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IDENTYFIKACJA EKONOMICZNEGO WPŁYWU MORSKICH FARM WIATROWYCH NA POZIOMIE LOKALNYM NA PODSTAWIE ANALIZY PRZYPADKU FARM BRYTYJSKICH I POLSKICH

IDENTIFICATION OF THE ECONOMIC IMPACT OF OFFSHORE WIND FARMS AT THE LOCAL LEVEL BASED ON CASE STUDIES OF BRITISH AND POLISH FARMS

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STRESZCZENIE

IDENTYFIKACJA EKONOMICZNEGO WPŁYWU MORSKICH FARM WIATROWYCH NA POZIOMIE LOKALNYM NA PODSTAWIE ANALIZY PRZYPADKU FARM BRYTYJSKICH I POLSKICH

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Rozwój morskiej energetyki wiatrowej (MEW) stanowi jeden z kluczowych filarów współczesnej transformacji energetycznej w Polsce i Europie. Sektor ten, mimo wysokiej kapitałochłonności, odgrywa strategiczną rolę w redukcji emisji gazów cieplarnianych, wzmacnianiu bezpieczeństwa energetycznego oraz tworzeniu nowych impulsów rozwojowych w regionach nadmorskich. Jednocześnie rodzi istotne wyzwania w zakresie sprawiedliwej dystrybucji kosztów i korzyści, szczególnie w gospodarkach, które dopiero rozpoczynają budowę krajowego sektora MEW. Wykształcenie lokalnych łańcuchów dostaw i kompetencji ma fundamentalne znaczenie dla powodzenia transformacji energetycznej w Polsce, która znajduje się na wczesnym etapie rozwoju sektora morskiej energetyki wiatrowej (ang. *offshore wind*).

Celem niniejszej rozprawy jest zidentyfikowanie i zbadanie ekonomicznych efektów rozwoju łańcucha dostaw dla morskiej energetyki wiatrowej na poziomie lokalnym, ze szczególnym uwzględnieniem porównania Polski i Wielkiej Brytanii. Praca ma charakter cyklu sześciu artykułów naukowych, które wspólnie tworzą spójną analizę ekonomicznych, przestrzennych i społecznych aspektów rozwoju sektora *offshore wind*. Badania obejmują zagadnienia kondycji finansowej przedsiębiorstw sektora odnawialnych źródeł energii, percepcji interesariuszy wobec inwestycji morskich, współistnienia gospodarki wiatrowej i innych sektorów w planowaniu przestrzennym, rozwoju rynku pracy oraz dystrybucji przestrzennej korzyści gospodarczych.

W ramach badań sformułowano pytania badawcze dotyczące: (1) czynników determinujących wyniki finansowe producentów energii; (2) wymaganych zasobów łańcucha dostaw dla osiągnięcia zakładanych celów instalacji MEW; (3) wartości renty przestrzennej z morskiej energetyki wiatrowej w Polsce; (4) czynników determinujących percepcję lokalnych interesariuszy względem MEW; (5) możliwości adaptacji metody *Spatial Economic Benefit Analysis (SEBA)* do porównania przestrzennej dystrybucji wartości łańcucha dostaw dla MEW w krajach o różnym poziomie dojrzałości sektora: w Polsce i Wielkiej Brytanii; (6) różnic w kształtowaniu się rynku pracy sektora MEW w zależności od dojrzałości sektora w danej gospodarce.

Na podstawie analizy literatury oraz studiów przypadków sformułowano hipotezy zakładające, że: (1) wyniki finansowe producentów energii różnią się w zależności od źródła wytwarzanej energii i producenci energii ze źródeł odnawialnych notują wyższe wyniki finansowe; (2) realizacja europejskich celów instalacji MEW wymaga rozwoju łańcucha dostaw; (3) renta przestrzenna z MEW jest wyższa niż z innych aktywności gospodarczych w przestrzeni morskiej; (4) akceptacja społeczna lokalnych interesariuszy jest uzależniona od bilansu korzyści i zagrożeń, wynikających z rozwoju MEW; (5) korzyści ekonomiczne wynikające z rozwoju *offshore wind* są przestrzennie nierównomierne i koncentrują się wokół istniejących centrów przemysłowych sektora gospodarki morskiej, ze względu na integrację inwestycji z lokalną bazą przemysłową i kompetencyjną; (6) rynek pracy sektora MEW różni się ze względu na poszukiwane kompetencje i ich dystrybucję przestrzenną, w zależności od poziomu dojrzałości sektora.

Zastosowana metodyka badań miała charakter wielowymiarowy: na poziomie mikro przeprowadzono analizę kondycji finansowej przedsiębiorstw sektora odnawialnych źródeł energii (OZE) w regionie Morza Bałtyckiego przy użyciu modeli danych panelowych; zastosowano analizę wartości renty przestrzennej w kontekście planowania przestrzeni morskiej oraz przeprowadzono badania percepcyjne wśród interesariuszy sektora *offshore wind* w Polsce. Na poziomie makroekonomicznym opracowano autorską adaptację metody *SEBA*, umożliwiającą porównanie przestrzennej dystrybucji korzyści gospodarczych w Polsce i Wielkiej Brytanii. Uzupełnieniem była analiza rynku pracy z wykorzystaniem danych *big data* z platformy LinkedIn, pozwalająca na identyfikację nowych zawodów i kompetencji w sektorze.

Wyniki badań przyczyniły się do uprawdopodobnienia zakładanych hipotez. Analiza percepcji interesariuszy wskazuje na wysokie oczekiwania wobec spodziewanych korzyści ekonomicznych, przy jednoczesnych obawach dotyczących ryzyka negatywnych skutków. Wykazano występowanie koncentracji przestrzennej w rozmieszczeniu korzyści ekonomicznych z rozwoju *offshore wind*. W Wielkiej Brytanii korzyści te w większym stopniu koncentrują się w ramach gospodarki narodowej, w regionach nadmorskich, dzięki skutecznej polityce przemysłowej i zjawisku sektorowego klastra przemysłowo-usługowego, obejmującego południowy obszar Morza Północnego. W Polsce, mimo podejmowanych prób rozwoju krajowych łańcuchów dostaw, korzyści są na razie ograniczone, a rynek znajduje się na etapie formowania podstaw instytucjonalnych i kompetencyjnych. Jednocześnie widać tendencję do tworzenia klastra w regionie nadmorskim, analogicznie jak w przypadku Wielkiej Brytanii.

Praca wnosi oryginalny wkład do literatury przedmiotu poprzez: (1) dostosowanie i rozwinięcie metody *SEBA* do analizy rynku *offshore wind* na wczesnym etapie rozwoju; (2) integrację podejść ekonomicznych, przestrzennych i społecznych w analizie sektora *offshore wind*, w tym poprzez wyliczenie renty przestrzennej dla MEW; (3) zastosowanie nowoczesnych narzędzi pozyskiwania danych metodą *web scrapingu* oraz analizy zbiorów danych (*big data*) w badaniach nad rynkiem pracy. Wyniki badań mają również znaczenie aplikacyjne - mogą wspierać projektowanie polityk publicznych w zakresie wsparcia rozwoju lokalnego łańcucha dostaw, planowania przestrzeni morskiej i rozwoju kompetencji dla sektora MEW. Ostatecznie, praca podkreśla znaczenie równowagi pomiędzy efektywnością ekonomiczną, zarządzaniem przestrzenią i społeczną akceptacją jako fundamentów skutecznej transformacji energetycznej.

Słowa kluczowe: morska energetyka wiatrowa, morskie planowanie przestrzenne, łańcuch dostaw, dystrybucja przestrzenna, local content

ABSTRACT

IDENTIFICATION OF THE ECONOMIC IMPACT OF OFFSHORE WIND FARMS AT THE LOCAL LEVEL BASED ON CASE STUDIES OF BRITISH AND POLISH FARMS

Tomasz Laskowicz

The development of offshore wind energy (OWE) constitutes one of the key pillars of the contemporary energy transition in Poland and Europe. Despite its high capital intensity, this sector plays a strategic role in reducing greenhouse gas emissions, strengthening energy security, and generating new development impulses in coastal regions. At the same time, it poses significant challenges related to the fair distribution of costs and benefits, particularly in economies that are only beginning to build their national offshore wind sector. The establishment of local supply chains and skills is of fundamental importance for the success of the energy transition in Poland, which remains at an early stage of offshore wind development.

The objective of this dissertation is to identify and examine the economic effects of offshore wind supply chain development at the local level, with particular emphasis on a comparative analysis between Poland and the United Kingdom. The dissertation takes the form of a cycle of six scientific articles that together provide a coherent analysis of the economic, spatial and social dimensions of offshore wind sector development. The research addresses issues such as the financial performance of renewable energy enterprises, stakeholder perceptions of offshore investments, the coexistence of wind energy with other maritime sectors in marine spatial planning, labour market development, and the spatial distribution of economic benefits.

The research questions concern: (1) factors determining the financial performance of energy producers; (2) the supply chain resources required to achieve offshore wind installation targets; (3) the value of spatial rent from offshore wind energy in Poland; (4) factors influencing local stakeholder perceptions of offshore wind energy; (5) the applicability of the Spatial Economic Benefit Analysis (SEBA) method for comparing the spatial distribution of supply chain value in countries at different stages of sectoral maturity - Poland and the United Kingdom; and (6) differences in the labour market structure of the offshore wind sector depending on its level of maturity within a given economy.

Based on a review of the literature and case studies, several hypotheses were formulated, assuming that: (1) the financial performance of energy producers differs depending

on the source of generated energy, with renewable energy producers achieving better results; (2) the achievement of European offshore wind installation targets requires the development of a dedicated supply chain; (3) spatial rent derived from offshore wind energy is higher than that from other marine economic activities; (4) local stakeholder acceptance depends on the balance between perceived benefits and risks resulting from offshore wind development; (5) economic benefits from offshore wind development are spatially uneven and tend to concentrate around existing industrial clusters of the maritime economy, due to the integration of investments with local industrial and competence bases; (6) the offshore wind labour market varies in terms of required skills and their spatial distribution, depending on the sector's level of maturity.

The applied research methodology was multidimensional. At the micro level, an analysis of the financial condition of renewable energy enterprises in the Baltic Sea region was conducted using panel data models. The study also included an analysis of spatial rent in the context of marine spatial planning and a stakeholder perception survey among representatives of the offshore wind sector in Poland. At the macroeconomic level, an original adaptation of the SEBA method was developed, enabling a comparison of the spatial distribution of economic benefits between Poland and the United Kingdom. This was complemented by a labour market analysis based on big data from the LinkedIn platform, allowing the identification of emerging professions and skills within the sector.

The findings confirmed most of the proposed hypotheses. The analysis of stakeholder perceptions indicates high expectations regarding anticipated economic benefits, accompanied by concerns about potential negative impacts. The results revealed a spatial concentration of economic benefits from offshore wind development. In the United Kingdom, these benefits are more strongly retained within the national economy and coastal regions, driven by effective industrial policy and the emergence of an industrial-service cluster in the southern North Sea area. In Poland, despite efforts to develop domestic supply chains, the benefits remain limited, and the market is still in the process of building its institutional and competence foundations. Nevertheless, a tendency towards the formation of a coastal cluster, analogous to that observed in the UK, is already visible.

This dissertation provides an original contribution to the literature by: (1) adapting and developing the SEBA method for analysing the offshore wind market at an early stage of its development; (2) integrating economic, spatial, and social approaches in the analysis of the offshore wind sector, including the estimation of spatial rent for offshore wind energy;

and (3) applying modern data acquisition tools such as web scraping and big data analysis in labour market research. The results also have practical implications, as they can support the design of public policies aimed at strengthening local supply chain development, marine spatial planning, and skills enhancement for the offshore wind sector. Ultimately, the study highlights the importance of maintaining a balance between economic efficiency, spatial management, and social acceptance as key pillars of an effective energy transition.

Keywords: *offshore wind energy, marine spatial planning, supply chain, spatial distribution, local content*

Spis Treści

1. Wstęp

1.1. Cel pracy i uzasadnienie podjętej tematyki badawczej

Morska energetyka wiatrowa (MEW), stała się w ostatnich dwóch dekadach jednym z najbardziej dynamicznie rozwijających się sektorów gospodarki morskiej, a zarazem kluczowym elementem europejskiej transformacji energetycznej. Jej znaczenie wykracza daleko poza wymiar technologiczny - obejmuje szeroki zakres zagadnień gospodarczych, społecznych i przestrzennych, czyniąc z niej przedmiot interdyscyplinarnych badań na styku ekonomii, geografii społeczno-ekonomicznej i polityki przestrzennej (Haggett, 2011; Kidd et al., 2019). Rozwój morskiej energetyki wiatrowej (ang. *offshore wind*) jest elementem nowej fali industrializacji przestrzeni morskiej, określanej mianem *blue economy*, która łączy rozwój technologiczny z dążeniem do neutralności klimatycznej (European Commission, 2023b; Kwiatkowski & Zaucha, 2023).

Zgodnie z założeniami Europejskiego Zielonego Ładu oraz pakietu Fit for 55, Unia Europejska przyjęła ambitne cele redukcji emisji gazów cieplarnianych o 55% do 2030 r. względem poziomu z 1990 r., a do 2050 r. - osiągnięcia pełnej neutralności klimatycznej (European Commission, 2019, 2023a). Osiągnięcie tych celów wymaga znacznego przyspieszenia instalacji odnawialnych źródeł energii, w tym w szczególności morskiej energetyki wiatrowej, która dzięki wysokiej efektywności i przewidywalności generacji może stanowić stabilne źródło energii w europejskim miksie energetycznym. W przyjętej przez Komisję Europejską Offshore Renewable Energy Strategy z 2020 r. zakłada się osiągnięcie 60 GW mocy morskiej energetyki wiatrowej zainstalowanej do 2030 r. oraz 300 GW do 2050 r., co wymaga mobilizacji znaczących zasobów kapitałowych, infrastrukturalnych i instytucjonalnych (European Commission, 2020).

W kontekście tych zmian, Polska, jako kraj będący na wczesnym etapie rozwoju sektora *offshore wind*, stoi przed wyjątkowym wyzwaniem, ale również historyczną szansą. Południowa część Morza Bałtyckiego charakteryzuje się płytkimi wodami i korzystnymi warunkami wiatrowymi, co stanowi sprzyjający obszar dla rozwoju *offshore wind* (Boniecka et al., 2016; Szejgiec-Kolenda et al., 2018). Rozwój morskiej energetyki wiatrowej jest złożonym procesem, który poza naturalnymi warunkami wymaga także budowy zaplecza przemysłowego, portowego oraz kompetencyjnego (Adamiec, 2023; Biniek, 2017). W tym sensie Polska znajduje się obecnie w sytuacji analogicznej do tej, w jakiej Wielka

Brytania była w połowie pierwszej dekady XXI w., rozpoczynając dynamiczny rozwój sektora offshore wind, który dziś stanowi jeden z filarów brytyjskiej gospodarki morskiej i polityki energetycznej (The Crown Estate, 2025). Warto jednak wziąć pod uwagę, że tradycja kultury morskiej w Polsce i zaplecze związane z przemysłem stoczniowym stanowić może dobrą bazę do rozwoju kompetencji w nowej branży sektora morskiego.

Znaczenie przemysłu morskiego i możliwość jego rozwoju w oparciu o wysokie technologie związane z branżą energetyczną, są podstawą motywacji do zwiększenia znaczenia lokalnych przedsiębiorstw w łańcuchu dostaw produktów i usług dla rozwoju morskiej energetyki wiatrowej w Polsce. W tym kontekście ważną kategorią analityczną staje się pojęcie *local content*, które odnosi się do udziału krajowych i lokalnych przedsiębiorstw, zasobów oraz kompetencji w procesie budowy, eksploatacji i serwisowania morskich farm wiatrowych (BVG Associates, 2015, 2019). W ujęciu ekonomicznym *local content* oznacza wartość strumieni środków inwestowanych, w gospodarkę krajową w wyniku realizacji inwestycji infrastrukturalnych. Ponadto *local content* stanowić może wskaźnik stopnia zaangażowania lokalnego sektora w łańcuchu dostaw i odzwierciedlać jego potencjał do generowania miejsc pracy, absorpcji technologii i rozwoju gospodarki narodowej.

W przypadku państw takich jak Wielka Brytania czy Dania, współczynnik *local content* stał się istotnym narzędziem monitorowania korzyści gospodarczych płynących z rozwoju sektora *offshore wind* i jednocześnie ważnym elementem uzasadnienia dla promocji morskiej energetyki wiatrowej poprzez system państwowych dopłat (Afewerki & Steen, 2023; Crowards et al., 2023). Wskaźnik *local content* pozwala nie tylko ocenić udział krajowych przedsiębiorstw w poszczególnych fazach inwestycji, ale także planować strategię oraz politykę przemysłową ukierunkowaną na wzmacnianie krajowego łańcucha dostaw (Glasson, Durning, Welch, et al., 2022; van der Loos et al., 2022).

W Polsce, gdzie nowy sektor dopiero się kształtuje, *local content* przyjmuje znaczenie jako potencjalne narzędzie wspierania krajowych kompetencji przemysłowych. Włączenie polskich przedsiębiorstw w struktury lokalnego i europejskiego łańcucha dostaw stanowi element polityki sektorowej i daje możliwość dystrybucji korzyści ekonomicznych, wynikających z transformacji energetycznej, w tym generowania nowych miejsc pracy (Kosek et al., 2025; *Offshore Wind Sector Deal*, 2021). Z tego względu badania nad *local content* umożliwiają diagnozę stopnia integracji krajowych podmiotów w sektorze oraz ocenę, w jakim zakresie rozwój morskiej energetyki wiatrowej może stać się impulsem dla lokalnego wzrostu gospodarczego i nowych inwestycji i miejsc pracy.

