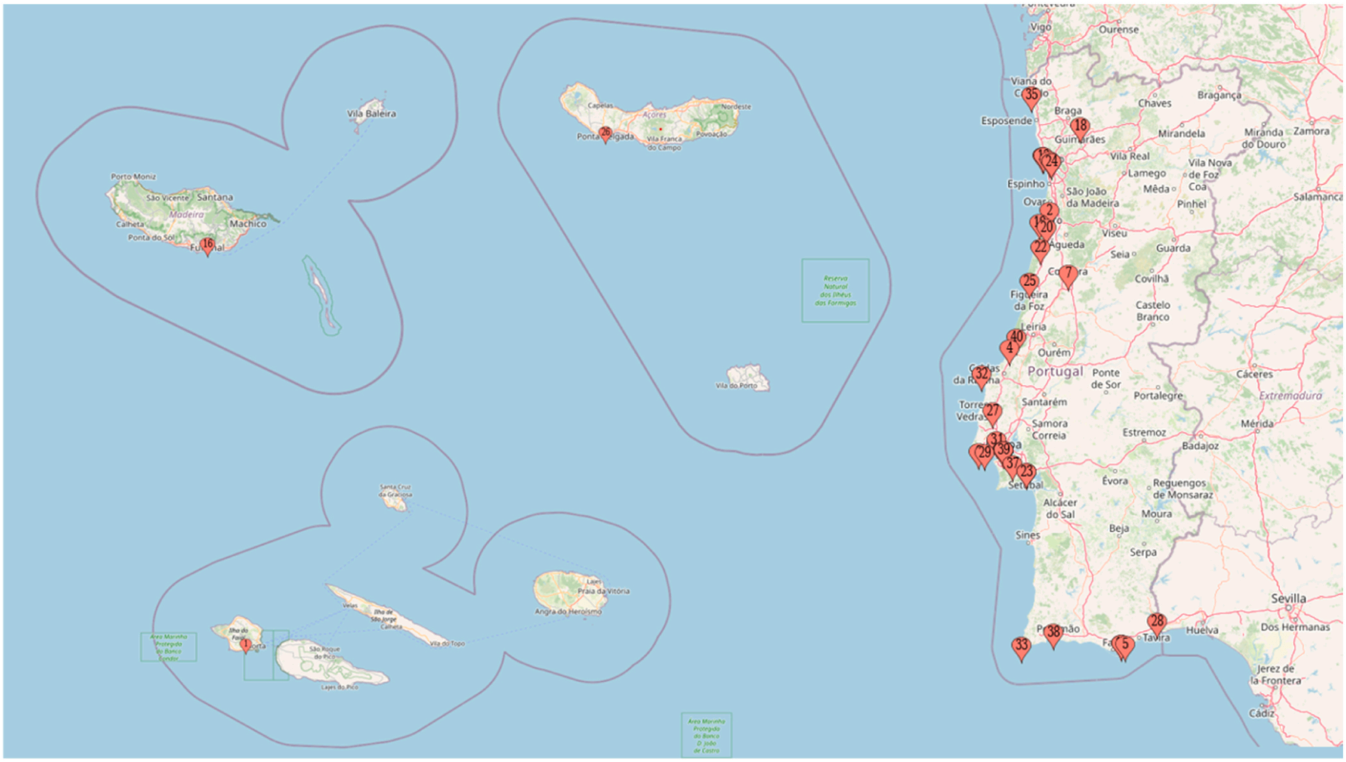

Fig. 1. Geographical distribution of respondents across Portugal.
Source: Own elaboration.

PLS-SEM due to its suitability for studies with small sample sizes and its ability to model complex relationships involving multiple constructs and mediators, as recommended by Hair et al. [47].

The study included six latent constructs. All constructs were modeled as reflective constructs, except Innovation, which was modeled as a reflective-formative construct to capture its multidimensionality. This dual nature of Innovation allows its indicators to both uniquely contribute to and collectively reflect the construct [24]. To illustrate the relationships between constructs and their reflective/formative nature, the conceptual model used in this study is presented in Fig. 2. This figure highlights the positioning of each construct and its corresponding indicators, offering a comprehensive overview of the research framework.