Rozwój offshore wind ma charakter systemowy i wielowymiarowy, ponieważ obejmuje zagadnienia energetyczne, ekonomiczne, przestrzenne, środowiskowe i społeczne (Flannery et al., 2018; Zaucha, 2018). Z punktu widzenia nauk społecznych szczególnego znaczenia nabiera zrozumienie, jakie efekty ekonomiczne generuje ten sektor w układzie przestrzennym, w tym jakie korzyści trafiają do społeczności i przedsiębiorstw lokalnych w znaczeniu regionalnym, a jakie pozostają skoncentrowane w ośrodkach centralnych i globalnych łańcuchach dostaw (Aitken, 2010; Allan et al., 2020). W opinii autora rozpatrywanie *local content* w kontekście gospodarki w skali narodowej nie jest dostatecznie precyzyjne i nie w pełni odpowiada na aktualną charakterystykę transformacji energetycznej, która ma tendencję do koncentracji w określonych przestrzeniach, uwarunkowanych ograniczeniami planistycznymi, czy technologicznymi.

Większość istniejących badań ocenia efekty ekonomiczne inwestycji energetycznych w ujęciu krajowym, przy wykorzystaniu wskaźników makroekonomicznych, takich jak PKB, zatrudnienie czy wpływy podatkowe (Burgess et al., 2018; Jasińska-Biliczak & Ikwuwunna, 2023). Jednak w przypadku morskiej energetyki wiatrowej, której realizacja wymaga koordynacji różnorodnych podmiotów: od przemysłu stoczniowego, przez logistykę, po usługi portowe i inżynieryjne, znaczenia nabiera stopień wykorzystania lokalnej gospodarki na poziomie regionalnym - w ramach jednostek terytorialnych na poziomie NUTS 2 i NUTS 3 (Kosek et al., 2025). Skuteczna polityka *local content* powinna sprzyjać trwałemu rozwojowi gospodarczemu regionów nadmorskich, wzmacniać ich potencjał społeczno-gospodarczy i zmniejszać ryzyko wykluczenia dostępu do korzyści wynikających z transformacji energetycznej (Glasson, Durning, & Welch, 2022; Kahouli & Martin, 2018).

Zrozumienie tego zjawiska i jego stałe monitorowanie wciąż jednak pozostaje wyzwaniem. Brak jednolitych i obiektywnych metod oceny udziału krajowych i lokalnych podmiotów w łańcuchach dostaw prowadzi do rozbieżności w raportowaniu i interpretacji wyników. Organizacje branżowe w Wielkiej Brytanii opracowały własne podejścia metodologiczne, jednak nie przyjęło się ono, jako powszechnie stosowane w krajach Unii Europejskiej, gdzie mierzenie wartości *local content* często jest fakultatywne (BVG Associates, 2015). W literaturze przedmiotu brakuje szczególnie narzędzi empirycznych pozwalających na uchwycenie przestrzennej dystrybucji korzyści ekonomicznych oraz ocenę ich wpływu na procesy rozwoju regionalnego i społeczną akceptację inwestycji (Gee & Siedschlag, 2020; Weig & Schultz-zehden, 2019).

Podobnie jak w wymiarze gospodarczym, także i w społecznym dostrzec można istotne różnice na poziomie lokalnym i krajowym, w zakresie zjawisk związanych z morską energetyką wiatrową. Lokalna percepcja rozwoju morskiej energetyki wiatrowej pozostaje złożona i często ambiwalentna (Johansen & Emborg, 2018; Lamy et al., 2020). Z jednej strony inwestycje te postrzegane są jako szansa rozwojowa - źródło nowych miejsc pracy, impuls modernizacyjny dla infrastruktury portowej czy stymulacja sektora usługowego (Allan et al., 2019). Z drugiej strony, postrzegane bywają również jako potencjalne zagrożenie dla dotychczasowych form użytkowania przestrzeni morskiej, w tym rybołówstwa i turystyki (Hooper & Austen, 2014; Voltaire et al., 2017). Liczne badania w ramach morskiego planowania przestrzennego (ang. *Marine Spatial Planning - MSP)* pokazują, że akceptacja społeczna inwestycji zależy w dużej mierze od rozumienia i doświadczania korzyści ekonomicznych przez społeczności lokalne (Domínguez-Tejo et al., 2016; Glasson, Durning, & Welch, 2022). Jednocześnie, poziom akceptacji społecznej jest bardziej złożony niż wynikający tylko z ewentualnych korzyści (lub strat) ekonomicznych (Johansen & Emborg, 2018).

W świetle przedstawionych uwarunkowań główny problem badawczy niniejszej pracy dotyczy braku spójnych, zweryfikowanych metod służących analizie ekonomicznych skutków rozwoju morskiej energetyki wiatrowej w ujęciu lokalnym i przestrzennym. Lider rozwoju morskiej energetyki wiatrowej w Europie - Wielka Brytania, wypracował modele analizy efektów sektora *offshore wind*, wśród których udział brytyjskich podmiotów w łańcuchu dostaw stanowi centralną oś zainteresowania i parametr kształtowania polityki sektorowej (The Crown Estate, 2025; Welisch & Poudineh, 2020). W Polsce, pomimo rosnącej liczby planowanych inwestycji, nadal brakuje kompleksowych narzędzi pozwalających przełożyć te doświadczenia na lokalne warunki instytucjonalne i gospodarcze. Zjawisko to dotyczy wielu krajów w regionie Morza Bałtyckiego i w całej Europie. Istniejące uwarunkowania umożliwiające rozwój energetyki wiatrowej na morzu mogą okazać się niewystarczające dla realizacji inwestycji, jeśli polityka sektorowa nie zostanie dostosowana do złożonego systemu naczyń połączonych pomiędzy udziałem lokalnych przedsiębiorstw w łańcuchu dostaw, dostępem do zasobów przestrzeni morskiej i akceptacją społeczną (Lindvall, 2023).

Można zidentyfikować wielowymiarowy poziom istniejącej luki badawczej zarówno na poziomie naukowym jak i branżowym. W pierwszej kolejności dotyczy aspektu metodologicznego, ponieważ brak jest jednolitej, naukowo zweryfikowanej metody pozwalającej na rzetelny pomiar udziału podmiotów krajowych w łańcuchach dostaw (*local content*) oraz przestrzennej dystrybucji efektów gospodarczych. W istniejących opracowaniach branżowych przeważają analizy oparte na podejściach makroekonomicznych lub deklaratywnych, które nie pozwalają precyzyjnie określić, w jakim stopniu inwestycje w sektorze *offshore wind* przekładają się na rozwój gospodarki lokalnej. Drugim wymiarem tej luki jest aspekt empiryczny, przejawiający się w niedostatku danych ilościowych i jakościowych dotyczących udziału lokalnych przedsiębiorstw i instytucji w łańcuchach dostaw, jak również w ograniczonej liczbie badań dotyczących percepcji społeczno-ekonomicznej rozwoju sektora *offshore wind* (Flannery et al., 2018; Morf et al., 2019).

Starania na rzecz podniesienia poziomu *local content*, wymagają zrozumienia, które czynniki są decydujące dla rozwoju lokalnego łańcucha dostaw. Choć jednym z kluczowych zjawisk jest stopień dojrzałości sektora, który rozwija się wraz z powstawaniem kolejnych etapów inwestycji i nowych mocy zainstalowanych, istotne jest także otoczenie instytucjonalne. Wciąż niewystarczająco silne są powiązania pomiędzy analizami ekonomicznymi a procesami planowania przestrzeni morskiej oraz politykami rozwoju regionalnego (Mogila et al., 2024; Tocco et al., 2024). W konsekwencji brakuje podejść integrujących ocenę efektów gospodarczych z decyzjami przestrzennymi i środowiskowymi, co utrudnia formułowanie długofalowych strategii dla gospodarki morskiej (Turski et al., 2018). Ważnych informacji w tym zakresie może dostarczyć badanie w wymiarze porównawczym, europejskich gospodarek z rozwiniętym sektorem *offshore wind*, wśród których liderem jest Wielka Brytania - z takimi krajami jak Polska, które dopiero rozwijają strukturę łańcucha dostaw produktów i usług dla MEW.

Dotychczasowe badania nad ekonomicznymi efektami *offshore wind* koncentrowały się przede wszystkim na poziomie makroekonomicznym, z wykorzystaniem modeli *input–output* i analiz przepływów międzygałęziowych (Mogila et al., 2024). Choć narzędzia te umożliwiają uchwycenie powiązań sektorowych i szacowanie efektów mnożnikowych, to w ograniczony sposób analizują przestrzenne zróżnicowanie korzyści gospodarczych na poziomie lokalnym. W praktyce, określone zjawiska często koncentrują się w ośrodkach portowych lub przemysłowych, tworząc klastry branżowe (Fernández-Macho et al., 2015; Junqueira et al., 2021). Z kolei metody stosowane do oceny wpływu lokalnego (*local economic impact*) mają zbyt ogólny charakter, by uchwycić zależności między skalą inwestycji, strukturą lokalnego rynku pracy a wartością dodaną na poziomie regionalnym. W efekcie powstaje potrzeba poszerzenia zakresu narzędzi badawczych, w celu połączenia analizy ekonomicznej z wymiarem przestrzennym i społecznym.

Odpowiedzią na tę potrzebę stała się koncepcja badawcza przyjęta w niniejszej rozprawie, oparta na adaptacji metody SEBA - Spatial Economic Benefit Analysis, opracowanej przez B. Weig i A. Schultz-Zehden (2019). Metoda ta, wykorzystywana pierwotnie do badania przestrzennych korzyści związanych z różnymi sektorami gospodarki morskiej w Niemczech, została przez autora zmodyfikowana i dostosowana do potrzeb analizy wschodzącego sektora *offshore wind* w Polsce. Zastosowane podejście umożliwiło porównanie geograficznej dystrybucji korzyści ekonomicznych pomiędzy Polską a Wielką Brytanią, pozwalając tym samym nie tylko na ocenę efektów lokalnych, lecz także na identyfikację potencjalnego kierunku przestrzennego rozwoju krajowego łańcucha dostaw.

W toku badań zastosowano również koncepcję renty przestrzennej (*spatial rent*), wywodzącą się z klasycznej teorii lokalizacji, lecz wciąż relatywnie rzadko dotychczas stosowaną w analizach gospodarki morskiej (Czermański et al., 2024; Zaucha & Matczak, 2018). Odwołując się do podejść rozwijanych m.in. przez Zauchę, w rozprawie potraktowano przestrzeń morską jako dobro ekonomiczne, którego wartość zależy od sposobu użytkowania oraz intensywności generowanych efektów gospodarczych (Zaucha, 2019). Analiza renty przestrzennej dla morskiej energetyki wiatrowej stanowi oryginalny wkład autora w rozwój narzędzi oceny ekonomicznej przestrzeni morskiej, łącząc wymiar gospodarczy i planistyczny w jeden spójny model interpretacyjny.

Niniejsza praca ma charakter interdyscyplinarny, łącząc perspektywy ekonomii, geografii gospodarczej i planowania przestrzennego. Jej znaczenie naukowe wynika z połączenia trzech komplementarnych podejść badawczych: po pierwsze, z rozwinięcia metodologii pomiaru efektów gospodarczych w sektorach morskich; po drugie, z zastosowania nowatorskiego podejścia przestrzennego do analizy *local content* i dystrybucji wartości dodanej; oraz po trzecie, z identyfikacji kryteriów wpływających na akceptację społeczną inwestycji w *offshore wind*. Dodatkowym wkładem jest propozycja nowego podejścia do analizy rynku pracy poprzez dane pozyskane bezpośrednio z portalu ogłoszeń pracy na przykładzie sektora *offshore wind*.

W wymiarze aplikacyjnym wyniki badań stanowią punkt odniesienia dla decydentów publicznych, deweloperów morskich farm wiatrowych i władz lokalnych przy formułowaniu strategii rozwoju sektora morskiej energetyki wiatrowej. Mogą one wspierać kształtowanie polityki *local content*, budowę łańcuchów dostaw oraz opracowanie mechanizmów kompensacji społeczno-ekonomicznych (Gee et al., 2019; Hooper et al., 2015). W szerszym ujęciu analiza ta dostarcza również wiedzy niezbędnej do prowadzenia zintegrowanej polityki przestrzennej, uwzględniającej równoważenie interesów gospodarczych, środowiskowych i społecznych.

Rozwój morskiej energetyki wiatrowej w Polsce to zatem nie tylko wyzwanie technologiczne, ale proces o znacznym potencjale transformacyjnym, który wpływa na strukturę gospodarki i relacje pomiędzy sektorem przemysłu morskiego, społecznościami lokalnymi oraz przestrzenią morską i obszarami przybrzeżnymi (Kidd et al., 2019; Wang et al., 2024). Zrozumienie ekonomicznego wymiaru MEW i logiki rozwoju łańcucha dostaw w przestrzeni stanowi istotny warunek kształtowania konkurencyjnej gospodarki morskiej, w oparciu o lokalny łańcuch dostaw, akceptację społeczną dla transformacji energetycznej i inkluzywny proces morskiego planowania przestrzennego.

Głównym celem pracy jest zatem stworzenie spójnego obrazu ekonomicznych mechanizmów rozwoju sektora morskiej energetyki wiatrowej w Polsce na tle doświadczeń europejskich. Ponadto podjęto próbę wskazania, w jaki sposób planowanie przestrzenne i mechanizmy kształtujące sektor morskiej energetyki wiatrowej wpływają na dystrybucję korzyści w skali lokalnej i regionalnej. Celem szczegółowym jest zbadanie, w jakim stopniu rozwój sektora *offshore wind* może przyczynić się do wzrostu konkurencyjności gospodarki morskiej w wymiarze regionalnym oraz do kształtowania nowych form aktywności ekonomicznej w regionach nadmorskich.

Przyjęta struktura pracy, oparta na cyklu sześciu artykułów naukowych, odzwierciedla powyższą logikę badawczą. Każdy z artykułów stanowi odrębne studium przypadku lub analizę tematyczną, której celem jest wniesienie unikalnego wkładu w rozpoznanie ekonomicznego wymiaru transformacji energetycznej w Polsce. Wspólnie tworzą one spójny obraz procesów zachodzących na styku gospodarki, przestrzeni i społeczeństwa - od poziomu globalnych trendów, poprzez analizę finansową i przestrzenną, aż po lokalny wymiar korzyści i kosztów rozwoju morskiej energetyki wiatrowej.

1.2 Struktura pracy naukowej

Struktura niniejszej rozprawy została zaprojektowana w sposób umożliwiający następujące po sobie pogłębianie analizy ekonomicznych, przestrzennych i społecznych aspektów rozwoju morskiej energetyki wiatrowej. Cykl sześciu artykułów naukowych składa się na spójną narrację badawczą, w której kolejne opracowania rozwijają i uzupełniają wcześniejsze ustalenia, tworząc wielowymiarowy obraz procesów towarzyszących transformacji energetycznej w Europie, ze szczególnym uwzględnieniem wschodzącego w Polsce sektora *offshore wind.*

Pierwszy artykuł, „Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region" (Energy Reports, 2022), otwiera cały cykl badawczy. Celem opracowania było zidentyfikowanie czynników determinujących wyniki finansowe producentów energii odnawialnej w regionie Morza Bałtyckiego, a także określenie wpływu rodzaju wytwarzanej energii, formy prawnej przedsiębiorstwa oraz uwarunkowań rynkowych i instytucjonalnych na ich kondycję finansową. Badanie obejmowało lata 2010-2020 i zostało wykonane w oparciu o model danych panelowych dla przedsiębiorstw z sektora energetyki odnawialnej i konwencjonalnej z siedmiu krajów regionu Morza Bałtyckiego: Finlandii, Niemiec, Polski, Estonii, Litwy, Łotwy i Szwecji.

Drugi artykuł, „Offshore wind energy potential in Europe: a forecast of installed capacities and costs" (Europa XXI, 2022), rozwija badania nad transformacją energetyczną w Europie, pod kątem instalacji morskich farm wiatrowych i zdolności łańcucha dostaw do realizacji założonych celów strategicznych. Opracowanie to analizuje tempo wzrostu mocy zainstalowanych w farmach morskich i prognozy dla kluczowych rynków kontynentu, uwzględniając zróżnicowanie geograficzne i technologiczne. Stanowi ono teoretyczne tło dla dalszych części rozprawy, wprowadzając element porównawczy i pokazując, że Polska znajduje się na wczesnym etapie rozwoju sektora w relacji do bardziej dojrzałych gospodarek, takich jak Wielka Brytania, Niemcy czy Dania. W tym sensie artykuł ten dostarcza strategicznego kontekstu dla rynku morskiej energetyki wiatrowej, w którym osadzone są kolejne badania.

„Economic Aspects of Marine Spatial Planning: The Case of Offshore Wind Farms in Poland" (Studia Regionalne i Lokalne, 2024) - stanowi wątek ekonomiczny wymiaru planowania przestrzennego obszarów morskich w kontekście rozwoju morskiej energetyki wiatrowej. Celem badania było określenie ekonomicznej wartości przestrzeni morskiej przeznaczonej pod inwestycje *offshore wind* oraz próba oszacowania tzw. renty przestrzennej generowanej przez ten sektor. W artykule zaprezentowano autorską metodę jej obliczenia, wykorzystującą dane dotyczące planowanej mocy zainstalowanej, kosztów inwestycyjnych (CAPEX), kosztów eksploatacyjnych (OPEX) oraz przewidywanych przychodów z produkcji energii elektrycznej. Zastosowane podejście pozwoliło na ilościowe porównanie wartości ekonomicznej przestrzeni przeznaczonej pod różne funkcje gospodarcze w polskiej strefie morskiej.

Badanie akceptacji społecznej w małych gminach nadmorskich podjęto w pracy: „The Perception of Polish Business Stakeholders of the Local Economic Impact of Maritime Spatial Planning Promoting the Development of Offshore Wind Energy" (Sustainability, 2021). Artykuł koncentruje się na analizie postrzegania rozwoju morskiej energetyki wiatrowej przez polskich interesariuszy w kontekście wdrażania planowania przestrzeni morskiej, tzn. na etapie przed rozpoczęciem inwestycji w zakresie budowy morskich farm wiatrowych. Celem badania było rozpoznanie poziomu świadomości wśród społeczności małych gmin nadmorskich oraz identyfikacja oczekiwań i opinii przedstawicieli lokalnych podmiotów wobec rozwoju sektora MEW w Polsce. Badanie miało charakter empiryczny i obejmowało mapowanie interesariuszy oraz wywiady pogłębione przeprowadzone w małych gminach nadmorskich, które w przyszłości mają pełnić funkcję zaplecza serwisowego i technicznego dla morskich farm wiatrowych. Przyjęto założenie, że to właśnie te miejscowości staną się centrami utrzymania działalności operacyjnej farm oraz kluczowymi punktami lokalnych łańcuchów dostaw, gdzie potencjalna koncentracja ewentualnych skutków transformacji może być wysoka. Analiza interesariuszy objęła przedsiębiorstwa prywatne, władze - w tym przedstawicieli samorządu i portu oraz organizacji branżowych. Badanie miało na celu zrozumienie, jak planowanie przestrzeni morskiej wpływa na postrzeganie potencjalnych korzyści i zagrożeń związanych z rozwojem *offshore wind* w skali lokalnej i jakie są obawy oraz oczekiwania w stosunku do planowanych inwestycji.

Kolejnym etapem rozwoju badań jest artykuł „Spatial distribution of economic benefits from offshore wind development - case studies of Poland and the United Kingdom", który stanowi centralny punkt rozprawy. Opracowanie to wprowadza autorską adaptację metody *Spatial Economic Benefit Analysis (SEBA)*, umożliwiającej identyfikację przestrzennej dystrybucji korzyści gospodarczych z rozwoju sektora morskiej energetyki wiatrowej. Porównanie Polski i Wielkiej Brytanii pozwoliło nie tylko ukazać różnice wynikające z poziomu dojrzałości sektora, ale również opracować narzędzia pomiaru i interpretacji efektów lokalnych. Szczególną wartość stanowi przestrzenna interpretacja wyników i nałożenie wartości ekonomicznej na powiązania międzysektorowe, prześledzone przez autora na podstawie rzeczywistych kontraktów zawieranych przez deweloperów morskich farm wiatrowych z podwykonawcami.

Zwieńczeniem cyklu jest artykuł „Analysis of offshore labour market trends: Evidence from Poland, Germany and the United Kingdom", który rozszerza perspektywę badawczą na wymiar europejski. Publikacja ta analizuje trendy na rynku pracy w sektorze *offshore wind*, identyfikując wzorce zatrudnienia, strukturę poszukiwanych specjalizacji zawodowych i kompetencji kluczowych dla rozwoju sektora. W badaniu uwzględniono także dystrybucję geograficzną publikowanych ofert pracy, które wykazują tendencję do koncentracji w określonych obszarach. Badanie pozwoliło uchwycić dynamikę powstawania nowych zawodów i ścieżek kariery w krajach o różnym poziomie dojrzałości sektora: Polski, Wielkiej Brytanii i Niemiec. Unikalnym elementem artykułu jest nowatorska próba wykorzystania danych z jednego z międzynarodowych portali ogłoszeń pracy (LinkedIn), pozyskana metodą *web scraping*.

Przedłożone artykuły tworzą spójną i logicznie powiązaną całość, w której poszczególne opracowania stanowią kolejne etapy analizy łańcucha dostaw morskiej energetyki wiatrowej w wymiarze lokalnym: od diagnozy kondycji finansowej przedsiębiorstw sektora energetycznego i prognoz rozwoju europejskiego łańcucha dostaw, ustalenie wartości renty przestrzennej, poprzez zrozumienie percepcji interesariuszy, aż po ocenę przestrzennej dystrybucji efektów ekonomicznych i zmian na rynku pracy. Taka konstrukcja rozprawy pozwala nie tylko na wieloaspektową analizę ekonomicznego wymiaru rozwoju morskiej energetyki wiatrowej, lecz również na sformułowanie wniosków o charakterze aplikacyjnym, które mogą być istotne dla polityki publicznej, zarządzania przestrzenią morską i kształtowania strategii lokalnego rozwoju gospodarczego w Polsce.

Przyjęte podejście badawcze pozwala na zintegrowane ujęcie złożonych procesów towarzyszących rozwojowi sektora morskiej energetyki wiatrowej w Polsce. Metodologia pracy została zaprojektowana w sposób umożliwiający analizę tego zjawiska z różnych perspektyw – finansowej, instytucjonalnej, przestrzennej i społecznej – oraz w różnych skalach: od mikroekonomicznej po makroregionalną. Zastosowane w badaniach metody empiryczne, obejmujące zarówno analizy ilościowe, jak i jakościowe, pozwalają uchwycić dynamikę procesów gospodarczych i terytorialnych, które kształtują rozwój nowego sektora gospodarki morskiej.

Każdy z artykułów wnosi odrębny wkład w rozwój wiedzy o ekonomicznym wymiarze sektora *offshore wind*, a ich łączne wyniki pozwalają na stworzenie modelu interpretacyjnego opisującego relacje między kapitałem finansowym, przestrzennym i społecznym w kontekście budowy nowego sektora gospodarki morskiej w Polsce. Zestawienie wyników badań w różnych skalach umożliwia nie tylko identyfikację barier i potencjałów, ale także porównanie doświadczeń Polski z krajami o bardziej zaawansowanym stadium rozwoju sektora, w tym przede wszystkim z Wielką Brytanią. Tym samym zaprojektowany cykl publikacji stanowi spójny, wielowymiarowy model badawczy, który integruje dorobek z zakresu ekonomii, geografii gospodarczej i planowania przestrzennego. Model ten pozwala na analizę morskiej energetyki wiatrowej nie tylko jako sektora technicznego, ale przede wszystkim jako procesu ekonomiczno-społecznego, mającego znaczenie dla rozwoju regionalnego, polityki energetycznej i budowy nowoczesnej, zrównoważonej gospodarki morskiej.

W kolejnym podrozdziale przybliżono pytania badawcze i metody zastosowane w poszczególnych artykułach.

1.3 Zarys metodologii badań własnych

W oparciu o przeprowadzoną analizę literatury, określenie celów pracy oraz identyfikację luk badawczych sformułowano zestaw pytań i hipotez badawczych, stanowiących logiczną konsekwencję wcześniejszych założeń teoretycznych. Ich konstrukcja ma na celu zweryfikowanie związków między uwarunkowaniami ekonomicznymi i przestrzennymi rozwoju sektora morskiej energetyki wiatrowej a lokalną dystrybucją korzyści gospodarczych.

Przyjęto, że każda z publikacji wchodzących w skład cyklu rozprawy doktorskiej odpowiada na co najmniej jedno zasadnicze pytanie badawcze. Zestawienie to pozwala uchwycić spójność całego procesu badawczego - od analizy finansowej kondycji przedsiębiorstw sektora odnawialnych źródeł energii, przez modelowanie potencjału europejskiego łańcucha dostaw i szacowanie renty przestrzennej dla morskiej energetyki wiatrowej, aż po badania percepcji interesariuszy, przestrzennej dystrybucji korzyści i trendów na rynku pracy.

Celem tej części pracy jest przedstawienie powiązanego układu pytań badawczych i odpowiadających im hipotez, stanowiących próbę odpowiedzi na kwestie, które łącznie mogą wypełnić zidentyfikowaną lukę poznawczą w zakresie ekonomicznego wymiaru rozwoju sektora *offshore wind* w Polsce i Europie. Zestawienie to, ujęte w formie tabelarycznej, porządkuje strukturę badawczą rozprawy oraz wskazuje relacje między poszczególnymi artykułami naukowymi tworzącymi spójny cykl publikacji.

Tabela 1. Pytania badawcze, hipotezy i metody badań w cyklu publikacji

Nr	Publikacja	Pytanie badawcze	Hipoteza badawcza	Metoda badawcza
1.	**Dopierała Ł., Mosionek-Schweda M., Laskowicz T., Ilczuk D. (2022).** ***Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region.*** **Energy Reports, 8, 11492–11503.**	Jakie czynniki determinują wyniki finansowe producentów energii odnawialnej w regionie Morza Bałtyckiego oraz w jaki sposób proces transformacji energetycznej wpływa na stabilność finansową tych przedsiębiorstw?	H1: Wyniki finansowe osiągane przez producentów energii ze źródeł odnawialnych są istotnie wyższe niż wyniki osiągane przez producentów energii ze źródeł konwencjonalnych. H2: Rodzaj wytwarzanej energii (hydro, solarnej, wiatrowej) determinuje wyniki finansowe jej producentów. H3: Spółki akcyjne produkujące energię charakteryzują się niższą rentownością niż spółki z ograniczoną odpowiedzialnością lub spółki osobowe. H4: Różnice w hurtowych cenach energii elektrycznej w analizowanych krajach mają istotny wpływ na wyniki finansowe producentów energii.	Analiza danych panelowych obejmującą przedsiębiorstwa energetyczne z regionu Morza Bałtyckiego w latach 2010–2020.
2.	**Laskowicz T. (2022).** ***Offshore wind energy potential in Europe: a forecast of installed capacities and costs.*** **Europa XXI, 42, 129–148.**	Jakie zasoby są wymagane, aby osiągnąć cele dotyczące instalacji morskiej energii wiatrowej w Europie do roku 2030 i w jaki sposób można je zmierzyć? W jaki sposób można zmierzyć znaczenie morskiej energetyki wiatrowej dla europejskiej transformacji energetycznej do roku 2030?	Przyjęto założenie, że rozwój europejskiego łańcucha dostaw dla sektora *offshore wind* pozostaje niewspółmierny wobec przyjętych celów klimatycznych i planowanych mocy zainstalowanych, co może prowadzić do wzrostu kosztów i opóźnień inwestycyjnych w krajach UE.	Analiza trendów prognostycznych; analiza porównawcza polityk krajowych, szacowanie ograniczenia emisji dwutlenku węgla.

Nr	Publikacja	Pytanie badawcze	Hipoteza badawcza	Metoda badawcza
3.	**Laskowicz T. (2024).** ***Economic Aspects of Marine Spatial Planning: The Case of Offshore Wind Farms in Poland.*** **Studia Regionalne i Lokalne, 3(97), 7–21.**	Ile wynosi wartość renty przestrzennej dla morskiej energetyki wiatrowej w Polsce?	Założono, że morska energetyka wiatrowa może wygenerować rentę przestrzenną, której potencjalna wartość przewyższa tradycyjne sektory gospodarki morskiej (np. rybołówstwo, transport).	Modelowanie wartości przestrzennej (*spatial rent*); analiza kosztów i wartości dodanej sektorów morskich.
4.	**Laskowicz T. (2021).** ***The Perception of Polish Business Stakeholders of the Local Economic Impact of Maritime Spatial Planning Promoting the Development of Offshore Wind Energy.*** **Sustainability, 13(6755), 1–17.**	Jakie czynniki determinują percepcję lokalnych interesariuszy wobec rozwoju sektora *offshore wind*? W jakim stopniu oczekiwane korzyści ekonomiczne wpływają na poziom akceptacji społecznej dla inwestycji morskich?	Przyjmuje się, że poziom akceptacji społecznej dla inwestycji w *sektorze offshore wind* pozostaje w bezpośrednim związku z postrzeganymi korzyściami ekonomicznymi na poziomie lokalnym; pozytywna ocena wpływu gospodarczego zwiększa gotowość interesariuszy do współpracy i ogranicza potencjalne konflikty sektorowe.	Wywiady pogłębione, skala Likerta, *desk research*.
5.	**Laskowicz T. (2025).** ***Spatial distribution of economic benefits from offshore wind development – case studies of Poland and the United Kingdom.*** **(manuscript submitted to *Przegląd Geograficzny*).**	Jak kształtuje się przestrzenna dystrybucja korzyści ekonomicznych wynikających z rozwoju łańcucha dostaw dla sektora morskiej energetyki wiatrowej? W jakim stopniu dostosowana metoda *Spatial Economic Benefit Analysis (SEBA),* może wspierać identyfikację tych efektów w krajach znajdujących się na różnych etapach rozwoju sektora?	Korzyści ekonomiczne wynikające z rozwoju morskiej energetyki wiatrowej są nierównomiernie rozmieszczone w przestrzeni i zależą od stopnia integracji sektora z lokalnymi łańcuchami dostaw oraz infrastrukturą portową.	Adaptacja i implementacja metody *SEBA*; analiza porównawcza przypadków (Polska-Wielka Brytania).

Nr	Publikacja	Pytanie badawcze	Hipoteza badawcza	Metoda badawcza
6.	**Majkowska A., Laskowicz T. (2025).** ***Analysis of offshore labour market trends: Evidence from Poland, Germany and the United Kingdom.*** **(manuscript submitted to *Local Economy*).**	W jaki sposób różnice w poziomie dojrzałości sektora morskiej energetyki wiatrowej w krajach europejskich wpływają na strukturę zatrudnienia oraz zapotrzebowanie na kompetencje w sektorze *offshore wind*?	Zakłada się, że stopień dojrzałości sektora *offshore wind* kształtuje strukturę zatrudnienia w sektorze - w gospodarkach rozwiniętych obserwuje się większą specjalizację zawodową i stabilność miejsc pracy, podczas gdy w krajach wschodzących, takich jak Polska, rynek pracy charakteryzuje się dynamicznym wzrostem i zapotrzebowaniem na zróżnicowane kompetencje	Analiza danych *big data, web scraping* (LinkedIn); porównanie trendów kompetencyjnych i zawodowych.

Sformułowane hipotezy badawcze odnoszą się do kluczowych pytań dotyczących ekonomicznego wymiaru rozwoju sektora morskiej energetyki wiatrowej w Polsce, stanowiąc teoretyczne przypuszczenia poddane następnie weryfikacji w procesie badawczym. Wskazują one zarówno na złożoność badanego zjawiska, jak i na wielowymiarowy charakter rozwoju łańcucha dostaw nowego sektora, obejmujący aspekty finansowe, przestrzenne, instytucjonalne i społeczne.

W celu weryfikacji powyższych hipotez dobrano zestaw narzędzi badawczych, które pozwalają na analizę problematyki z wielu perspektyw. Na poziomie mikroekonomicznym przeanalizowano kondycję finansową przedsiębiorstw sektora odnawialnych źródeł energii w regionie Morza Bałtyckiego, stosując badanie panelowe. W badaniu wykorzystano modele efektów stałych i losowych, przy czym ostateczny wybór modelu został dokonany na podstawie testu Hausmana. Wybór tej metody wynikał z konieczności oceny, przyjętych założeń dotyczących efektywności alokacji kapitału w generowanie energii ze źródeł odnawialnych. Przeprowadzono badania percepcji interesariuszy biznesowych w Polsce, obejmujące zarówno ankiety, jak i wywiady pogłębione. To jakościowe uzupełnienie pozwoliło uchwycić oczekiwania, obawy i bariery wskazywane przez przedstawicieli lokalnej społeczności, reprezentujących zróżnicowane podejście do oczekiwań względem skutków inwestycji w regionie nadmorskim. Na poziomie makroekonomicznym wykonano prognozy rozwoju mocy zainstalowanej i kosztów inwestycji w Europie, które osadziły polski przypadek w szerszym kontekście geograficznym i technologicznym. Istotną częścią metodologii było wprowadzenie koncepcji renty przestrzennej (*spatial rent*), służącej do kwantyfikacji wartości ekonomicznej przestrzeni morskiej zajmowanej przez farmy wiatrowe. Jej zastosowanie pozwoliło na powiązanie analizy ekonomicznej z procesami morskiego planowania przestrzennego (MSP), ukazując MSP jako instrument nie tylko środowiskowy, ale również gospodarczy. W celu oszacowania wartości wygenerowanej z każdego z polskich projektów *offshore wind*, objętych wsparciem w ramach mechanizmu różnicowego, założono technologiczne parametry poszczególnych projektów. Kluczowym elementem badań jest adaptacja i rozwinięcie metody *Spatial Economic Benefit Analysis (SEBA)*. W swojej pierwotnej formie metoda ta stosowana była w Niemczech do badania sektorów morskiej energetyki wiatrowej i żeglugi morskiej. W niniejszej rozprawie SEBA została rozszerzona i dostosowana do warunków Polski i innych krajów znajdujących się na wczesnym etapie rozwoju sektora. Adaptacja obejmowała integrację SEBA z danymi przestrzennymi dotyczącymi istniejącego sektora przemysłu morskiego branży *offshore wind* i szacowanej wartości kontraktów łańcucha dostaw. Dzięki temu możliwe było przestrzenne alokowanie ilościowych wskaźników dystrybucji korzyści i zrozumienie przyczyn kształtowania się klastrów sektorowych.

Badania uzupełniono o analizę rynku pracy z wykorzystaniem narzędzi *big data*, w szczególności danych pozyskanych metodą *web scraping* z portalu LinkedIn, co pozwoliło uchwycić dynamikę zatrudnienia i zapotrzebowania na kompetencje w sektorze *offshore wind* w Polsce, Niemczech i Wielkiej Brytanii. Wybór tej metody podyktowany był chęcią oparcia badań na możliwie najbardziej aktualnych danych, które stanowią najlepsze odwzorowanie bieżącego stanu rozwoju rynku oraz rozwój metody analizy danych źródłowych. Integracja tego wymiaru z analizami ilościowymi i jakościowymi pozwoliła na lepsze uchwycenie dynamiki procesów zachodzących w czasie rzeczywistym ze znacznym potencjałem do rozwoju metody w kolejnych badaniach i stworzenia narzędzia monitorującego stan rozwoju i kondycję rynku pracy w sektorze *offshore wind*. Metoda może zostać zaadoptowana do analizy także innych sektorów, szczególnie wschodzących lub identyfikowania trendów na rynku pracy na wczesnym etapie.

Jednocześnie należy podkreślić, że wiele spośród postawionych pytań badawczych odnosi się do zjawisk dopiero kształtujących się - rozwój morskiej energetyki wiatrowej w Polsce znajduje się we wczesnej fazie wdrażania, a dostępność danych empirycznych jest ograniczona. Brak ugruntowanych narzędzi pomiaru *local content* czy analizy przestrzennej dystrybucji korzyści gospodarczych wymagał dostosowania i rozwinięcia istniejących metod badawczych. Z tego względu autor, w toku realizacji cyklu publikacji, zaproponował oryginalne rozwiązania metodyczne, które umożliwiły prowadzenie analiz mimo niepełnych danych ilościowych.