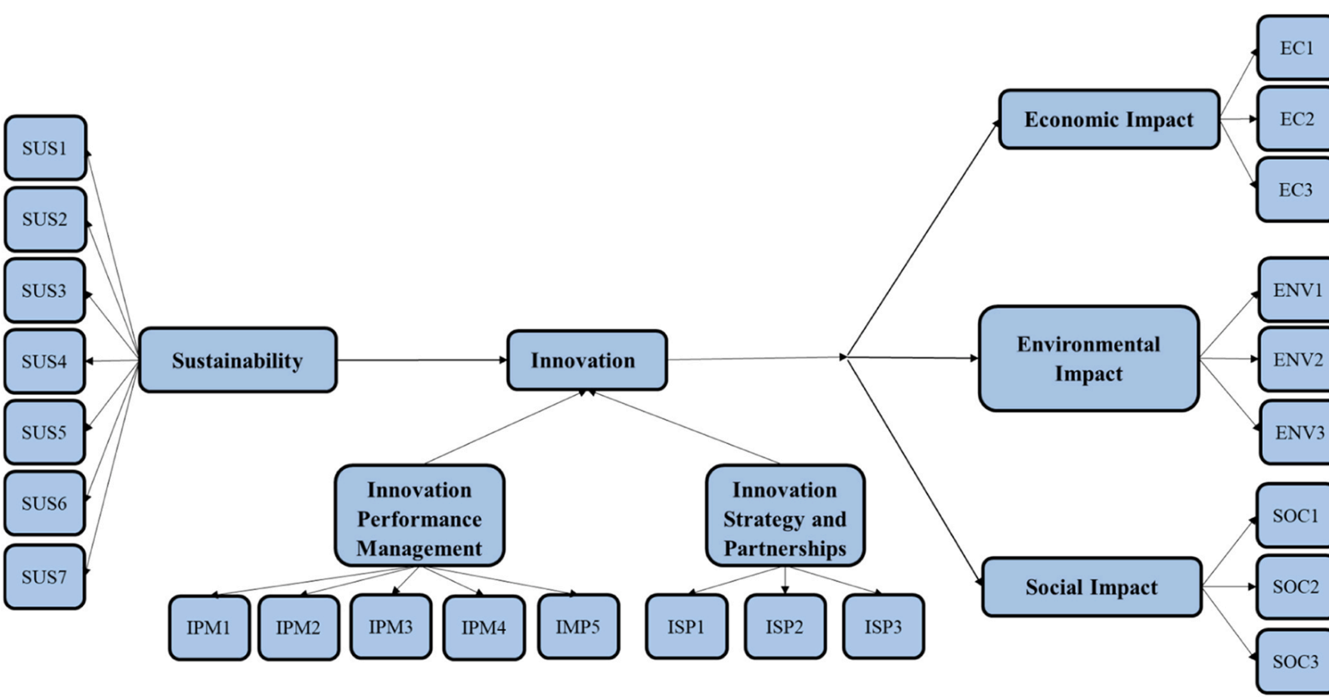

Fig. 2. Conceptual model of the Constructs and Indicators.
Source: Own elaboration.

Descriptive analysis began with frequency distributions and percentile metrics to characterize the sample Multicollinearity among the formative indicators of the Innovation construct was assessed using collinearity statistics to ensure the unique contribution of each indicator to the construct. For the reflective constructs, traditional reliability measures such as Cronbach's alpha and composite reliability (CR) were applied to assess internal consistency.

Convergent and discriminant validity were evaluated for all constructs. For reflective constructs, convergent validity was assessed using average variance extracted (AVE), while discriminant validity was confirmed using the Fornell-Larcker criterion. For the reflective-formative Innovation construct, redundancy analysis and indicator significance testing were used to evaluate its validity and appropriateness. Finally, using PLS-SEM to assess the hypothesized relationships and determine the paths within the model.

The sample size adequacy for this study was assessed using the A-priori Sample Size Calculator for Structural Equation Models [102]. Based on the study parameters, an anticipated effect size of 0.5, a desired statistical power level of 0.8, six latent variables, 24 observed variables, and a significance level (α) of 0.05, the calculator determined that a minimum of 40 responses was required to detect the specified effects. The study meets this minimum threshold, demonstrating sufficient statistical power for detecting medium-to-large effects.

Although the calculator also recommends a sample size of 100 to address the structural complexity of the model and enhance generalizability, the achieved sample of 40 meets the minimum threshold. PLS-SEM remains appropriate in this context, designed to maximize predictive accuracy and is less reliant on stringent distributional assumptions, making it appropriate for the constraints of this study [46].

Despite the limitations associated with a smaller sample size, the findings offer an initial understanding of the relationships between sustainability, innovation, and multidimensional impacts within Portugal's Blue Economy.

4. Findings

4.1. Preliminary univariate analysis

4.1.1. Sample profile

The sociodemographic characteristics of the participating companies are presented in Table 2, providing a detailed overview of the sample. The analysis focused on key variables such as sector, company size, age, and recent innovation activities. This information helps contextualize the sample and highlights the diversity of firms operating within Portugal's Blue Economy.

The majority of respondent companies were from Aquaculture (27.5 %). The remaining participants represented Biotechnology (15.0 %), Maritime industry (12.5 %), Research and Education (10.0 %), Blue bioeconomy (7.5 %), Renewable energies (7.5 %), Port activities (7.5 %), Shipbuilding/repair (5.0 %), Fishing (5.0 %), and Maritime transport (2.5 %). To further clarify the activity profile of each firm, Appendix A includes their respective CAE codes (*Classificação Portuguesa das Atividades Económicas*), which represent the official Portuguese classification system for economic activities.

In terms of company size, the sample was predominantly composed of 33 micro companies, followed by 4 small companies and 3 medium-sized companies. This distribution mirrors the structure of the Portuguese economy, where 99.9 % of enterprises are SMEs [49], and micro-enterprises make up the vast majority (96.2 %). This finding emphasizes the regional focus and local resource reliance of smaller enterprises within the Blue Economy sectors.

The age of the companies ranged from 1 to 65 years, with a mean age of 15.75 years (SD = 15.397). The distribution includes a mix of newly established firms (7.5 %) and long-standing companies (22.5 %), indicating a balance of fresh perspectives and experienced operations within the sample.

Table 2
Demographic analysis of participating companies.

Category	Subcategories	Frequency (N)	Percent (%)
Sector	Aquaculture	11	27,50
	Port activities	3	7,50
	Blue bioeconomy,	3	7,50
	Biotechnology	6	15,00
	Research/ Education	4	10,00
	Shipbuilding (repair)	2	5,00
	Renewable energies	3	7,50
	Maritime industry	5	12,50
	Fishing	2	5,00
	Maritime transport	1	2,50
Company Size	Micro Company	33	82,50
	Small Company	4	10,00
	Medium Company	3	7,50
Company's Age	< 5 Years	3	7,50
	5–9 Years	15	37,50
	10–14 Years	7	17,50
	15–19 Years	6	15,00
	≥ 20 Year	9	22,50
Introduced Product Innovation in the Last 3 Years	Yes	30	75,00
	No	10	25,00
Introduced Process Innovation in the Last 3 Years	Yes	31	22,50
	No	9	77,50
Introduced Marketing Innovation in the Last 3 Years	Yes	22	55,00
	No	18	45,00
Introduced Organizational Innovation in the Last 3 Years	Yes	20	50,00
	No	20	50,00

Source: Own elaboration.

The majority of companies reported introducing innovations over the past three years, particularly in product (75 %) and process development (77.5 %). Notably, 80 % of firms engaged in more than one type of innovation, suggesting a broadly integrated approach. However, given that 7.5 % of firms did not report any innovation activity, and 12.5 % engaged in only one type, this indicates variation in adaptive capacity across the sector. These results suggest that innovation may serve as a strategic tool for many, but not all, firms in responding to sustainability and competitiveness pressures.

4.1.2. Constructs' descriptive overview

Descriptive statistics for the six latent variables are presented in Table 3, including measures of central tendency, dispersion, and distribution (mean, standard deviation, skewness, and kurtosis). These metrics provide a foundational understanding of the dataset prior to structural model estimation and hypothesis testing.

As shown in Table 3, sustainability-related constructs reported the highest mean scores, suggesting that surveyed firms perceive sustainability as a strategic priority and recognize its positive impacts. In contrast, innovation-related constructs, particularly Innovation Performance Management, exhibited lower mean values and greater variability. This pattern indicates that while sustainability is broadly integrated across firms, innovation practices remain less consistently implemented, pointing to both organizational challenges and opportunities for improvement.

4.2. Structural equation modelling

4.2.1. Measurement model analysis

This section presents the validation of the measurement model using PLS-SEM. The measurement model analysis focuses on assessing reliability, convergent validity, discriminant validity, and collinearity for

Table 3
Descriptive statistics (N = 40).

Latent Variables	N	Mean	Std. Deviation	Skewness	Std. Error	Kurtosis	Std. Error
Sustainability	40	4,0239	0,50111	−0,5220	0,374	−0,174	0,733
Innovation Strategy	40	3,3875	0,70447	−0,5180	0,374	−0,209	0,733
Innovation Performance Management	40	3,3550	0,92762	−0,4529	0,374	−0,273	0,733
Economic Impact	40	3,7083	0,66747	−0,9470	0,374	1,880	0,733
Environmental Impact	40	3,7333	0,90959	−0,6357	0,374	0,188	0,733
Social Impact	40	3,7333	0,62793	−0,1105	0,374	−0,489	0,733

Source: Own elaboration.

both first-order and second-order constructs to ensure the robustness of the subsequent structural model estimation [46]. This study includes first-order reflective constructs and one second-order reflective-formative construct (Innovation).

As shown in Table 4, all first-order reflective constructs demonstrated high reliability, with Cronbach's alpha and CR values exceeding the recommended threshold of 0.70. Convergent validity was confirmed as the AVE for all constructs surpassed the minimum criterion of 0.50, indicating that each construct explains more than 50 % of the variance in its indicators [46]. Additionally, all factor loadings exceeded 0.70, demonstrating strong individual indicator reliability. However, one indicator of Social Impact had a factor loading of 0.678, which, while slightly below the ideal threshold, was considered approximate enough and theoretically relevant for the construct.

Discriminant validity was assessed using the Fornell–Larcker criterion, which states that the square root of a construct's AVE should exceed its correlations with other constructs [39]. As shown in Table 5, all diagonal values (in bold) are higher than the corresponding inter-construct correlations, confirming discriminant validity for the first-order constructs.

A two-stage disjoint approach [92] was employed to construct the second-order formative variable Innovation, composed of two first-order reflective constructs: Innovation Performance Management and Innovation Strategy and Partnerships. To assess the validity of this higher-order construct, collinearity diagnostics were performed, with all variance inflation factor (VIF) values below the threshold of 5, indicating no multicollinearity [46]. Outer weights were also examined to evaluate the contribution of each first-order dimension. As shown in Table 6, the results confirm the reliability and discriminant validity of the second-order construct and its dimensions.