Dobór metod badawczych każdorazowo wynikał z dostępności danych, ich jakości oraz możliwości porównawczych, ale jednocześnie wykraczał poza standardowe metody spotykane w literaturze przedmiotu. W efekcie, istotnym elementem innowacyjności niniejszej rozprawy jest nie tylko analiza zjawisk gospodarczych towarzyszących rozwojowi sektora *offshore wind*, lecz także rozwój i dostosowanie samych metod badawczych do specyfiki gospodarki znajdującej się na wczesnym etapie transformacji energetycznej z udziałem morskiej energetyki wiatrowej. Choć zaproponowane rozwiązania nie eliminują w pełni istniejących ograniczeń poznawczych, stanowią one istotny krok w kierunku budowy nowoczesnych, zintegrowanych narzędzi analizy sektorów morskich. Tym samym wyznaczają potencjalne kierunki dalszych badań w zakresie modelowania ekonomicznego, analizy międzysektorowych interakcji oraz pomiaru *local content* w kontekście rozwoju nowego sektora gospodarki morskiej w Polsce i Europie.

1.4 Wyniki i dyskusja

Zrealizowany cykl artykułów tworzy spójny i komplementarny zestaw badań, które łącznie pozwoliły na pogłębione zrozumienie ekonomicznego wymiaru rozwoju morskiej energetyki wiatrowej w Polsce na tle europejskim. Odpowiadając na kolejne pytania badawcze, autor zweryfikował hipotezy dotyczące finansowych, instytucjonalnych i przestrzennych uwarunkowań transformacji energetycznej, ukazując jednocześnie mechanizmy lokalnej dystrybucji korzyści gospodarczych.

Artykuł „Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region" (Dopierała, Mosionek-Schweda, Laskowicz, Ilczuk, 2022) stanowił punkt wyjścia dla całego cyklu badawczego. Celem opracowania była identyfikacja czynników determinujących wyniki finansowe producentów energii elektrycznej w regionie Morza Bałtyckiego. Analiza panelowa obejmowała dane z lat 2010-2020 i dotyczyła przedsiębiorstw z siedmiu krajów. Wyniki analiz potwierdziły, że rentowność przedsiębiorstw energetycznych jest silnie zróżnicowana między krajami regionu Morza Bałtyckiego i zależy od rodzaju wytwarzanej energii, formy prawnej oraz poziomu hurtowych cen energii elektrycznej.

W szczególności wykazano, że producenci energii odnawialnej osiągają wyższe wyniki finansowe niż podmioty wykorzystujące źródła konwencjonalne, a w sektorze odnawialnych źródeł energii najwyższą rentownością charakteryzują się przedsiębiorstwa wytwarzające energię z wiatru. Wyniki wskazały, że rozwój sektora odnawialnych źródeł energii pozostaje uzależniony od otoczenia regulacyjnego i stabilności systemów wsparcia. Zmienność instrumentów polityki energetycznej, w tym zasad przyznawania taryf gwarantowanych oraz mechanizmów aukcyjnych, wpływała negatywnie na przewidywalność zwrotu z inwestycji.

Drugi artykuł, „Offshore wind energy potential in Europe: a forecast of installed capacities and costs" (Laskowicz, 2022) stanowi analizę prognostyczną dotyczącą rozwoju morskiej energetyki wiatrowej w Europie w perspektywie do roku 2030 i 2050. Punktem wyjścia dla badania były dwa zasadnicze pytania: jakie zasoby są wymagane do osiągnięcia celów instalacji mocy *offshore wind* w Europie do 2030 roku oraz w jaki sposób można zmierzyć znaczenie tego sektora dla europejskiej transformacji energetycznej. Wykorzystując dane z baz branżowych WindEurope i 4C Offshore, autor przeprowadził prognozę mocy zainstalowanej oraz kosztów inwestycyjnych (CAPEX) i eksploatacyjnych (OPEX), uwzględniając zróżnicowanie w zakresie rozwiązań technologicznych, stosowanych w Europie. Wyniki analiz wskazały, że choć planowana moc zainstalowana w Unii Europejskiej do 2050 r. ma osiągnąć 300 GW, tempo rozwoju infrastruktury portowej, produkcyjnej i logistycznej nie nadąża za ambitnymi celami, wyznaczonymi przez rządy państw europejskich. W artykule podkreślono, że ograniczona dostępność wyspecjalizowanych komponentów (w tym przede wszystkim turbin) oraz wzrost kosztów materiałów i transportu mogą prowadzić do wystąpienia tzw. efektu wąskiego gardła w europejskim łańcuchu dostaw w przypadku braku rozwoju łańcucha dostaw. Badanie zwróciło również uwagę na potrzebę rozwoju krajowych i regionalnych kompetencji przemysłowych, co wpisuje się w szerszy kontekst budowy *local content* i stanowiło wstęp do analizy przestrzenno-ekonomicznej zaprezentowanej w kolejnych częściach cyklu. W artykule przeanalizowano także wpływ rozwoju morskiej energetyki wiatrowej na europejski miks energetyczny, który do 2030 roku mógłby opierać się w ponad 14% na morskiej energetyce wiatrowej, pod warunkiem realizacji zakładanych scenariuszy. Oszacowano, że zagospodarowanie 1 kilometra kwadratowego przestrzeni morskiej na rzecz produkcji energii elektrycznej z farm wiatrowych może prowadzić do rocznej redukcji nawet 9235 ton dwutlenku węgla względem produkcji opartej o obecny miks energetyczny z przeważającą rolą paliw kopalnych.

Trzeci artykuł: „Economic Aspects of Marine Spatial Planning: The Case of Offshore Wind Farms in Poland" (Laskowicz, 2024) to kontynuacja analizy ekonomicznej efektywności planowanych projektów morskich farm wiatrowych w polskiej strefie Morza Bałtyckiego oraz docelowo oszacowania wartości renty przestrzennej generowanej przez te inwestycje. Na podstawie danych dotyczących mocy zainstalowanej, wskaźników produktywności (*capacity factor*), kosztów inwestycyjnych i eksploatacyjnych (*CAPEX, OPEX*) oraz prognoz przychodów z produkcji energii opracowano model pozwalający na oszacowanie ekonomicznej wartości przestrzeni morskiej przeznaczonej pod farmy wiatrowe. Analiza wykazała wysoką opłacalność finansową planowanych projektów, przy wewnętrznej stopie zwrotu (IRR) mieszczącej się w przedziale od 9,43% do 12,65%. Obliczona renta przestrzenna, zależna od przyjętego współczynnika *capacity factor*, wyniosła od 7,69 do 17,91 mln euro na km^2. Średnia ważona wartość renty przestrzennej kształtowała się na poziomie od 10,72 mln euro/km^2 do 13,30 mln euro/km^2 w zależności od przyjętego scenariusza efektywności technologicznej. Wyniki te potwierdziły, że morska energetyka wiatrowa charakteryzuje się wyjątkowo wysoką efektywnością ekonomiczną w przeliczeniu na jednostkę przestrzeni morskiej.

Wyniki badań opublikowane w artykule: „The Perception of Polish Business Stakeholders of the Local Economic Impact of Maritime Spatial Planning Promoting the Development of Offshore Wind Energy" (Laskowicz, 2021) dostarczyły informacji na temat postrzegania rozwoju morskiej energetyki wiatrowej przez przedstawicieli społeczności nadmorskich. Zrealizowano wywiady pogłębione z przedstawicielami interesariuszy w wybranych gminach nadmorskich, które w przyszłości staną się zapleczem operacyjnym dla farm wiatrowych na Morzu Bałtyckim. Badanie obejmowało identyfikację interesariuszy, wywiady pogłębione oraz ankietę opartą na pięciostopniowej skali Likerta, w której respondenci proszeni byli o ocenę wpływu inwestycji *offshore wind* na lokalną gospodarkę - zarówno w wymiarze pozytywnym, jak i negatywnym. Uzyskane wyniki wskazały jednoznacznie, że uczestnicy badania oczekują wyraźnego wpływu ekonomicznego planowanych inwestycji (dominowały odpowiedzi w kategorii „zdecydowanie się zgadzam"), przy czym większość respondentów dostrzegała przewagę efektów pozytywnych, takich jak rozwój infrastruktury, nowe miejsca pracy czy napływ kapitału do lokalnych przedsiębiorstw. W przypadku potencjalnych skutków negatywnych - związanych głównie z ograniczeniem przestrzeni dla tradycyjnych sektorów, jak rybołówstwo czy turystyka - opinie były bardziej zróżnicowane i nie tworzyły jednolitego stanowiska. Artykuł potwierdził, że lokalne postrzeganie korzyści ekonomicznych stanowi czynnik determinujący akceptację społeczną dla rozwoju sektora morskiej energetyki wiatrowej. Jednocześnie zwrócono uwagę na potrzebę większej przejrzystości komunikacji pomiędzy inwestorami a społecznościami nadmorskimi, tak aby proces transformacji energetycznej mógł przebiegać z poszanowaniem zasad sprawiedliwej transformacji.

Piąty artykuł: „Spatial distribution of economic benefits from offshore wind development: case studies of Poland and the United Kingdom" (Laskowicz, 2025) – przedstawia wyniki analizy przestrzennej dystrybucji korzyści gospodarczych z wykorzystaniem metody *Spatial Economic Benefit Analysis (SEBA)*. Zastosowane narzędzie umożliwiło identyfikację obszarów koncentracji efektów ekonomicznych w Polsce i Wielkiej Brytanii, wskazując wyraźne skupienie korzyści w regionach portowych i zapleczach logistycznych. W Polsce najwyższą koncentrację aktywności gospodarczej związanej z morską energetyką wiatrową odnotowano w rejonach Gdańska, Łeby i Ustki. Znaczenie tych obszarów wynika z istniejącej infrastruktury portowej, w tym pełnionych funkcji na etapie instalacji i eksploatacji farm wiatrowych. W Wielkiej Brytanii największą koncentrację korzyści zidentyfikowano w na obszarach Szkocji, Anglii Wschodniej i regionu Humber, które tworzą rdzeń przemysłowego pasa obsługującego sektor *offshore wind* na Morzu Północnym. Analiza zestawionych danych wykazała, że w obu krajach występują podobne mechanizmy koncentracji przestrzennej korzyści gospodarczych, silnie zależne od dostępności infrastruktury oraz lokalizacji kluczowych podmiotów w łańcuchu dostaw. Stwierdzono także ograniczoną liczbę wyspecjalizowanych dostawców komponentów takich jak turbiny, wieże czy kable, którzy obsługują równolegle rynki Polski i Wielkiej Brytanii, co może świadczyć o ograniczonej konkurencji w sektorze. W basenie południowej części Morza Północnego wytworzył się pas przemysłowy sekotra *offshore wind*, obejmujący Wielką Brytanię, Holandię, Belgię i Danię, stanowiący zintegrowany obszar działalności przedsiębiorstw uczestniczących w europejskim łańcuchu dostaw dla morskiej energetyki wiatrowej. Istnieją przesłanki stanowiące o tym, że wraz z rozwojem morskiej energetyki wiatrowej w południowej części Morza Bałtyckiego, łańcuch dostaw obsługujący polski sektor MEW, może stać się rdzeniem analogicznego pasa przemysłowego, obsługującego inwestycje w niemieckiej części Morza Bałtyckiego oraz kraje bałtyckie.

Szósty artykuł – „Analysis of offshore labour market trends: Evidence from Poland, Germany and the United Kingdom" (Majkowska & Laskowicz) - odnosił się do hipotezy, zakładającej, że różnice w poziomie dojrzałości sektora morskiej energetyki wiatrowej wpływają na strukturę zatrudnienia i zapotrzebowanie na kompetencje. Analiza danych pozyskanych w formie *web-scrapingu*, pochodzących LinkedIn potwierdziła, że rozwój sektora *offshore wind* prowadzi do powstawania nowych miejsc pracy i specjalizacji w obszarach inżynierii, logistyki i usług operacyjnych. W Wielkiej Brytanii i Niemczech obserwowano większą stabilność i specjalizację zawodową, natomiast w Polsce relatywnie wysokie zapotrzebowanie na pracowników, wyrażone dużą liczbą aktywnych ofert pracy w analizowanym zakresie czasowym. Choć autorzy zachowali ostrożność w zakresie wyciągania daleko idących wniosków, wynikających z tej obserwacji, przeprowadzona analiza daje silne podstawy do rozróżnienia specyfiki rynków pracy w analizowanych krajach, spośród których Polska miała relatywnie więcej aktywnych ofert pracy niż Niemcy i Wielka Brytania. Wszystkie analizowane rynki pracy koncentrują się wokół stolic krajów, co może wynikać ze specyfiki portalu LinkedIn i charakteru publikowanych ofert pracy.

Wyniki całego cyklu publikacji potwierdzają wzajemne powiązania pomiędzy czynnikami finansowymi, instytucjonalnymi, przestrzennymi i społecznymi w kształtowaniu lokalnych efektów ekonomicznych rozwoju sektora morskiej energetyki wiatrowej. Zastosowane podejście badawcze, umożliwiło nie tylko weryfikację postawionych hipotez, ale również rozwinięcie i adaptację narzędzi analitycznych do specyfiki polskiej gospodarki morskiej. W ten sposób rozprawa przyczynia się do poszerzenia wiedzy o mechanizmach lokalnej dystrybucji korzyści w sektorach gospodarki morskiej oraz do rozwoju metod oceny ekonomicznych efektów transformacji energetycznej w ujęciu przestrzennym.

Analizując łącznie wszystkie uzyskane wyniki, można stwierdzić, że potwierdzają one zasadnicze hipotezy badawcze rozprawy. Po pierwsze, źródło wytwarzania energii elektrycznej determinuje wynik finansowy jej producentów, a wyniki finansowe osiągane przez producentów energii ze źródeł odnawialnych są wyższe niż producentów energii ze źródeł konwencjonalnych. Po drugie, rozwój łańcucha dostaw dla sektora *offshore wind* w Europie jest niewspółmierny do celów instalacji morskiej energetyki wiatrowej, zakładanych przez rządy państw europejskich i może stanowić barierę dla osiągnięcia zakładanych mocy zainstalowanych do 2030 roku. Po trzecie, renta z przestrzeni morskiej przeznaczonej na rozwój MEW jest wyższa niż renta z innych form aktywności gospodarczej, wymagającej dostępu do przestrzeni morskiej. Po czwarte, poziom akceptacji wśród lokalnej społeczności jest powiązany z możliwością partycypacji w łańcuchu dostaw i poczucia odniesienia korzyści, przewyższających negatywne skutki. Ponadto, wykazano że, przestrzenna dystrybucja efektów ekonomicznych nie jest równomierna i koncentruje się wokół wybranych portów i ośrodków przemysłowych zarówno w Wielkiej Brytanii i w Polsce. Na podstawie analizy rynku pracy w sektorze morskiej energetyki wiatrowej, stwierdzono, że w Polsce MEW znajduje się w fazie dynamicznego wzrostu i rozwój sektora przyczynia się do tworzenia nowych miejsc pracy, w ramach zauważalnych wzorców przestrzennych.

Wyniki cyklu artykułów łącznie tworzą spójny obraz transformacji energetycznej jako procesu wielowymiarowego: gospodarczego, przestrzennego i społecznego. Dowodzą, że morska energetyka wiatrowa nie tylko przyczynia się do dekarbonizacji gospodarki, lecz także kształtuje nowy wymiar gospodarki morskiej opartej na technologii i współpracy lokalnych interesariuszy. Przeprowadzone badania wypełniają istotną lukę w literaturze, oferując empiryczne podstawy do projektowania polityki gospodarczej i przestrzennej w obszarze morskiej energetyki odnawialnej.

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3. Przedstawienie dorobku naukowego

3.1. Wykaz aktywności naukowych niebędących częścią rozprawy doktorskiej

3.1.1. Wystąpienia konferencyjne:

Elementem działalności naukowej autora jest aktywny udział w konferencjach krajowych i międzynarodowych, na których prezentował wyniki badań wpisujących się w tematykę rozprawy doktorskiej.

Autor uczestniczył w następujących wydarzeniach naukowych, prezentując wystąpienia:

- Laskowicz T. (2022), The value of the supply chain for the construction of offshore wind farms in Poland and the Baltic States, referat wygłoszony podczas konferencji Science and Education for Sustainable Development, Gdańsk, 24-25 listopada 2022 r.

Wystąpienie poświęcone było analizie wartości ekonomicznej łańcucha dostaw w sektorze morskiej energetyki wiatrowej w regionie Morza Bałtyckiego i stanowiło rozwinięcie badań opublikowanych w czasopiśmie Europa XXI.

- Laskowicz T., Majkowska A. (2024), Analysis of offshore labour market trends using offshore wind energy in the Baltic Sea region as an example, referat wygłoszony podczas Multidisciplinary Conference "BEING SEA-EU", Valletta (Malta), 10-12 czerwca 2024 r.

Referat prezentował wyniki badań dotyczących trendów na rynku pracy w sektorze *offshore wind*, przeprowadzonych z wykorzystaniem danych *big data* z portalu LinkedIn. Wystąpienie wpisywało się w tematykę artykułu złożonego do czasopisma Local Economy i stanowiło część badań nad rozwojem kompetencji zawodowych w branży energetyki morskiej.

- Laskowicz T. (2025), Koszt „social license to operate": ekonomiczne zaangażowanie deweloperów farm wiatrowych a rozwój nadmorskich społeczności lokalnych, wystąpienie podczas Konferencji Naukowej „Dylematy współczesnej gospodarki", Sopot, 31 stycznia 2025 r.

Wystąpienie dotyczyło zagadnienia ekonomicznego wymiaru akceptacji społecznej dla inwestycji w morskie farmy wiatrowe, stanowiąc uzupełnienie badań nad współistnieniem sektora MEW z tradycyjnymi gałęziami gospodarki morskiej.

3.1.2. Współpraca międzynarodowa i raporty naukowo-badawcze:

Autor od 2023 roku aktywnie uczestniczy w pracach zespołu badawczego realizującego międzynarodowy projekt *Blue Supply Chains* (2023–2025), współfinansowany w ramach priorytetu *Water-smart Societies* programu *Interreg Baltic Sea Region*. Projekt ten jest ukierunkowany na wspieranie transformacji energetycznej w gospodarce morskiej poprzez wdrażanie innowacyjnych rozwiązań w zakresie elektryfikacji infrastruktury portowej, redukcji emisji w transporcie morskim oraz rozwoju zielonych łańcuchów dostaw (*green supply chains*). Działania realizowane w jego ramach mają na celu stworzenie trwałych modeli współpracy między portami, operatorami terminali i jednostkami badawczymi, a także wzmocnienie odporności sektora morskiego na wyzwania klimatyczne w duchu koncepcji zrównoważonego rozwoju.