Discriminant validity was reassessed following the formation of the second-order construct "Innovation," using the Fornell–Larcker [39] criterion. As shown in Table 7, all first-order constructs exhibit adequate discriminant validity, with the square root of the AVE (on the diagonal, in bold) exceeding the correlations with other constructs.

The results of the measurement model analysis confirm that the constructs in this study exhibit strong reliability and validity. These findings provide a robust foundation for the subsequent structural model analysis.

4.2.2. *Structural model analysis*

The structural model analysis phase evaluates the hypothesized relationships among latent variables, allowing for an evaluation of the model's explanatory power and the strength of the relationships proposed in the theoretical framework.

The R^2 values reflect the proportion of variance explained by the independent variables in each construct (Table 8). In this study, the R^2 value for Innovation was 0.471, indicating that sustainability explains 47.1 % of the variance in innovation. This highlights sustainability's strong role as a driver of innovation, particularly in resource-intensive industries like the Blue Economy. For Economic Impact ($R^2 = 0.182$) and Environmental Impact ($R^2 = 0.116$), innovation explains a modest but meaningful proportion of the variance.

These results align with prior studies demonstrating that SOI can

Table 4
Construct reliability and validity (first-order constructs).

Latent Variable	Items	Factor Loadings	Mean (M)	Standard Deviation (STDEV)	Cronbach's alpha	CR	AVE
Innovation Performance Management	INP1	0,786	0,751	0,146	0,891	0,904	0,698
	INP2	0,814	0,806	0,082	-	-	-
	INP3	0,896	0,894	0,035	-	-	-
	INP4	0,896	0,893	0,044	-	-	-
	INP5	0,777	0,771	0,079	-	-	-
Innovation Strategy and Partnerships	INS1	0,864	0,870	0,039	0,815	0,818	0,730
	INS2	0,886	0,885	0,042	-	-	-
	INS3	0,813	0,799	0,088	-	-	-
Sustainability	SUS1	0,764	0,767	0,062	0,894	0,900	0,610
	SUS2	0,757	0,734	0,143	-	-	-
	SUS3	0,857	0,841	0,072	-	-	-
	SUS4	0,781	0,758	0,118	-	-	-
	SUS5	0,770	0,766	0,090	-	-	-
	SUS6	0,774	0,767	0,096	-	-	-
	SUS7	0,759	0,756	0,076	-	-	-
Economic Impact	EC1	0,748	0,678	0,196	0,776	0,880	0,682
	EC2	0,907	0,889	0,148	-	-	-
	EC3	0,814	0,768	0,198	-	-	-
Social Impact	SOC1	0,678	0,598	0,324	0,711	0,858	0,594
	SOC2	0,888	0,788	0,279	-	-	-
	SOC3	0,729	0,649	0,275	-	-	-
Environmental Impact	ENV1	0,927	0,916	0,081	0,833	1,011	0,736
	ENV2	0,815	0,804	0,118	-	-	-
	ENV3	0,828	0,805	0,121	-	-	-

Source: Own elaboration.

Table 5
Discriminant validity (first-order constructs).

Latent Variable	Economic Impact	Environmental Impact	Innovation Performance Management	Innovation Strategy and Partnerships	Social Impact	Sustainability
Economic Impact	**0,826**					
Environmental Impact	0,603	**0,858**				
Innovation Performance Management	0,379	0,427	**0,835**			
Innovation Strategy and Partnerships	0,350	0,166	0,484	**0,855**		
Social Impact	−0,192	−0,344	−0,340	0,003	**0,771**	
Sustainability	0,113	0,199	0,477	0,702	−0,063	**0,781**

Source: Own elaboration. Note: Diagonal elements in bold represent the square root of AVE. Values below the diagonal represent correlations among constructs.

Table 6
Construct reliability and validity after generating second-order constructs.

Latent Variable	Items	Scale Type	Loadings/ Weights	Cronbach's alpha	AVE	VIF
Innovation	Innovation Performance Management	Formative	0,855	NA	NA	1,308
	Innovation Strategy and Partnerships		0,869	-	-	1,308
Sustainability	SUS1	Reflective	0,763	0,894	0,610	NA
	SUS2		0,775	-	-	NA
	SUS3		0,757	-	-	NA
	SUS4		0,761	-	-	NA
	SUS5		0,856	-	-	NA
	SUS6		0,783	-	-	NA
	SUS7		0,768	-	-	NA
Economic Impact	EC1	Reflective	0,750	0,776	0,679	NA
	EC2		0,909	-	-	NA
	EC3		0,806	-	-	NA
Social Impact	SOC1	Reflective	0,890	0,711	0,623	NA
	SOC2		0,628	-	-	NA
	SOC3		0,825	-	-	NA
Environmental Impact	ENV1	Reflective	0,920	0,833	0,740	NA
	ENV2		0,849	-	-	NA
	ENV3		0,807	-	-	NA

Source: Own elaboration. Note: VIF < 5 indicates no collinearity issues. NA = not applicable for formative indicators.

Table 7
Discriminant validity after generating second-order constructs.

Latent Variable	Economic Impact	Environmental Impact	Social Impact	Sustainability
Economic Impact				
Environmental Impact	**0,725**			
Social Impact	0,274	**0,362**		
Sustainability	0,215	0,233	**0,302**	

Source: Own elaboration.
Note: AVE value is not available for the second-order formative construct "Innovation" which is excluded from this assessment.

Table 8
R^2 Values.

Construct	R^2 Value	R^2 Adjusted
Innovation	0,471	0,457
Economic Impact	0,182	0,161
Environmental Impact	0,116	0,093
Social Impact	0,049	0,024

Source: Own elaboration.

enhance profitability and reduce environmental harm through resource-efficient technologies [9,111]. However, the R^2 value for Social Impact (0.049) is notably weaker, reflecting challenges in achieving meaningful social outcomes through innovation alone.

The hypothesized relationships were evaluated using path coefficients derived from the structural model. The significance of these coefficients was determined using bootstrapping procedures with 5000 resamples [46]. The results of the direct and indirect effects are presented in Table 9.

The findings indicated that the influence of Sustainability on Innovation was significant and positive ($\beta = 0.686$, $p < 0.01$), demonstrating that an increase in sustainability efforts substantially drives innovation. Similarly, the effects of Innovation on Economic Impact ($\beta = 0.427$, $p < 0.05$) and Environmental Impact ($\beta = 0.341$, $p < 0.05$) were positive and significant. However, the relationship between Innovation and Social Impact was not significant ($\beta = -0.222$, $p = 0.391$).

The results of the structural model analysis for indirect paths indicated that Sustainability had a significant indirect effect on Economic Impact ($\beta = 0.293$, $p = 0.020$) and Environmental Impact ($\beta = 0.234$, $p = 0.039$) through Innovation, supporting H3a and H3b. However, the indirect effect of Sustainability on Social Impact was not significant ($\beta = -0.152$, $p = 0.403$), meaning H3c was rejected. Since the direct effect of Innovation on Economic and Environmental Impacts was significant, the mediating role of Innovation was partial.

5. Discussion

This study examines the interplay between sustainability, innovation, and their multidimensional impacts within the Blue Economy. The findings advance our understanding of how firms operationalize SOI to pursue economic and environmental objectives while addressing ongoing challenges related to social equity. Situated in the context of Portugal's Blue Economy, the study sheds light on both the current landscape of SOI and its transformative potential, alongside key limitations. The findings offer implications for policy design, governance models, and firm-level innovation strategies, with relevance that extends beyond the national setting to other maritime economies

Table 9
Results of structural model (direct and indirect paths).

Paths		Beta	T statistics	P values	Results	Hypothesis
Direct	Sustainability → Innovation	0,686	6,830	0,000**	Supported	H1
	Innovation → Economic Impact	0,427	2,579	0,010*	Supported	H2a
	Innovation → Environmental Impact	0,341	2,044	0,041*	Supported	H2b
	Innovation → Social Impact	−0,222	0,858	0,391	Not supported	H2c
Indirect	Sustainability → Innovation → Economic Impact	0,293	2,321	0,020*	Supported	H3a
	Sustainability → Innovation → Environmental Impact	0,234	2,061	0,039*	Supported	H3b
	Sustainability → Innovation → Social Impact	−0,152	0,836	0,403	Not supported	H3c

Source: Own elaboration. *Note: **$p < 0.01$, $p < 0.05$, based on two-tailed test; $t = 1.96$.

navigating similar sustainability challenges.

The PLS-SEM results indicate a strong, positive effect size for the path between sustainability and innovation ($\beta = 0.686$, $p < 0.00$), supporting the idea that sustainability initiatives function as important internal drivers of innovation across the surveyed firms, regardless of sector or size. This aligns with prior conceptual perspectives from Institutional Theory, which posit that firms may respond to external regulatory, normative, or mimetic pressures by adopting innovative practices [58, 82]. Although such institutional pressures were not empirically tested in this study, they provide a valuable contextual lens for interpreting why sustainability might be strategically embedded into innovation practices in highly regulated or norm-sensitive industries like the Blue Economy.

Examples from Portugal's Blue Economy, such as the adoption of circular economy practices, resource-efficient technologies, and renewable energy solutions, illustrate this dynamic. For instance, advancements in microorganism-based aquafeeds, such as those supported by the *XtremeAquaCrops* project coordinated by CCMAR, have helped reduce operational costs while mitigating environmental harm [15] These developments exemplify how firms leverage sustainability challenges to create innovation opportunities, transitioning from compliance burdens to strategic advantages. This reflects global patterns, where companies embedding sustainability into their core strategies demonstrate greater adaptability to market disruptions and resource constraints [41,44].