Uniwersytet Gdański, jako partner badawczy projektu, odpowiada za przygotowanie i realizację komponentu analityczno-badawczego obejmującego m.in. opracowanie studiów wykonalności dla inwestycji związanych z elektryfikacją urządzeń portowych w wybranych portach regionu Morza Bałtyckiego. W ramach tego komponentu autor uczestniczy w pracach zespołu badawczego odpowiedzialnego za analizę przypadku *Gdynia Container Terminal (GCT)*, wnosząc istotny wkład w przygotowanie analizy ekonomicznej oraz modelu finansowego inwestycji dotyczącej retrofittingu i elektryfikacji suwnic typu RTG. Opracowane analizy obejmowały zarówno szacunki kosztów inwestycyjnych *(CAPEX)* i operacyjnych *(OPEX)*, jak i ocenę potencjalnych korzyści środowiskowych i ekonomicznych, w tym redukcję emisji gazów cieplarnianych, zwiększenie efektywności energetycznej oraz poprawę konkurencyjności portów.

Rezultatem prowadzonych prac badawczych są dwa raporty naukowo-badawcze, które stanowią istotny wkład w rozwój wiedzy o praktycznych aspektach zielonej transformacji portów morskich:

- Laskowicz T., Jankiewicz J., Oniszczuk-Jastrząbek A., Czermański E., Rulffs J., Teilmann K., Møller J.H. (2024), Role of port authorities in green port operation activities, raport naukowo-badawczy, Uniwersytet Gdański. Data publikacji: 30 czerwca 2024 r., https://interreg-baltic.eu/project/bluesupplychains/#output-0

- Czemański E., Bartłomiejczyk M., Laskowicz T., Rulffs J., Teilmann K., Møller J.H. (2025), Demonstrated electrification process of port operations in Gdynia Container Terminal and Port of Skagen, raport naukowo-badawczy, Uniwersytet Gdański. Data publikacji: 30 czerwca 2025 r., https://interreg-baltic.eu/project/bluesupplychains/#output-2

Udział autora w projekcie *Blue Supply Chains* stanowi integralny element jego działalności badawczej, łącząc zagadnienia z zakresu zielonej transformacji portów, ekonomiki inwestycji infrastrukturalnych oraz zrównoważonych łańcuchów dostaw w gospodarce morskiej. Realizowane prace wnoszą istotny wkład w rozwój wiedzy o praktycznych aspektach dekarbonizacji sektora morskiego, a także wpisują się w szerszy kontekst badań nad transformacją energetyczną i konkurencyjnością portów regionu Morza Bałtyckiego.

3.1.3. Współpraca z otoczeniem gospodarczym

Istotnym elementem działalności autora jest współpraca z otoczeniem społeczno-gospodarczym, realizowana poprzez Biuro Analiz i Ekspertyz Uniwersytetu Gdańskiego - jednostkę Centrum Transferu Technologii, której celem jest integracja środowiska naukowego z praktyką gospodarczą i wspieranie procesów wdrażania innowacji.

W ramach współpracy autora z otoczeniem gospodarczym zostało wykonane studium prewykonalności inwestycji:

- Czermański E., Oniszczuk-Jastrząbek A., Kotowska I.N., Kozłowski Ł., Laskowicz T. (2022), Studium prewykonalności inwestycji tonażowej polegającej na zakupie 2 jednostek typu CTV na potrzeby podjęcia działalności armatorskiej na rynku offshore, raport naukowo-badawczy, Uniwersytet Gdański, Gdańsk. https://repozytorium.bg.ug.edu.pl/info/report/UOG3b279005c02345038f0ea6a2521b8378/

Autor odpowiadał za część analityczno-ekonomiczną, obejmującą ocenę opłacalności inwestycji, analizę rynkową oraz prognozę zapotrzebowania na usługi jednostek typu *Crew Transfer Vessel (CTV)*, przeznaczonych do obsługi morskich farm wiatrowych na Morzu Bałtyckim.

Autor uczestniczył w pracach nad opracowaniem Kodeksu Dobrych Praktyk Współistnienia Morskich Farm Wiatrowych i Rybołówstwa Morskiego, zrealizowanego na zlecenie jednego z największych polskich stowarzyszeń branżowych reprezentujących sektor rybołówstwa.

Celem tego opracowania było wypracowanie modelu współpracy między sektorem rybołówstwa a rozwijającym się sektorem morskiej energetyki wiatrowej, a także identyfikacja i mitygacja potencjalnych konfliktów przestrzennych i ekonomicznych wynikających ze współdzielenia przestrzeni morskiej.

3.2. Wykaz publikacji stanowiących rozprawę doktorską

3.2.1. Lista publikacji

1. Dopierała Ł., Mosionek-Schweda M., Laskowicz T., Ilczuk D. (2022), Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region, Energy Reports, Vol. 8, pp. 11492–11503, DOI: 10.1016/j.egyr.2022.09.009, IF = 5.1, MEiN = 100 pkt.
2. Laskowicz T. (2022), Offshore wind energy potential in Europe: a forecast of installed capacities and costs, EUROPA XXI, vol. 42, pp. 129–148, DOI: 10.7163/Eu21.2022.42.5, MEiN = 40 pkt.
3. Laskowicz T. (2024), Economic Aspects of Marine Spatial Planning: The Case of Offshore Wind Farms in Poland, Studia Regionalne i Lokalne, nr 3(97), pp. 7–21, DOI: 10.7366/1509499539701, MEiN = 40 pkt.
4. Laskowicz T. (2021), The Perception of Polish Business Stakeholders of the Local Economic Impact of Maritime Spatial Planning Promoting the Development of Offshore Wind Energy, Sustainability, vol. 13, art. 6755, pp. 1–17, DOI: 10.3390/su13126755, IF = 3.3, MEiN = 100 pkt.
5. Laskowicz T. (2025), Spatial distribution of economic benefits from offshore wind development – case studies of Poland and the United Kingdom, artykuł złożony do czasopisma „Przegląd Geograficzny” w dniu 1 września 2025 r.
6. Majkowska A., Laskowicz T. (2025), Analysis of offshore labour market trends: Evidence from Poland, Germany and the United Kingdom, artykuł złożony do czasopisma „Local Economy” w dniu 12 sierpnia 2025 r.

3.2.2. Miary bibliometryczne

Przybliżone wartości miar bibliometrycznych autora na podstawie dostępnych baz danych:

- Cytowania: 46
- h-index: 3
- Sumaryczny IF: 9,089
- Sumaryczny SNIP: 3,041
- Sumaryczny CiteScore: 12,9
- Sumaryczna punktacja ministerialna: 310

Dane pochodzą z profilu autora w Bazie Wiedzy Uniwersytetu Gdańskiego oraz portalu Google Scholar według stanu na dzień 30.09.2025 r.

3.2.3. Oświadczenia współautorów publikacji

Sopot, dnia 30.09.2025

Oświadczenie współautorów publikacji

Niniejszym podaję wkład autorski w publikację (dane bibliograficzne):

Tytuł książki/czasopisma: Local Economy

Wydawnictwo: SAGE Journals

Identyfikator książki/czasopisma (ISSN, ISBN, DOI): ISSN: 0269-0942; Online ISSN: 1470-9325

Data i miejsce przesłania do czasopisma: 12 sierpnia 2025 r. (w momencie składania oświadczenia artykuł w procesie publikacji)

Tytuł artykułu: The Role of Offshore Wind Energy Development in Job Creation: A Real-Time Data Analysis Using LinkedIn in Poland, Germany and United Kingdom

L.p.	Imię i nazwisko współautora	Procentowy wkład autorski	Szczegółowy opis wkładu autorskiego	Data i podpis współautora
1	Agata Majkowska	50%	Metodyka badania, Analiza formalna, Badania, Opracowanie wersji pierwotnej manuskryptu, Wizualizacja, Nadzór merytoryczny, Zarządzanie projektem	30.09.2025 Majkowska Agata
2	Tomasz Laskowicz	50%	Konceptualizacja badania, Analiza formalna, Zasoby, Opracowanie wersji pierwotnej manuskryptu, Recenzja i redakcja tekstu, Wizualizacja, Nadzór merytoryczny, Zarządzanie projektem	30.09.2025 Laskowicz Tomasz

Sopot, dnia 30.09.2025

Oświadczenie współautorów publikacji

Niniejszym podaję wkład autorski w publikację (dane bibliograficzne):

Tytuł książki/czasopisma: Energy Reports

Wydawnictwo: Elsevier

Identyfikator książki/czasopisma (ISSN, ISBN, DOI): https://doi.org/10.1016/j.egyr.2022.09.009

Data i miejsce wydania: 17 września 2022 r., tom: 8, strony: 11492-11503

Tytuł artykułu: Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region

L.p.	Imię i nazwisko współautora	Procentowy wkład autorski	Szczegółowy opis wkładu autorskiego	Data i podpis współautora
1	Łukasz Dopierała	40%	Konceptualizacja badania, Metodyka, Analiza formalna, Badania, Zasoby, Opracowanie wersji pierwotnej manuskryptu, Recenzja i redakcja tekstu, Wizualizacja, Nadzór merytoryczny, Zarządzanie projektem, Pozyskanie finansowania	30.09.2025 PODPIS ZAUFANY ŁUKASZ DOPIERAŁA 06.10.2025 18:12:41 GMT+0200 Dokument podpisany elektronicznie podpisem zaufanym
2	Magdalena Mosionek-Schweda	30%	Konceptualizacja badania, Metodyka, Analiza formalna, Badania, Zasoby, Opracowanie wersji pierwotnej manuskryptu, Recenzja i redakcja tekstu, Nadzór merytoryczny, Zarządzanie projektem,	30.09.2025 PODPIS ZAUFANY MAGDALENA MOSIONEK-SCHWEDA 06.10.2025 14:53:20 GMT+0200 Dokument podpisany elektronicznie podpisem zaufanym
3	Tomasz Laskowicz	20%	Konceptualizacja badania, Analiza formalna, Badania, Zasoby, Opracowanie wersji pierwotnej manuskryptu, Wizualizacja	30.09.2025 PODPIS ZAUFANY TOMASZ LASKOWICZ 06.10.2025 20:43:43 GMT+0200 Dokument podpisany elektronicznie podpisem zaufanym
4	Daria Ilczuk	10%	Konceptualizacja badania, Analiza formalna, Badania, Zasoby, Opracowanie wersji pierwotnej manuskryptu, Recenzja i redakcja tekstu,	30.09.2025 PODPIS ZAUFANY DARIA ILCZUK 06.10.2025 18:30:01 GMT+0200 Dokument podpisany elektronicznie podpisem zaufanym

4. Artykuły naukowe stanowiące rozprawę doktorską

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Research paper

Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region

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ABSTRACT

Fighting greenhouse gas emission requires actions to reduce energy usage and increase the proportion of renewable energy sources in the total energy production. Managing this energy transformation process requires significant financial outlays, so financial performance is crucial; it enables energy producers to make future energy transformation decisions. The study discussed in this paper evaluated the financial performance of renewable energy producers in comparison to conventional energy producers in the Baltic Sea Region. The research also aimed to determine how the financial performance is influenced by firm-specific and country-specific factors. We analyzed a unique panel dataset of 328 energy producers, most of which were private limited companies, in the period ranging from 2011 to 2019. Using random effects and fixed effects models, we found that private limited companies had a better financial performance than public limited companies. The size of the company's assets had an ambiguous effect on its financial performance. Moreover, the difference in the performance of various type of energy producers was small. However, since the Paris Agreement, the impact of electricity prices on both ROA and ROE of the producers has been increasing.

1. Introduction

In an effort to achieve climate neutrality, the European Union (EU) adopted Fit for 55 in July 2021, which was viewed as the next step in addressing this issue after The European Green Deal. According to the new strategy, the EU aims to reduce its net greenhouse gas emissions by at least 55% before 2030 in comparison to 1990 (European Commission, 2021a). Since the European energy sector is responsible for 75% of the EU's emissions, transitioning energy producers to using renewable energy sources (RES) is crucial to achieving the emissions reduction goal. The new target, a 38%–40% share of RES in the European total energy mix, has been set (European Commission, 2021b). However, it is important to note that not every country achieved its RES total energy mix goals set for 2020, which were established as part of each country's national plan. By identifying why some countries failed to meet their target goals, while other succeeded, we may improve our understanding of the process and potentially find a way to accomplish the process of energy transition more successfully.

The new EU strategy places a significant amount of emphasis on offshore renewable energy, setting an ambitious target of 300 GW for installed offshore wind capacity by 2050 (in 2020 the installed capacity was: 12 GW) across all EU sea basins (European Commission, 2021b). The results of the study on the Baltic Sea Region showed that the region's offshore wind power potential exceeded 93 GW for its installed capacity and 325 TWh for its yearly energy generation (European Commission, 2019). Eight countries from the Baltic Sea Region have signed the Baltic Sea Declaration agreeing to develop their offshore wind capacity. The signatories are Denmark, Germany, Poland, Finland, Sweden, Latvia, Lithuania, and Estonia. These eight countries, which represent all the EU countries from the Baltic Sea Region, were considered in the present research study. They were chosen in order to assess the financial performance of energy producers from countries with different economic conditions but similar geographical characteristics (including direct access to the open sea, level of insolation and windiness). Moreover, due to their relatively close proximity to one another, countries located in the Baltic Sea Region are already connected by international energy grids and they trade energy with each other to compensate for the lack of energy production in one country or the overproduction peaks in another (Studzieniecki et al., 2022). The international connections between these countries and the commonality of their energy market could be beneficial for their energy transition and help stabilize the energy system based on RES (less reliance on fossil-based energy sources) (Newbery et al., 2018).

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Table 1
Energy mix characteristics for the analyzed countries.

Country	Main source of renewable energy produced in 2019 (% of RES)	RES as a percentage of electricity produced in 2019	Final energy consumption in 2020 [million tons of oil equivalent (Mtoe)]	RES as a percentage gross final energy consumption target for 2020	Met the EU RES gross final energy consumption target for 2020?
Denmark	Wind (69%)	65.35	15.5	30	Yes
Germany	Wind (50%)	40.82	262.3	18	Yes
Poland	Wind (57%)	14.35	93.5	15	No
Finland	Hydro (43%)	38.07	24.4	38	Yes
Sweden	Hydro (66%)	71.19	43.1	49	Yes
Latvia	Hydro (73%)	53.42	4.2	40	Yes
Lithuania	Wind (55%)	18.79	6.1	23	Yes
Estonia	Solid biofuels (59%)	22.00	2.8	25	Yes

For the 20 years European countries have made a concerted effort to fulfill their obligations to transform the types of energy sources they use. However, not all countries have met their renewable energy source targets for 2020 (Table 1). One of the possible reasons for this could be the analyses of the financial performance of the energy producers when making the decision to move from fossil fuels to renewable sources. Energy producers are responsible for executing the EU's plan and their country's national plan by making decisions on investing in new power generating sources. This requires significant financial investment and it is expected that investors will base their decisions on the financial outcome (Steffen, 2018).

The study presented in this paper evaluated the financial performance of renewable energy producers in comparison to traditional energy producers in the Baltic Sea Region. It also aimed to determine how the financial results of the analyzed entities are influenced by the firm-specific factors (legal form, size of the entity, type of energy produced), and the country-specific factors (especially price of electricity). To the best of our knowledge, no previous research has considered the influence of a country's average annual wholesale electricity price on the financial performance of RES producers. In our opinion, this factor represents the overall energy market situation as it includes changes in energy demand and supply. While energy prices determine the revenues of the energy producers, influencing the supply, they also influence the decisions made by energy consumers.

The study covered the period from 2011 to 2019. It utilized the Orbis database as the primary source of financial data as well as other characteristics of the analyzed enterprises.

To the best of our knowledge, this is the first study that investigated three types of RES producers (hydro, solar, wind) located in eight countries from the so-called the Baltic Sea Region. Most other studies have investigated a particular type of renewable energy in two to three countries (mostly Lithuania, Latvia, and Estonia). Moreover, to evaluate the financial performance of RES producers, we used company-specific factors (size, legal form, etc.) and included a country's average annual wholesale electricity price as the country-specific factor. Since we collected data from the Orbis database, we accessed a much larger number of energy producers than other studies, including those formed as partnerships. Previous studies only used public limited and private limited companies in their analyses. Finally, among the factors influencing the financial performance of energy producers, we included the depreciation value as an indicator of the level of asset consumption and as an operating cost that reduces the companies' taxable profit, thus affecting profitability.

Thus, our analyses provide knowledge about the profitability of the enterprises producing energy from renewable sources and the factors influencing their financial performance. These issues are relevant in the context of the increasing importance of these entities in the energy sector in connection with the implementation of climate goals at the EU level or the global level (as expressed in the Paris Agreement).

The rest of this paper is structured as follows. Section 2 presents the literature review focusing on studies addressing energy producers, their financial performance, and financial incentives for energy producers to foster the transition from fossil fuels to renewable energy sources. Section 3 explains the method used for the research and the process of data collection and analysis. Section 4 discusses the results of the analyses. The last section presents a summary of the research and the debate on the conclusions from the research. It also identifies the study's limitations and suggests some directions for further research.

2. Literature review

Along with climate change, RES plays an important role in sustainable development and environmentally friendly activities. To improve the share of alternative energy sources in the mixture of all types of energy sources, investors are encouraged by various solutions related to the use of renewable energy, which also has an impact on the financial performance of enterprises. Previous studies on this subject mainly focused on government support, especially in China. For example Zhang et al. (2014) reported that government subsidies have significant positive effects on the financial performance of wind energy producers, but the government background of the firms' executives weakens those effects. In further research (Zhang et al., 2015) indicated that the effectiveness of subsidies to improve the performance of alternative energy producers differs due to the type of energy source that is used: a subsidy for wind energy increases the corporation's profitability better than a subsidy for solar energy. Several studies have also drawn similar conclusions regarding the effectiveness of government subsidies for the photovoltaic industry in China (Xiong and Yang, 2016; Xu et al., 2020). However, Sun et al. (2020) reported on the effectiveness of tax incentives from the perspective of the profitability of renewable energy producers. Other researchers focusing on Europe, such as Ibarloza et al. (2018), analyzed the economic and financial performance of Spanish companies involved in solar energy production influenced by public regulation. Tsiblostefanakis and Mantouka (2009) examined the impact of the contribution of public funds on the investment efficiency of RES producers in Greece. According to Zimon and Zimon (2020), in Poland, alternative energy producers benefit from government preferences, such as an easier connection to the grid, no need to obtain a license, and exemptions from commercial balancing costs. However, this support has not been effective in motivating the implementation of RES.

In addition to the determinants of RES development, a few studies have reported on the potential factors influencing the achieved financial performance of RES producers. However, to date, this issue has received little attention.

Researchers frequently include various measures to determine the economic efficiency and financial performance of an enterprise (Hassan, 2019), such as: earnings per share (EPS), return on assets (ROA), return on equity (ROE), and return on capital employed (ROCE) (Feng et al., 2018; Nakao et al., 2007; Ruggiero and Lehkonen, 2017; Schabek, 2020; Zhang et al., 2014). Halkos and Tzeremes (2012) reported that the firms' financial performance can be expressed by their level of ROA and ROE. Iwata and Okada (2011) used seven financial performance indices — ROE, ROA, return on investment (ROI), return on invested capital (ROIC), and return of sales (ROS), Tobin's q, and the natural logarithm of Tobin's q and they examined the behaviors of various stakeholders to clarify how financial performance is influenced by different environmental issues. King and Lenox (2001) used ROA, ROE, ROI, and Tobin's q to determine a firm's market valuation over the replacement value of its assets.

In the literature, there are mainly two categories of factors that affect the financial results of RES producers: the specificity of the firm and the specificity of the country (Morina et al., 2021). Studies have reported that the most important firm-specific factors are the company size, asset, and sales growth, turnover, liquidity, and leverage, as well as the number of years the company has been engaged in the activity and its ownership structure and board size. King and Lenox (2001) included the company's size, annual growth of the firm (calculated as the percentage change in sale), and leverage (calculated as the ratio of its debt to assets). Gupta (2017) used leverage as a variable that captures the distress risk of the firm. Feng et al. (2018) stated that ownership circulation (based on tradable shares) has a positive relationship with a firm's economic performance; in Chinese listed companies, this type of ownership always means a better corporate governance structure and a more efficient decision-making process, which will improve profits.

Country-specific factors are related to the issue of public intervention to correct market imperfections and foster uncertainty about the profitability of RES production. According to Falcone and Sica (2019), in Italy, biomass power plants are financially supported by several public programs and entitled to Green Certificates. For example, Eder and Mahlberg (2018) stated that the managerial efficiency is lower in Austrian biogas producers that receive higher production subsidies in the form of feed-in-tariffs in comparison to other plants. This suggests that the government accepts these inconveniences in RES generation in its attempt to reach its ambitious renewable energy targets. Bohl et al. (2013) highlighted the possible impact that public policies and subsidies have on the emergence of alternative energy stock price bubbles in research on German renewable energy exchanges. It is worth emphasizing that researchers also noted that macroeconomic factors, such as inflation, financial crises, and growth of gross domestic product, are important for determining a firm's profitability (Morina et al., 2021). In addition, Duffy et al. (2020) indicated that apart from capital costs, technological factors are also an important issue, based on the results of onshore wind energy from Denmark, Germany, Ireland, Norway, Sweden and the United States. Similar results about the importance of technological advancements and cost reductions of land-based wind were obtained by Wiser et al. (2016).

The economic and financial literature also presents the results of research on energy issues in the Baltic Sea Region. Those studies have shown that the most frequently discussed issues for this area are energy security, energy efficiency, and national legislation regulating the energy system, including renewable energy. Some studies also indicated possible prospects for energy development in certain Baltic States. However, only a few publications focused on producers of RES. Moreover, to the best of our knowledge, no publications have analyzed the performance of producers of energy from renewable sources (including wind, solar, and hydroelectric power) in the group considering all the countries in the Baltic Region. Thus, this paper fills this research gap.

An analysis of the energy security level in the Baltic States was conducted by Augutis et al. (2020) and Galinis et al. (2020). Augutis et al. (2020) assessed the Energy Security Level index for three countries, Lithuania, Latvia, and Estonia, for the research period of 2008 to 2016. Their findings revealed that Estonia is the best-performing country regarding energy security. They reported that this result is due to domestically extracted oil shale as local fuel, a high share of RES in the energy mix, low energy dependency, and low dependency on natural gas (Augutis et al., 2020). Energy security in the Baltic Region in the context of energy transition and carbon price paths was also considered by Galinis et al. (2020). That study analyzed Lithuania, Latvia, Estonia, and Finland. They concluded that energy security in the Baltic countries is mainly related to the electricity system. They also emphasized the need to develop a renewable energy system (renovation of existing hydroelectric power plants, construction of wind farms, combined heat and power (CHP) plants using biomass and municipal waste, and CHP plants using natural gas and biogas, as the best options for electricity generation in the Baltic countries, regardless of the carbon price path (Galinis et al., 2020). Aslani et al. (2014) proposed three different scenarios of renewable energy policies by 2020 for Finland to discuss dependency and security of energy supply. They concluded that despite 7% electricity and heat consumption growth by 2020, dependency on imported sources will decrease between 1% and 7% depending on the scenarios.

The current body of literature also includes research that considers the energy efficiency of the Baltic States using different methodological approaches. Hsiao et al. (2019) used the stochastic frontier analysis model to measure total-factor energy efficiency (TFEE) and disaggregate input efficiency for 10 countries across the Baltic Sea – Germany, Denmark, Estonia, Finland, Lithuania, Latvia, Norway, Poland, Russian Federation, and Sweden – from 2004 to 2014. Their study results indicated that the higher renewable energy consumption and urban population rate, the greater the TFEE scores. Moreover, the energy efficiency performance was better in Norway, Sweden, Finland, and Latvia in comparison to the other analyzed countries. A different approach to energy efficiency analysis was used by Miskinis et al. (2020). They calculated the primary energy intensity indicators for nine Baltic countries – Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, and Sweden – for the period 2000 to 2018. The results indicated that primary energy intensity in the Baltic countries was 2–3 times higher than the average in the EU-27; this can be due to the inefficient energy transformation sector as well as the existing energy saving potential in the remaining sectors of the countries' national economies (Miskinis et al., 2020). Korberg et al. (2020) used the energy system analysis tool EnergyPLAN to analyze the role of biogas and biogas-derived fuels in a 100% renewable energy system for Denmark. Their main conclusion is that using biogas and biomethane for power, heat, or industrial sectors can reduce dry biomass consumption by up to 16%.

Regarding research on renewable energy, some studies evaluated the strategies and policies aimed at supporting the development of energy from renewable sources, as well as the barriers to this development. Klevas et al. (2007) analyzed the preconditions for sustainable energy development in three Baltic States – Estonia, Latvia, and Lithuania – in 2005 right after the accession of these countries to the EU. Based on a detailed overview of the present RES policies and measures implemented in the Baltic States, Klevas et al. (2007) proposed the guidelines for countries' local sustainable energy development using EU structural funds co-financing. Similarly, Streimikiene and Klevas (2007) considered the possibilities of using the EU structural funds to implement renewable energy projects in the Baltic States (Estonia, Lithuania, and Latvia). They also stated that Estonia differed from other countries because of its carbon intensive structure of total primary energy supply (TPES) and the high energy and carbon intensity of its economy. Latvia has the highest share of RES in TPES. Moreover, the main renewable energy sources in the analyzed countries are firewood and hydroelectric power. Streimikiene and Klevas (2007) presented some recommendations for sustainable energy policy development in the Baltic States. They used the Energy Indicators for Sustainable Development tool for analyzing trends, setting energy policy goals, and monitoring progress towards these goals for three Baltic States (Estonia, Latvia, and Lithuania). They emphasized the significant role of promotion of RES and energy efficiency improvements for sustainable development in the Baltic States' energy sector. The same group of countries is analyzed by Štreimikiene et al. (2016). That study confirmed that Estonia achieved the best results in increased use of RES and energy efficiency improvements; however, other Baltic countries have also made significant progress in the use of RES and in improved energy efficiency since their EU accession in 2004. Streimikiene et al. (2009) indicated that corporate social responsibility plays a significant role in the energy sector of the Baltic States as it can aim at sustainable energy development, increase a company's energy efficiency, and enhance the use of renewables. Lu et al. (2020) analyzed the main barriers (social, economic, technological, and regulatory) to RES penetration in the Baltic States and the success of the policies dealing with these barriers. They stated that Estonia archived the best results in RES penetration by exceeding its overall RES target for 2020 by 115%. Moreover, all countries need to develop better policies for approaching their RES targets in transport because the barriers in this area are the most difficult to overcome. Pinson et al. (2017) based on Denmark's efforts to achieve a fully renewable energy system point out the most important aspects as market mechanisms adequately supporting renewable energy integration and a more holistic view of energy production and consumption. Factors determining the effective use of RES in the economy were also analyzed by Wang et al. (2021). In their analyses the authors used Denmark, Germany, and Great Britain as benchmarks.

Bobinaite (2015) presented the results of a comparative analysis of the financial sustainability of companies producing electricity from wind resources in the Baltic States from 2009 to 2013. Based on financial ratios and Altman, Liss, and Tafler bankruptcy forecasting models, Bobinaite (2015) stated that the operational efficiency of the analyzed companies was higher in Estonia and Lithuania than in Latvia. Moreover, Latvian companies demonstrated middle but increasing bankruptcy probabilities while Estonian companies showed a high risk of bankruptcy, but the risk was decreasing (Bobinaite, 2015). Rytter et al. (2015) focused on biomass and waste in Nordic and Baltic countries. That study assumed the high potential to further increase the use of forest fuels (e.g. unprocessed wood products) as an important tool in envisioning the independence of fossil energy sources.

There is also research on the impact of sustainability practices on the financial performance of companies located in the Baltic states. Pham et al. (2021) analyzed 116 listed Swedish companies and concluded that the adoption of certain sustainability practices is significantly and positively associated with financial performance measured by financial indicators, such as earnings yield, return on assets, return on equity, and return on capital employed. Similar research for financial companies was carried out by Rahi et al. (2022). The authors studied the impact of sustainability practices (including environmental practices) on the financial performance of 39 financial firms from Sweden, Denmark, Finland, and Norway. Their results revealed a negative relationship between ESG practices and financial performance, expressed by return on invested capital, return on equity, and earnings per share. The authors concluded that sustainability practices require long-term investments that negatively influence financial performance.

The results of the literature review presented above confirm the lack of publications on the performance of renewable energy producers located in the Baltic States. The cited authors mainly analyzed renewable energy policies and strategies as well as energy security issues, and most of the research focused on three countries: Lithuania, Latvia, and Estonia. Consequently, our study fills the research gap in the literature.

Based on a literature review, the following research hypotheses were formulated:

H1: The financial performance achieved by RES producers is significantly higher than those achieved by conventional energy producers.

H2: The type of energy produced (hydro, solar, wind) determines the financial performance of its producers.

H3: Public limited companies that produce energy are characterized by lower profitability than either private limited companies or partnerships.

H4: Differences in the wholesale electricity price in the analyzed countries have a significant impact on the financial performance of energy producers.

The H1 and H2 hypotheses are in line with the theory that financial resources are invested in new technologies in exchange for the possibility of achieving an attractive rate of return (Levine, 2004). Therefore, these hypotheses are related to the innovative theory of entrepreneurship.

The H3 hypothesis relates to theories of capital structure, including the pecking order theory, signaling theory, and market timing theory. The pecking order theory is based on the asymmetry of information between a company's management and external investors (Modigliani and Miller, 1958; Myers, 1984). This indicates that enterprises avoid sources of financing that result in information costs, which are understood as the negative impact of a given financial decision on the market value of the enterprise. Information asymmetry theory is the link between the pecking order theory and signaling theory, which focuses on explaining the negative or positive reaction of the capital market to companies' decisions on the issue of various securities (Ross, 1977). Finally, managers adjust their decisions to issue shares to market conditions, not only to financial needs and available internal sources of financing, which is consistent with the market timing theory (Baker and Wurgler, 2002). Decisions regarding the selection of financing sources made in accordance with signaling theory and market timing theory, affected by the asymmetry of information, do not result from companies' efforts to optimize their capital structure. In practice, this means financing activities with equity capital and not using external (debt) capital, and thus, not using financial leverage. This often applies to large public companies.

The H4 hypothesis is related to the neoclassical theory of the enterprise and, in particular, to price as a carrier of information about the market. In this context, the rise in energy prices is related to an increase in demand. The associated shifting of the equilibrium point creates opportunities for companies to maximize profits (Kirzner, 1973).

3. Data and methods

To verify the research hypotheses for the present study, we mainly followed the methodology proposed by Ruggiero and Lehkonen (2017) and Schabek (2020). We based our research on panel financial data obtained from the Orbis database. In the first step, we selected a group of energy producers in Denmark, Estonia, Finland, Germany, Lithuania, Latvia, Poland, and Sweden using the North American Industry Classification System (NAICS 2017) codes. Thus, we obtained an initial dataset of 1142 companies. However, based on the NAICS 2017 codes, it was not possible to identify the main source of energy production in each of the companies, as most companies have several codes assigned to them at once. Consequently, we analyzed the description of the activity and the main business line for each company using the Orbis database and the companies' websites. In further analysis, we only used companies that had one dominant energy source (which accounted for over 50% of the company's energy mix). Following Ruggiero and Lehkonen (2017), we removed the firms that were only engaged in electricity distribution from the sample and we kept the firms that mainly focused on electricity generation. We included companies producing wind, solar, hydro, and fossil energy for the study. We also eliminated companies that lacked financial performance data from the dataset. Ultimately, we obtained a dataset of 328 companies with available financial performance results for at least one year. Due to this selection, companies from Estonia and Latvia were not included in the final sample. To the best of our knowledge, this sample is several times larger than those used in previous studies. Our panel included unbalanced data for 2011–2019.

The obtained sample mainly consists of wind energy producers (71%). Solar energy producers accounted for 11% of the sample and hydroelectric power producers accounted for 9%. The study also included companies producing energy from fossil fuels (9%), which were the control group. Most of the companies (54%) are located in Germany. Contrary to previous studies (Gupta, 2017; Morina et al., 2021; Schabek, 2020), our dominant group was private limited companies (86%). However, our sample also includes partnerships (8%) and public limited companies (6%). By public limited company, we mean joint-stock companies listed on the public market. Similarly, private limited companies are unlisted companies. Finally, partnerships include general partnerships and limited partnerships.

We included two measures of financial performance, which we used as dependent variables in the model (see Table 2). The first measure is ROA, calculated as earnings before taxes, divided by total assets. The second is ROE, calculated as earnings before taxes divided by total equity. We used ROA and ROE calculated for gross earnings because we did not want our results to be distorted by differences in the taxation of companies. We did not use Tobin's q because most of the companies in our sample are not listed on the stock exchange.

Based on the literature review, we identified a set of independent variables, which we divided into firm-specific factors and country-specific factors following Morina et al. (2021). The first group includes the size of the company (*LogA*), the depreciation to total assets ratio (*DepA*), the financial leverage, which is also a measure of risk (*DA*), as well as the operating revenues to assets ratio (*RA*). Moreover, following Schabek (2020) we included dummy variables in the model that define the type of energy produced (*Wind*, *Solar*, *Hydro*, *Fossil*) and the legal form of the company (*Public*, *Private*, *Partner*). We were unable to include capital expenditure in the model due to the lack of adequate data for most of the companies in our sample.

The size of the company is one of the fundamental factors that can influence its financial performance. In larger companies, it is related to the economies of scale. We suppose that this factor may have a positive impact on ROA and ROE. As a rule, the logarithm of total assets is used as a measure of firm size (Lassala et al., 2021; Martí-Ballester, 2017). Appendix (Table A.1) presents the assets of the companies in the research sample.

Depreciation is an operating cost that significantly affects profit before taxes; thus, it impacts a company's financial performance (also expressed by ROA and ROE as in our study). In the literature, the depreciation in relation to fixed assets is most often analyzed because this ratio informs how the company is replacing its old fixed assets with new ones. Firms acquire fixed assets in the hope of increasing their revenues. In the case of energy producers, fixed assets usually constitute a high share of a company's total assets; therefore, having no data on fixed assets, we used the depreciation to total assets ratio following Neves et al. (2019). We expected that the depreciation to assets ratio would have a negative effect on financial performance.

The level of leverage is related to the company's financing structure. It can be measured as the ratio of total debt to total assets (Ruggiero and Lehkonen, 2017; Schabek, 2020; Sun et al., 2020). However, the increase in the share of debt in financing also increases the company's risk of bankruptcy. In such a situation, investors expect a potentially higher return on capital. Therefore, we expected the increase in leverage to have a positive effect on ROE.

Operating revenues to assets ratio represents the productivity of the company's assets. Studies have reported that this ratio has a positive impact on ROA and ROE (Baik et al., 2013; Chadha and Sharma, 2016). In the case of energy producers, differences in the technological advancement of companies may cause significant changes in the value of this ratio. We expected a positive impact of operating revenues to assets ratio on financial performance.

Schabek (2020) showed that the source of energy influences the financial performance of its producers. That study found that solar and wind energy companies are more financially efficient than fossil energy firms. To check this relationship, we added a dummy variable to the model, which represents four types of energy producers. Following Schabek (2020), we considered the legal form of the company. We expected public limited companies to have lower ROE than private limited companies and partnerships.

The literature shows that national governments use various legal and organizational solutions to support the development of renewable energy. It is not possible to identify all the country-specific factors within one model. However, determining whether country specificities have a significant impact on financial efficiency will help identify countries that have better solutions and help provide suggestions for further research. To consider the influence of country-specific factors on ROA and ROE, we introduced a dummy variable for each country (*DE, DK, FI, LT, PL, SE*) into the model. We also included the country's average annual wholesale electricity price (*Price*) to approximate the local energy market situation. We believe that the wholesale price of energy synthetically describes the market situation, considering changes in energy demand and supply. We expected rising energy prices to have a positive impact on ROA and ROE. Table 3 presents the descriptive statistics of the variables used in the research, while Appendix (Table A.2) presents the correlation matrix between the independent variables.