Innovation emerged as a significant enabler of both economic and environmental outcomes, reinforcing its dual role in enhancing financial stability and ecological stewardship. This dual impact reflects the logic of the TBL [28], which posits that SOI can generate economic value while minimizing environmental harm. For example, at the national Port of Sines, the adoption of onshore-power supply and emission reduction technologies decreased operational costs and lowered carbon emissions by nearly 14 % over recent years [8]. Similarly, Portuguese researchers are converting coastal algae into biodegradable bioplastics with fertilizing properties, creating new market opportunities while mitigating marine pollution [107]. Beyond theoretical consistency, these examples highlight innovation's capacity to integrate sustainability dimensions in practice, helping firms navigate the complexity of interconnected goals.

In the economic domain, innovation has been instrumental in driving job creation, market expansion, and cost efficiency, particularly in sectors like aquaculture and offshore renewable energy [38]. For instance, economic modeling shows that commercial-scale floating offshore wind farms along Portugal's coast can be financially viable, especially when supported by mechanisms like contract-for-difference schemes, which paves the way for local supply chain development and green-collar employment opportunities [114]. Similarly, the implementation of digital monitoring and precision-feed systems in Portuguese aquaculture operations has enhanced productivity and included initiatives like SWIMS™ (Smart Water Integrated Management System), a digital platform for aquaculture monitoring and maintenance, enabling up to 50 % reduction in maintenance efforts [11,70]. These examples illustrate how innovation not only sustains economic performance but also supports firms' adaptive capacity in dynamic resource environments.

From an environmental standpoint, innovation has advanced carbon reduction, biodiversity conservation, and ecosystem restoration. Technologies aimed at energy efficiency, waste valorization, and circular processes have enabled firms to decouple growth from environmental degradation. However, realizing these environmental benefits often hinges on the inclusion of diverse stakeholders, particularly in coastal and resource-dependent regions where community engagement can determine the success of innovation uptake [100]. This aligns with prior studies emphasizing the strategic integration of ecological imperatives into core business models [12,5].

For instance, Portuguese aquaculture and fisheries firms have started converting marine-processing by-products, such as shellfish and fish waste, into high-value biopolymers, bioactive compounds, or feed supplements, supporting both waste reduction and enhanced ecosystem care [75,109]. These trends challenge the outdated view that profitability and sustainability are at odds, supporting Verdolini *et al.*'s (2021) claim that environmental goals can reinforce competitive advantage.

In contrast to its economic and environmental effects, the relationship between sustainability and social outcomes, via the influence of innovation, was not significant ($\beta = -0.152$, $p = 0.403$). This outcome reinforces critiques that many SOI tend to prioritize technological efficiency or ecological outcomes while underemphasizing social equity and community well-being [12,3]. The absence of significant social impacts suggests that firms may lack structured frameworks or incentives to meaningfully integrate social concerns into innovation practices [16].

This gap is especially concerning given the foundational role that equity and inclusion play in achieving systemic sustainability. Without intentional strategies to incorporate the needs of affected stakeholders, innovation risks reinforcing existing disparities rather than resolving them. For instance, large-scale coastal renewable energy projects often reduce environmental footprints but overlook local community participation and benefit-sharing [55].

This gap underscores the need for deliberate strategies to integrate social considerations into innovation processes. Approaches such as co-creation, stakeholder engagement, and equity-driven policies can help ensure that innovation delivers inclusive and equitable outcomes [52, 97,100]. To illustrate, participatory innovation models have shown promise in fisheries management and marine conservation efforts, offering actionable strategies to bridge the gap between technological advancements and community well-being [50,112].

A closer look at innovation patterns across the sample reveals that most firms (32 out of 40) pursued more than one type of innovation, with 13 implementing all four (product, process, marketing, and organizational). This multidimensional engagement suggests that innovation in the Blue Economy is not only sector-driven but also strategically diversified, potentially reflecting the cross-cutting nature of sustainability challenges [27]. Conversely, firms that implemented only product innovation were typically younger and smaller, aligning with existing findings that startups often embed innovation in their value proposition but may lack the maturity to institutionalize broader organizational change [43].

While the sample size limited formal subgroup analysis, the distribution of innovation types across sectors tentatively supports the idea that firms in more innovation-intensive industries (e.g., marine biotechnology, offshore renewables) are structurally more inclined to adopt SOI practices. These sectors are often shaped by stronger R&D networks, regulatory frameworks, and international market pressures, which can incentivize firms to innovate across multiple domains simultaneously [57]. In contrast, traditional sectors such as fisheries and maritime transport may face higher barriers to diversification, including capital constraints, legacy infrastructure, or lower absorptive capacity for new technologies [21].

This diversity also reinforces the rationale for purposive sampling. By selecting firms affiliated with national innovation and sustainability platforms, the study intentionally sought to "make visible" the mechanisms of SOI in a context where such practices are more likely to be observed [76]. In qualitative sampling logic, this approach is appropriate for theory-building, especially when the goal is to understand emergent or complex processes like SOI within an evolving policy and market landscape [98]. However, the findings also demonstrate that a sustainability orientation, while necessary, is not sufficient. Innovation plays a critical translational role in converting sustainability commitments into tangible outcomes. This supports recent research arguing that innovation acts not just as a mediator but as a strategic integrator of sustainability goals within firm operations [36,56].