To analyze the impact of specific factors on the financial performance of energy producers, we utilized panel modeling using the random effects (RE) and fixed effects (FE) estimating methods. Following Ruggiero and Lehkonen (2017) and Schabek (2020), we applied the analytical form of the model:

$$Y_{i,t} = \beta_0 + \sum_{k=1}^{n} \beta_k X_{k,it} + \alpha_i + \varepsilon_{i,t} \tag{1}$$

where:

– $Y_{i,t}$ represents the dependent variable for the firm i in the time t,

– β_0 represents the constant term,

– $X_{k,it}$ is the kth independent variable for the firm i in the period t,

Table 2
Definitions of the research variables.

Variable	Definition	Expected sign of the coefficient
ROA	Profit or loss (before taxes) divided by total assets (%).	n/a
ROE	Profit or Loss (before taxes) divided by equity (%).	n/a
LogA	Decimal logarithm of total assets.	+
DepA	Depreciation divided by total assets.	–
DA	Total debt divided by total assets.	+
RA	Operating revenue divided by total assets.	+
Price	Average annual wholesale power price in the producer's country (EUR/MWh).	+
Wind	Dummy variable equals 1 if the company produces more than 50% of wind energy, 0 otherwise.	+
Solar	Dummy variable equals 1 if the company produces more than 50% of solar energy, 0 otherwise.	+
Hydro	Dummy variable equals 1 if the company produces more than 50% of hydro energy, 0 otherwise.	+/−
Fossil	Dummy variable equals 1 if the company produces more than 50% of fossil energy, 0 otherwise.	–
Public	Dummy variable equals 1 in the case of a publicly traded company, 0 otherwise.	–
Private	Dummy variable equals 1 in the case of a private limited company, 0 otherwise.	+
Partner	Dummy variable equals 1 in the case of a partnership, 0 otherwise.	+/−
DE	Dummy variable equals 1 if the company is located in Germany, 0 otherwise.	+/−
DK	Dummy variable equals 1 if the company is located in Denmark, 0 otherwise.	+/−
FI	Dummy variable equals 1 if the company is located in Finland, 0 otherwise.	+/−
LT	Dummy variable equals 1 if the company is located in Lithuania, 0 otherwise.	+/−
PL	Dummy variable equals 1 if the company is located in Poland, 0 otherwise.	+/−
SE	Dummy variable equals 1 if the company is located in Sweden, 0 otherwise.	+/−

Table 3
Descriptive statistics of the entire sample.

Variable	Mean	St. Dev.	Median	Min	Max
ROA	1.11	11.88	1.10	−100.00	99.02
ROE	6.90	44.32	5.42	−291.21	263.90
LogA	4.48	0.87	4.51	0.00	7.00
DepA	0.06	0.07	0.05	0.00	0.73
DA	0.63	0.75	0.67	0.00	22.29
RA	0.47	1.57	0.15	−0.55	37.29
Price	39.33	7.74	37.73	22.77	55.34
Wind	0.71	0.45	1.00	0.00	1.00
Solar	0.11	0.32	0.00	0.00	1.00
Hydro	0.09	0.29	0.00	0.00	1.00
Fossil	0.09	0.28	0.00	0.00	1.00
Public	0.08	0.28	0.00	0.00	1.00
Private	0.86	0.35	1.00	0.00	1.00
Partner	0.06	0.23	0.00	0.00	1.00
DE	0.54	0.50	1.00	0.00	1.00
DK	0.07	0.25	0.00	0.00	1.00
FI	0.08	0.27	0.00	0.00	1.00
LT	0.01	0.08	0.00	0.00	1.00
PL	0.14	0.35	0.00	0.00	1.00
SE	0.16	0.37	0.00	0.00	1.00

– β_k represents the parameter for kth independent variable,
– α_i is individual-specific effect for the firm i that does not vary across time,
– $\varepsilon_{i,t}$ is the error term which assumes different values for each firm at each point in time.

Panel data provide statistical information on each research unit over a period. The combination of cross-sectional data and time series increases the number of observations, thus providing more information on the phenomenon being studied. Combining cross-sectional and time series observations allows for the identification and measurement of effects that cannot be observed on typical cross-sectional data or typical time series (Baltagi, 2005). In particular, panel data make it possible to distinguish the individual effects from the effects caused by external factors. It becomes possible to control the influence of the individual, internal differentiation of entities. In the case of panel data, FE and RE models are most often used. Both have strengths and weaknesses.

FE models constitute an appropriate specification if the research process focuses on a selected group of entities, and the conclusions resulting from the study are limited only to the examined units. They are most often used for the so-called long panels with a small number of entities and a long test period. FE models are based on the assumption that the differences between the research units can be represented by different values of the constant in the model. RE models are appropriate if the panel is a sample from which conclusions are drawn for the entire population. Then, it is assumed that the group effect is an implementation of a random variable (Baltagi, 2005).

The relatively large number of companies in our panel and a short time series suggest that the RE model was more appropriate for analysis in our study. Furthermore, our specification includes variables that are constant over time. Parameters for these variables cannot be estimated for the FE model. Nevertheless, we decided to estimate both the RE and FE models. This approach is often found in the literature to check the robustness of the results, especially when the signs of the estimated time-varying parameters and their statistical significance are more important for the inference than their exact values (Ruggiero and Lehkonen, 2017; Schabek, 2020). We used in the estimation robust standard errors adjusted for clusters. We also considered the pooled ordinary least square regression (OLS) approach using clustered standard errors, however, the F-test and the Breusch–Pagan test indicated that the FE models and RE models are more appropriate.

In the initial phase of the research, we also considered the inclusion of the dynamic generalized method of moments (GMM) models proposed by Arellano and Bover (1995) and Blundell and Bond (1998), which are sometimes used to assess the financial performance of energy producers (Morina et al., 2021). These models assume a persistence of financial performance. In our case, however, it was not possible to develop a model with an appropriate specification because the dynamic effect was insignificant. This could be due to an unbalanced panel with a relatively large number of young companies and thus a short time series. The results of our study are presented in the next section.

4. Results and discussion

This section presents an analysis of the company-specific and country-specific factors affecting the ROA and ROE of renewable energy producers. In our sample, ROA showed lower values and lower variability (mean 1.11%, standard deviation 11.88 pp.) than ROE (mean 6.90%, standard deviation 44.32 pp.). For ROE, outliers were also more frequent. The analysis of the average values over time shows that, in 2011–2019, the ROA of the renewable energy producers in our study followed an upward trend, as opposed to the ROA of the fossil energy producers (see Fig. 1). In the case of average ROE, we observed an upward trend for the hydroelectric

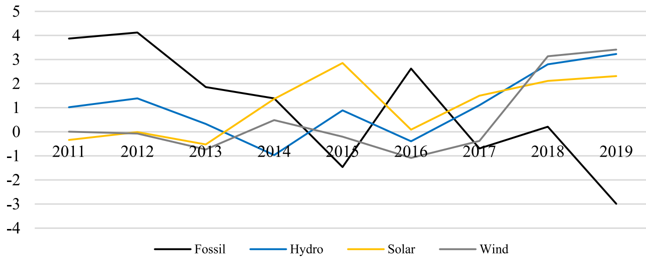

Fig. 1. Average ROA of energy producers in the research sample in 2011–2019.

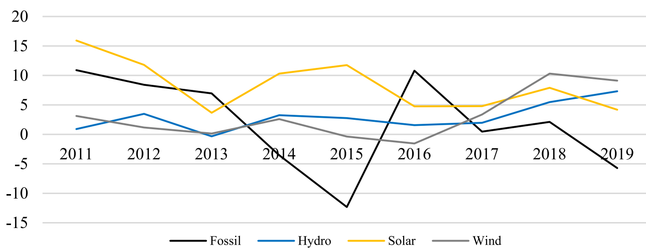

Fig. 2. Average ROE of energy producers in the research sample in 2011–2019.

and wind energy producers. In the case of solar energy producers, we saw stabilization. The average ROE of fossil energy producers was in a downward trend (see Fig. 2). This is partially consistent with the finding reported by Schabek (2020) who pointed to the increase in ROE of renewable energy producers and the decline in ROE of conventional energy producers in 2014–2017 in emerging countries. However, his observations only considered hydroelectric and solar energy producers. In the case of the Baltic Sea Region, the increase in the average ROE of the solar energy producers is not as great. However, the average ROE of the wind energy producers has been growing dynamically since 2016.

We initially estimated the model for a sample of both renewable and fossil fuel producers to determine if they differ in financial performance (see Table 4). The adjustment of the models to empirical data is not high. However, we do not consider this to be a limitation of the method because, in this study, the statistical significance of individual parameters is more important than the adjustment to empirical data, and this research is explanatory, not predictive. RE models generally maximize *between* R^2 and FE models maximize *within* R^2. Overall, RE models better explain both ROA and ROE.

The estimated model indicates that *DepA* has a significant impact on the dependent variables. The increase in *DepA* reduces both ROA and ROE. This relationship is very clear and in line with the work of Neves et al. (2019), which used a dynamic model to analyze electricity sector companies in Portugal.

A similar relationship occurs in the case of *DA*. Thus, a higher level of financial leverage and an increase in risk reduce the financial performance of energy producers in the short term. This is consistent with the results of Ruggiero and Lehkonen (2017), who used a similar methodology, but contradictory to the results of Morina et al. (2021), who obtained a statistically insignificant value of the parameter for dynamic and RE models and a positive value for the pooled estimation. Schabek (2020) obtained partially consistent results, because, in that study, the risk parameter was statistically significant and negative in the ROA models, but not significant in the case of ROE.

In the analyzed model, the variable parameters indicating the type of renewable energy were not significant at any of the standard significance levels; consequently, the producers of wind, solar, and hydro energy were not more financially efficient than the producers of energy from fossil fuels. This contradicts (Schabek, 2020) results, which indicated the higher efficiency of solar and wind power producers. This finding is consistent with Tomczak's (2019) results, which showed that there was no statistical difference in the financial performance of companies using RES and those only producing energy from fossil fuels (that study's sample included firms from the Baltic countries and Central Europe in 2008–2017). However, the parameters of our model indicate that private limited companies and partnerships achieve higher ROA than public limited companies. A similar, but weaker, dependence occurs for private limited companies and public limited companies in the case of ROE. This is in line with the work of Schabek (2020), which reported a lower financial performance for public limited companies in emerging countries, but it partially contradicts the findings reported in Feng et al. (2018), which argued that companies with a high proportion of traded equities exhibit better corporate governance and higher returns than companies with a low proportion of traded equities.

Our model shows that the price of electricity may be one of the main factors influencing the financial performance of renewable energy producers. In the case of the sample including conventional energy producers, the models show the impact of *Price* on both ROA and ROE. We also observed significant differences in the financial performance of energy producers between countries. To determine the impact of *Price* and the heterogeneity of countries on ROA and ROE only for renewable energy producers, we estimated the model parameters, excluding fossil energy firms. The results are presented in Table 5.

The observed dependencies are also important in the case of the sample only limited to producers of renewable energy. The price of energy has an impact, especially on ROE. There are still relationships between the country dummy variables and both ROA and ROE. German and Danish companies achieved statistically higher ROA (Polish companies were the reference). In turn, Swedish companies showed a lower ROA. However, in the case of ROE, higher performance was achieved by the Danish companies. The Swedish companies had lower efficiency than the other studied companies.

The analysis of the variability over time showed an increase in average ROA and average ROE for renewable energy producers in the last years of the period under study. This may be due to policy changes related to the signing of the Paris Agreement. To check the robustness of the results over time, we estimated the RE models for ROA and ROE in the 2011–2015 and 2015–2019 sub-periods. The results are presented in Table 6.

The results obtained earlier for *DepA* and *DA* were confirmed regardless of the considered sub-period. However, the impact of some of the remaining factors changes in the sub-periods. The electricity price affected the ROA and ROE of the renewable energy producers, especially in 2015–2019. We believe that the performance of energy producers increasingly depends on this factor. In 2011–2015, the wind and solar energy producers achieved significantly higher ROA than the hydroelectric power producers (in the case of ROE, only the solar energy producers differed significantly from the hydroelectric power producers). However, in 2015–2019, this relationship was no longer visible. There were also changes in the performance of companies from specific countries. In 2011–2015, the performance of the companies did not differ significantly from the reference country. In 2015–2019, the German and Danish companies achieved a significantly better performance than the other countries in terms of both ROA and ROE.

In our models, the company size parameter (*LogA*) was only significant for the FE models in the case of ROA. Most previous studies have shown this factor to be significant, but these studies did not include the depreciation to total assets ratio (Morina et al.,

Table 4
Determinants of financial performance of the entire sample.

Variable	ROA				ROE			
	RE		FE		RE		FE	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Const.	−1.26	0.91	−31.36	0.18	39.25	0.36	−1.86	0.97
LogA	0.34	0.86	9.16	0.07	−9.23	0.16	1.36	0.89
DepA	−63.32	0.00	−63.80	0.00	−147.55	0.00	−134.75	0.00
DA	−14.11	0.00	−21.21	0.00	−18.75	0.04	−24.68	0.03
RA	0.88	0.40	2.51	0.23	9.69	0.22	13.08	0.24
Price	0.11	0.04	0.11	0.05	0.43	0.06	0.46	0.05
Wind	2.44	0.43	–	–	−5.90	0.74	–	–
Solar	2.41	0.50	–	–	6.90	0.72	–	–
Hydro	−2.66	0.37	–	–	−20.52	0.29	–	–
Private	4.50	0.01	–	–	16.64	0.07	–	–
Partner	5.31	0.04	–	–	16.81	0.18	–	–
DE	6.08	0.00	–	–	9.39	0.17	–	–
DK	3.41	0.15	–	–	33.17	0.06	–	–
FI	1.67	0.30	–	–	−4.83	0.65	–	–
SE	−3.89	0.04	–	–	−14.69	0.07	–	–
Within R^2	0.25		0.28		0.09		0.09	
Between R^2	0.12		0.00		0.17		0.02	
Overall R^2	0.18		0.03		0.12		0.04	
Obs.	1241		1241		1094		1094	
Groups	270		270		244		244	
F-test	$F(260{,}966) = 3.07$ p-value = 0.00				$F(234{,}845) = 4.24$ p-value = 0.00			
Breusch–Pagan test	$LM = 62.76$ p-value = 0.00				$LM = 83.86$ p-value = 0.00			
Hausman test	$\chi^2(5) = 120.13$ p-value = 0.00				$\chi^2(5) = 11.93$ p-value = 0.04			

Note: This table presents the results of the ROA and ROE panel model estimation for the entire sample. *Fossil, Public,* and *PL* variables are not presented as they are reference groups. The *LT* variable is omitted due to the small number of observations and collinearity. RE stands for random effects and FE stands for fixed effects. Cluster–robust standard errors were used in the estimation. The F-test, Breusch–Pagan test, and Hausman test were performed for RE models without time-invariant dummy variables.

Table 5
Determinants of financial performance for the renewable energy producers.

Variable	ROA				ROE			
	RE		FE		RE		FE	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Const.	−11.01	0.31	−34.14	0.15	−15.62	0.67	−14.87	0.77
LogA	1.62	0.45	10.03	0.05	−3.13	0.64	2.75	0.79
DepA	−57.98	0.00	−58.85	0.00	−125.44	0.01	−112.67	0.04
DA	−14.47	0.00	−21.84	0.00	−15.77	0.09	−20.06	0.09
RA	0.85	0.41	2.44	0.23	9.91	0.22	12.91	0.24
Price	0.11	0.05	0.11	0.07	0.53	0.03	0.58	0.02
Wind	4.11	0.01	–	–	6.87	0.54	–	–
Solar	4.26	0.04	–	–	20.12	0.17	–	–
Private	6.11	0.00	–	–	22.73	0.04	–	–
Partner	6.89	0.01	–	–	21.75	0.12	–	–
DE	7.05	0.00	–	–	11.58	0.14	–	–
DK	4.42	0.07	–	–	37.73	0.04	–	–
FI	1.53	0.41	–	–	−5.01	0.67	–	–
SE	−3.92	0.06	–	–	−15.14	0.05	–	–
Within R^2	0.24		0.27		0.08		0.08	
Between R^2	0.12		0.00		0.14		0.02	
Overall R^2	0.17		0.03		0.10		0.03	
Obs.	1125		1125		983		983	
Groups	250		250		224		224	
F-test	$F(241{,}870) = 2.86$ p-value = 0.00				$F(215{,}754) = 4.37$ p-value = 0.00			
Breusch–Pagan test	$LM = 41.74$ p-value = 0.00				$LM = 70.30$ p-value = 0.00			
Hausman-test	$\chi^2(5) = 111.22$ p-value = 0.00				$\chi^2(5) = 10.54$ p-value = 0.06			

Note: This table presents the results of the ROA and ROE panel model estimation for a sample of renewable energy producers. *Hydro, Public,* and *PL* variables have not been presented as they are reference groups. The *LT* variable was omitted due to the small number of observations and collinearity. RE stands for random effects and FE stands for fixed effects. Cluster–robust standard errors were used in the estimation. The F-test, Breusch–Pagan test, and Hausman test were performed for RE models without time-invariant dummy variables.

2021; Ruggiero and Lehkonen, 2017; Schabek, 2020). Zimon and Zimon (2020) also found that the scale effect allowed companies operating in the sector related to renewable energy to increase profits and it had a positive effect on their financial liquidity (that study's sample only covered the RES producers from Poland). To see if a model without a *DepA* variable would be a better solution, we removed this variable. The results of estimated models are presented in the Appendix (Table A.3). Models that do not consider the *DepA* indicate the significance of the company's size. However, models with *DepA* better describe the volatility of ROA and ROE. Therefore, while we believe that the size of a company's assets may have a positive impact on the ROA and ROE

Table 6
Determinants of financial performance of renewable energy producers in sub-periods.