Importantly, firms do not operate in a vacuum. Their engagement with SOI may be shaped by anticipated regulatory shifts, market expectations, or the pursuit of legitimacy in a policy environment increasingly oriented toward ecological modernization [61]. This strategic positioning, seeking to be ahead of compliance curves, could explain why firms in this sample adopted innovation proactively, even in the absence of direct mandates. Thus, the study not only highlights the enabling role of innovation but also points to the broader institutional and economic logics that condition how SOI unfolds in practice.

6. Conclusion

6.1. Theoretical and empirical contributions

This study offers a comprehensive exploration of the interplay between sustainability, innovation, and their multidimensional impacts within the Blue Economy, with a specific focus on Portugal. The findings confirm the catalytic role of SOI in enhancing economic and environmental performance, while highlighting the persistent underperformance of the social dimension. These insights contribute to the refinement of existing frameworks by reinforcing the value of SOI theory and Institutional Theory, while calling for their expansion to incorporate sector-specific and context-dependent variables [12,106]. By identifying the limited influence of innovation on social outcomes, the research underscores a critical gap in current models and advocates for integrating participatory approaches and equity-driven policies into SOI strategies [3].

The results support the TBL logic as far as innovation can simultaneously generate economic and environmental value. However, they also expose the limitations of assuming inherent synergy across sustainability dimensions. In practice, trade-offs may emerge between profitability, ecological protection, and social equity [45,80]. For instance, innovations aimed at cost efficiency or environmental performance may not inherently lead to community well-being or equitable benefit distribution. This disconnect suggests that positive performance in one dimension does not automatically extend to others.

Moreover, the assumption that all three pillars of the TBL, economic, environmental, and social, can be pursued equally and simultaneously has come under scrutiny in scholarship [80,85]. While the framework promotes balance, firms often operate under an inherently economic logic of survival and competitiveness, which tends to prioritize financial viability over social outcomes. Economic performance often becomes the enabler for environmental and social investments, not their equal counterpart.

This hierarchy is reflected in policy structures as well, particularly in the EU, where regulatory and funding mechanisms increasingly reinforce environmental performance, often through mechanisms that also deliver cost savings (e.g., energy efficiency, waste reduction). These aligned incentives contribute to the observed synergy between economic and environmental outcomes. In contrast, social impacts, such as equity, inclusion, or community engagement, may lack similar institutional reinforcement or direct financial return, making them more vulnerable to neglect in innovation strategies. This institutional asymmetry must be addressed if innovation is to fulfill its transformative promise across all sustainability domains.

The findings demonstrate that SOI is not merely an outcome or a response to external pressures but can function as a strategic enabler for firms aiming to enhance their competitive advantage. At the same time, the results caution against treating innovation as a universal solution, emphasizing the need for more inclusive and participatory approaches to address persistent gaps in social equity. By providing a nuanced understanding of the mechanisms through which sustainability and innovation intersect, this research offers theoretical direction for scholars and actionable insights for policymakers and practitioners aiming to balance economic, environmental, and social goals in the Portuguese Blue Economy.

6.2. Policy and practice implications

From a policy perspective, the results point to the importance of aligning financial incentives with holistic sustainability goals. Policymakers and industry leaders can draw on this study to better align innovation strategies with sustainability goals. For example, supportive policies, including R&D tax credits and subsidies for renewable energy, can amplify innovation and accelerate environmental performance. This is evidenced by the success of offshore wind energy incentives in Scandinavia, where cost reductions and technological advancements were directly linked to state-backed instruments [10]. In Portugal, similar mechanisms could be adapted to support sectors such as aquaculture, biotechnology, and waste valorization, while also embedding social performance metrics into funding eligibility.

While this study did not conduct sector-specific statistical analysis due to the limited sample size, the descriptive profile revealed relevant differences in how firms operationalize sustainability. Innovation in traditional sectors such as fisheries and port activities appears to be shaped more by compliance logic [17,79], whereas emerging sectors like offshore renewables and marine biotechnology seem more responsive to research incentives and EU innovation funding [30,38]. This highlights the importance of contextualizing SOI strategies according to sectoral characteristics such as technological maturity, regulatory exposure, and access to funding [2,5].

Investments in high-impact sectors such as aquaculture, offshore renewable energy, and sustainable waste management can drive economic growth while addressing ecological challenges. Initiatives like microorganism-based aquafeeds demonstrate the dual economic and environmental benefits of such advancements [91]. Embedding social equity in innovation through deliberate efforts to integrate equity-driven strategies, such as participatory innovation frameworks and workforce development programs, is essential to ensure inclusive benefits. Stakeholder engagement tools, as seen in community-based conservation models, provide templates for scalable adoption [50]. Finally, partnerships across academia, industry, and government can accelerate knowledge transfer and the diffusion of best practices, particularly in resource-intensive and innovation-driven sectors [89,90].

This research thus contributes to the theoretical discourse by showing that while SOI can mediate performance outcomes, it does so unevenly. Innovation alone is insufficient unless embedded within institutional, financial, and participatory frameworks that address all dimensions of sustainability simultaneously.

6.3. Limitations and future research

This study presents several limitations. While the use of PLS-SEM enabled a robust assessment of complex relationships, the reliance on cross-sectional survey data limits causal inference and may obscure informal or emergent social dynamics that escape standard measurement. Second, the sample composition, dominated by micro and small firms, reflects the structural characteristics of Portugal's maritime economy [49] but limits the generalizability of findings to larger or more capital-intensive firms. Furthermore, sectors such as tourism and offshore renewable energy were underrepresented relative to others like fisheries and aquaculture, limiting the capacity to analyze sector-specific dynamics.

The absence of sector-specific modeling constrains the ability to generalize across all industries. Structural factors, such as regulatory demands, access to innovation infrastructure, and market maturity, may condition how SOI unfolds. For instance, compliance-driven innovation is more prevalent in regulated legacy sectors, while emerging industries may benefit from greater flexibility and experimentation [21,57]. Though not empirically tested, prior literature and the sectoral context of Portugal's Blue Economy suggest that SOI cannot follow a one-size-fits-all approach [38,41]. A tailored approach that accounts for these contextual differences may help deliver more holistic outcomes, especially in addressing the persistent underperformance of the social dimension.

Accordingly, while the study contributes to understanding SOI within the Portuguese Blue Economy, it also reveals four important areas for future research:

1. Deepening the social dimension: Future studies should examine how inclusive models, such as co-creation with communities or participatory governance, can help embed social equity more firmly into innovation strategies, particularly in sectors where community well-being is directly affected.
2. Longitudinal Studies: Exploring changes over time could provide a clearer picture of how sustainability and innovation interact as firms adapt to evolving environmental, regulatory, and market conditions around them.
3. Comparative Analyses: Broadening contextual comparisons across countries or industries could identify patterns and divergences in how SOI is implemented, helping to distinguish between context-specific strategies and those that may be more broadly applicable.
4. Policy Innovation: Researching policy design to assess how regulatory frameworks and incentive mechanisms shape firm behavior, with particular attention to how policy innovation can support long-term, systemic shifts toward sustainability.

In conclusion, SOI emerges not as a universal remedy, but as a context-sensitive process shaped by institutional logics, sectoral dynamics, and governance architectures. To unlock its full potential, especially on the social front, firms and policymakers must co-develop integrated, equity-driven models that position innovation not only as an economic tool, but as a vector for inclusive sustainability. In doing so, the Blue Economy can evolve from a growth paradigm into a blueprint for resilient and equitable development.

CRediT authorship contribution statement

Hugo Emanuel dos Reis Sales da Cruz Pinto: Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Jennifer Nicole Elston:** Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Carla Filipa Sequeira Valente Nogueira:** Writing – review & editing, Validation, Supervision, Methodology.

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.

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Appendix A

Economic Activities of the Surveyed Companies

The list below shows the industry classification codes of the 40 firms that responded to the survey.

CAE	Description
70220	Consultancy activities for maritime and fisheries management
1130	Cultivation of aquatic plants and vegetables used in aquaculture
10893	Manufacture of specialized feeds for aquaculture species
21100	Research and development in marine pharmaceuticals
10204	Processing and preservation of aquaculture products
72110	Research and experimental development in marine biotechnology
03210-R3	Marine aquaculture
10913-R3	Manufacture of sustainable aquaculture feed
10201-R3	Processing of marine and aquaculture-derived food products
3111	Marine fishing and resource harvesting
86230-R3	Development of renewable energy solutions in the maritime sector
85591-R3	Training and education in marine and Blue Economy-related fields
72190	Research and development in natural sciences applied to marine sectors
47750	Retail of reused maritime or aquaculture equipment
63110	Data hosting and analytics for marine and aquaculture operations
3111	Fishing operations
94995	Support and advocacy for organizations in the Blue Economy
10840	Production of aquaculture-specific feed
41200	Construction of aquaculture facilities

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CAE	Description
74900	Professional and technical services for Blue Economy innovations
10201	Processing and preservation of seafood products
52220	Logistic services for ports and water-based transportation
3210	Aquaculture operations
46382	Wholesale fish and aquaculture products
46494	Wholesale of biotechnological goods for marine applications
30112	Building and repair of vessels for aquaculture and marine activities
30120	Maintenance and repair of ships and boats for Blue Economy use
31150	Development of precision instruments for marine and aquaculture use
47600	Retail of specialized equipment for marine and aquaculture industries
26200	Manufacturing technologies for marine resource monitoring
85591	Training and education for marine sustainability and innovation
74100	Design services for marine-related technologies
28110	Manufacturing turbines for offshore renewable energy
71120	Engineering consultancy for maritime and aquaculture infrastructure
52291	Maritime agency services
52240	Cargo handling for maritime and aquaculture operations
52102	Warehousing for marine and fisheries industries
52292	Logistics support for marine and aquaculture operations
47410	Retail of advanced technologies for marine innovation
64202	Holding companies managing Blue Economy-related enterprises

*Please note that in Portugal a company can have more than one Portuguese Classification of Economic Activities (CAE), this is a compilation of all CAEs of the companies questioned.

Data availability

The data that has been used is confidential.

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