Variable	ROA				ROE			
	2011–2015		2015–2019		2011–2015		2015–2019	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Const.	−8.64	0.36	1.67	0.91	−3.70	0.93	23.22	0.59
LogA	2.34	0.25	−2.65	0.32	−1.39	0.85	−13.71	0.09
DepA	−54.10	0.00	−66.56	0.00	−201.32	0.00	−113.23	0.03
DA	−7.24	0.01	−15.25	0.00	−9.35	0.41	−25.25	0.07
RA	−0.11	0.90	1.60	0.41	12.52	0.13	10.29	0.29
Price	0.01	0.88	0.28	0.00	0.31	0.25	0.74	0.00
Wind	3.60	0.02	3.34	0.10	14.65	0.38	−3.67	0.63
Solar	4.17	0.02	2.95	0.26	34.80	0.07	1.72	0.88
Private	2.38	0.17	7.54	0.00	5.52	0.80	34.81	0.00
Partner	3.15	0.34	7.88	0.00	21.28	0.40	30.03	0.04
DE	3.56	0.09	9.47	0.00	3.97	0.74	23.90	0.00
DK	−3.60	0.49	6.65	0.02	49.68	0.11	47.86	0.02
FI	−0.38	0.86	3.30	0.12	−0.90	0.94	1.33	0.91
SE	−4.14	0.08	−1.77	0.43	−21.53	0.06	−12.74	0.21
Within R^2	0.17		0.32		0.10		0.12	
Between R^2	0.26		0.18		0.18		0.22	
Overall R^2	0.12		0.24		0.11		0.15	
Obs.	522		738		466		638	
Groups	177		213		159		190	

Note: This table presents the results of the ROA and ROE panel model estimation for a sample of the renewable energy producers for the 2011–2015 and 2015–2019 sub-periods. *Hydro, Public,* and *PL* variables have not been presented as they are reference groups. The *LT* variable was omitted due to the small number of observations and collinearity. Cluster–robust standard errors were used in this random effects panel estimation.

of renewable energy producers, the depreciation to total assets ratio is a more important factor.

5. Conclusions

In addition to higher mobility, economic grow, and industrial activity it is expected that a higher level of energy production will be required in Europe to meet energy demand. Fighting greenhouse gas emission requires actions to reduce energy usage and increase the proportion of RES in the total energy production. Managing this energy transformation process requires significant financial outlays, thus financial performance is crucial; it enables energy producers to make future energy transformation decisions. At the same time, it is essential for the energy industry to ensure that energy prices are competitive. For these reasons, we analyzed the impact that energy wholesale prices and the financial indicators for energy producers have on their financial performance. Our research provides more information about the differences between returns generated by energy producers in the Baltic Sea Region.

The significant drop in the cost of new RES installations could be one of the reasons why many new enterprises decided to enter the market and invest capital in green energy production. In the analyzed timeframe, there was an increase in the number of companies registered as energy producers. This shows that there is interest in investing in new ventures based on renewable energy production. A variety of factors must be considered when choosing the optimal source of renewable energy; however, the study's results provide evidence that the financial performance achieved by RES producers does not differ significantly from the financial performance of conventional energy producers (which is inconsistent with the H1 hypothesis). However, the wind and solar energy producers achieved significantly higher ROA than the hydroelectric power producers, especially in 2011–2015. Thus, the H2 research hypothesis may be positively verified.

One of the important factors for potential investment-related decisions is that private limited companies demonstrate higher financial performance than public limited companies (which supports the H3 hypothesis). Moreover, the size of company's assets has an inconclusive effect on its financial performance. We believe that, in the case of producers' financial performance, the depreciation to total assets ratio is a more important factor than the size of a company's assets. It is useful to combine these conclusions with the findings reported in Nicolli and Vona's (2019) study, which showed that decreasing the monopolistic position of a few big players in energy production market in favor of various types of actors has a positive effect on RES development. Firms with high levels of assets are often state-owned. This can lead to high market shares for energy production, while negatively affecting financial efficiency. Large state-owned enterprises are often characterized by negative features, for example, an increase in bureaucratic procedures that may eliminate the positive effects caused by the economies of scale. We believe that further research on the impact of the size of the assets on the financial performance of renewable energy producers is necessary.

In conclusion, the financial performance of the analyzed enterprises in the obtained dataset confirmed the H4 hypothesis, about the relationship between energy wholesale prices and the financial results of energy producers. This situation could lead to the conclusion that energy transformation is partly financed by energy consumers. The danger of such an interpretation is that further energy transformation will require energy prices to achieve a high level, which means a higher cost for individuals and a lower level of competitiveness for the economy.

Countries use a wide range of incentives that have been developed to build a framework for beneficial energy transformation (Nicolli and Vona, 2019). Our study's results show a significant difference in the financial performance of energy producers located in different countries. Based on this outcome, further studies are needed to determine the country-specific factors that caused the higher financial performance of the energy producers in Denmark or Germany and the significantly lower financial performance of the energy producers in Sweden. The results show the need for further support for renewable energy technologies to improve their competitiveness and their ability to replace fossil-based technologies in line with climate policy objectives. Capital behaves in accordance with the market assessment of the relationship between risk (investment in new generation capacity) and potential profit resulting from the sale of energy.

In order to reach further targets for the share of RES in energy production, policymakers need to provide a framework in which the beneficiaries of any increase in energy prices are mainly RES producers. In the process of commercialization and through economies of scale, individual RES technologies can achieve decreasing cost of energy production (measured by the levelized cost of energy, LCOE) and can operate on fully commercial terms (Timilsina, 2021).

There is wide range of options for other future research regarding the subject discussed in this paper. Therefore, we strongly encourage other researchers to follow and develop the research area, especially by adding more country-specific factors to the ones used in our study. As the energy wholesale price was one of the indicators considered to be crucial for the financial performance of energy producers, different types of data should be analyzed to obtain new findings and set the direction for the future path of RES development. As auctions have become one of the crucial elements to support RES (del Río and Kiefer, 2021), the auction results and the effectiveness of the support in terms of the financial performance of enterprises participating in the auctions could shed new light on the obtained results.

This study has some limitations. The main limitation is the unbalanced data panel, which includes companies in the initial phase of their operations. Thus, the study also may include entities that have not yet achieved their full performance potential. However, we decided that removing these companies from our research sample could significantly distort the results. An additional limitation of the research is the lack of some financial information of analyzed companies. Therefore, further research may consider these limitations.

CRediT authorship contribution statement

Łukasz Dopierała: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Magdalena Mosionek-Schweda:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Tomasz Laskowicz:** Conceptualization, Formal analysis, Investigation, Resources, Writing – original draft, Visualization. **Daria Ilczuk:** Conceptualization, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing.

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.

Data availability

The authors do not have permission to share data.

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Appendix

See Tables A.1–A.3.

Table A.1
Assets of the companies in the research sample (in thousands of EUR).

Legal form	Mean	Standard deviation	Minimum	25th percentile	Median	75th percentile	Maximum
Partnerships	213 192.3	450 223.1	28.1	12 309.3	30 763.0	95 407.1	2 019 198.0
Private limited companies	115 509.2	303 615.6	1.0	13 092.3	29 333.2	69 504.5	2 455 385.0
Public limited companies	740 507.5	1 777 368	63.4	35 211.8	131 715.6	554 980.7	9 887 486.0

Table A.2
Correlation between independent variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LogA (1)	1.00																
DepA (2)	−0.12	1.00															
DA (3)	−0.20	0.02	1.00														
RA (4)	−0.14	0.00	0.07	1.00													
Price (5)	−0.11	−0.09	0.06	0.06	1.00												
Wind (6)	−0.15	0.13	0.09	−0.06	−0.08	1.00											
Solar (7)	−0.23	0.00	0.25	−0.00	0.039	−0.50	1.00										
Hydro (8)	0.13	−0.17	−0.24	0.03	0.01	−0.54	−0.14	1.00									
Fossil (9)	0.33	−0.02	−0.10	0.10	0.09	−0.46	−0.11	−0.13	1.00								
Public (10)	0.19	−0.02	−0.26	0.01	0.00	−0.30	−0.10	0.25	0.29	1.00							
Private (11)	−0.15	0.00	0.20	−0.02	−0.01	0.21	0.10	−0.19	−0.22	−0.84	1.00						
Partner (12)	−0.02	0.02	0.05	0.03	0.01	0.09	−0.01	−0.06	−0.07	−0.07	−0.48	1.00					
DE (13)	−0.21	0.03	0.33	0.13	0.04	−0.19	0.32	−0.01	−0.02	−0.01	0.04	−0.05	1.00				
DK (14)	−0.03	0.13	−0.14	−0.03	−0.10	0.14	−0.06	−0.08	−0.07	0.29	−0.30	0.08	−0.20	1.00			
FI (15)	0.04	−0.10	−0.06	−0.07	0.06	−0.11	−0.07	0.19	0.04	−0.13	0.05	0.13	−0.36	−0.08	1.00		
PL (16)	0.13	−0.08	−0.02	−0.00	0.22	0.01	−0.14	−0.09	0.24	0.14	−0.14	0.04	−0.37	−0.08	−0.15	1.00	
SE (17)	0.13	0.05	−0.27	−0.08	−0.23	0.24	−0.19	−0.02	−0.17	−0.14	0.18	−0.11	−0.52	−0.11	−0.20	−0.21	1.00

Note: The *LT* variable is omitted due to the small number of observations.

Table A.3
Determinants of financial performance of renewable energy producers, without considering the level of assets amortization.

Variable	ROA				ROE			
	RE		FE		RE		FE	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Const.	−25.62	0.00	−40.24	0.00	−53.18	0.01	−49.56	0.06
LogA	3.88	0.02	9.78	0.00	3.51	0.29	8.62	0.13
DA	−10.55	0.00	−17.33	0.00	−8.06	0.29	−12.40	−12.40
RA	0.58	0.16	0.49	0.36	3.52	0.08	3.41	0.10
Price	0.14	0.01	0.15	0.01	0.50	0.02	0.54	0.01
Wind	1.31	0.33	–	–	0.03	0.99	–	–
Solar	2.24	0.18	–	–	15.27	0.24	–	–
Private	6.31	0.00	–	–	23.04	0.02	–	–
Partner	6.75	0.00	–	–	20.93	0.09	–	–
DE	6.43	0.00	–	–	16.08	0.01	–	–
DK	3.22	0.16	–	–	36.98	0.03	–	–
FI	0.32	0.81	–	–	−4.55	0.68	–	–
LT	5.47	0.00	–	–	15.63	0.00	–	–
SE	−3.41	0.04	–	–	−11.27	0.06	–	–
Within R^2	0.12		0.14		0.03		0.03	
Between R^2	0.08		0.00		0.10		0.01	
Overall R^2	0.08		0.01		0.07		0.00	
Obs.	1330		1330		1159		1159	
Groups	272		272		250		250	
F-test	$F(263,1054) = 2.49$ p-value = 0.00				$F(241,905) = 4.18$ p-value = 0.00			
Breusch–Pagan test	$LM = 47.40$ p-value = 0.00				$LM = 89.79$ p-value = 0.00			
Hausman-test	$\chi^2(4) = 109.66$ p-value = 0.00				$\chi^2(4) = 8.93$ p-value = 0.06			

Note: This table presents the results of the ROA and ROE panel model estimation for a sample of the renewable energy producers. *Hydro, Public,* and *PL* variables have not been presented as they are reference groups. RE stands for random effects and FE stands for fixed effects. Cluster–robust standard errors were used in the estimation. The F-test, Breusch–Pagan test, and Hausman test were performed for RE models without time-invariant dummy variables.

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OFFSHORE WIND ENERGY POTENTIAL IN EUROPE: A FORECAST OF INSTALLED CAPACITIES AND COSTS

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Abstract. Offshore wind installation targets of EU Member States were considered. The analysis of the national plans showed that EU target can be exceeded, provided the appropriate resources are committed: offshore space, capital and supply chain. Spatial plans were analyzed and the need for the number of installed turbines was determined. The capital needs to cover the costs of investment outlays were analyzed. A projection for the number of wind turbines installed in Europe up to 2030 was presented. The analysis identified how the resources committed to the targets will contribute to: the generation of electricity, the reduction in greenhouse gas emissions and contribution to improving Europe's energy independence.

Keywords: decarbonization, energy, energy transformation, European Union, Green Deal, maritime spatial plan, offshore wind.

Introduction

Offshore wind energy is one element of the energy transition in Europe (EC, 2019). The development of this form of energy production has been ongoing for 20 years, dictated primarily by the demand for access to cheap renewable energy. Already in 2009, the European Parliament and the Council of the European Union (EU) adopted Directive 2009/28/EC, which set a target of a minimum 20% share of renewable energy consumption by 2020 (EP, 2008). By signing the Paris Agreement in 2016, the EU committed to increase the share of renewable energy to 32% by 2030 and reduce greenhouse gas emissions (UN, 2015). However, after 2022, when the European energy industry was shaken by the disruption of energy supplies, EU Member States (MS) changed their approach to energy (Sturm, 2022). Even greater importance has been given to the European energy transition, which, in addition to its mission to reduce greenhouse gas emissions, also carries the possibility of increasing European energy independence (Kuzemko et al., 2022). According to the EU's Green Deal policy, decarbonization is one of the primary goals of the Energy Transition. Other goals set out in the Green Deal concern rebuilding economic potential after the COVID pandemic and ensuring the competitiveness of European industry, based on green technologies (EC, 2019). The outbreak of the energy crisis in Europe exposed its dependence on Russian fossil fuels. In response to energy supply constraints and price volatility, the European Commission prepared the REPowerEU program, which aims to make Europe less dependent on Russian fossil fuel imports while increasing the importance of renewable energy sources (EC, 2022; Lonergan et al., 2022).

As a result of the disruption to the existing European energy structure, the offshore wind installation targets set by individual EU MS have changed. Many countries have decided to enlarge their plans for installing offshore wind farms. This has resulted in challenges that need to be addressed in order to successfully meet the targets for offshore wind farm installations.

There are valuable investment-specific multi-criteria assessment studies in the literature that assess the development potential of a given offshore wind farm project based on a number of factors (Ziemba, 2022). There are also sustainability indices that allow the assessment of progress towards achieving sustainable development in relation to policies, regions or nations (Ziemba et al., 2022). To the author's knowledge, there is a lack of up-to-date research about how to place the European offshore wind development plans in the broad context of the post-war energy transition in Europe, i.e., within a framework of spatial, financials and manufacturing aspects. This article analyzes the direction of offshore wind energy development in Europe, taking into account selected resources needed to meet the objectives of offshore wind farm installations: the marine space allocated for energy development, according to the maritime spatial plans; capital to cover necessary expenditures; and supply chains able to deliver components in a timely manner and at acceptable prices.

The development of offshore wind energy is one of the elements that increases the pressure on the marine ecosystem. In order to manage maritime space in a sustainable and efficient way, the EU has adopted a directive on the need to plan maritime space taking into account the many activities taking place at sea, including the development of renewable energy sources (EU, 2014). Efforts to plan appropriately for the use of marine space for activities that may be mutually exclusive cannot completely eliminate trade-offs (Püts et al., 2023), so access to marine space is a condition for offshore wind energy development. Spatial plans adopted by EU MS provide the basis for the offshore wind farm development process and allow the potential for electricity generation to be estimated.

Figure 1 presents the two sides of the offshore wind farm process: the resources required for the investment and the expected outcomes resulting from the construction of an offshore wind farm.

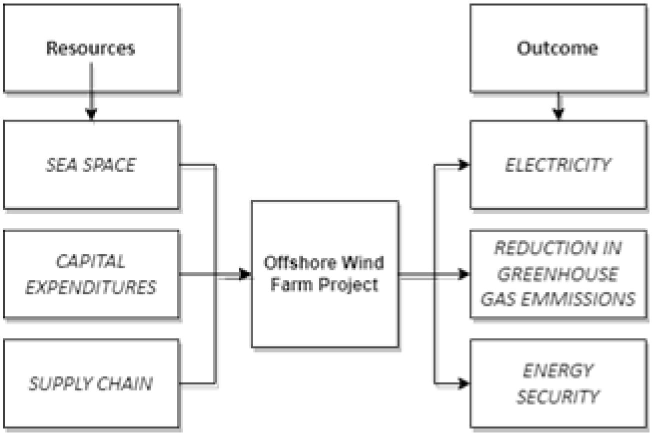

Figure 1. Selected resources required for offshore wind farms and expected investment outcomes

The parameters investigated were attempted to be selected in such a way as to present a maximally objective and up-to-date picture of the current state of offshore wind energy development in Europe, based on available data and information. It should be acknowledged that an undoubted research difficulty is the attempt to juxtapose the historical data available on the market, with planned development of the sector. Analysis of data on existing wind farms is used to prepare technical assumptions (distance from land, depth of foundation, type of foundation) for future projects in individual EU MS. The purpose of this article is to assess the resources for future wind farm development and to forecast its impacts that will materialize before 2030. However, the offshore wind sector is subject to dynamic changes that are caused by a number of factors, such as changes in technology, developments in the supply chain, economic changes, and other developments. The medium-term forecast up to 2030 coincides with EU targets and country-specific declarations for the realization of wind farm installations. At the same time, there is enough data on the expected dynamics of change in this period to make realistic assumptions and, based on these, to come up with a forecast based on concrete numbers.

This paper therefore seeks to identify the most important aspects of offshore wind development in the EU and the UK that can be analyzed in a measurable way and, based on the data collected, to determine the potential for installing the assumed generation capacity within a given timeframe. The paper takes into consideration the required commitment of capital and supply chain that will be needed to meet the targets, the availability of maritime space, and the possible obstacles that may cause difficulties in the implementation of current European energy policy.

The research in this paper is guided by two scientific questions, that delimit the scope of the analysis:

1. What resources are required to meet the goals of installing offshore wind power in Europe by 2030, and how are they to be measured?
2. How to measure the importance of offshore wind energy for the European energy transition up to 2030?

Chapter one presents the current importance and status of offshore wind energy development. The assumptions and calculation methods used, including projections, are presented in the methodology chapter. The results of the analyses and data compilation are presented next, with emphasis on the data on the assumed installed capacity and the amount of energy produced per year, and the expected results in terms of greenhouse gas emissions reduction are computed. In the chapter presenting the results, data on the ability to meet demand for offshore wind farm components (turbines) against planned demand up to 2030 is presented. The final part contains a discussion and proposal on the conclusions that can be drawn from the analyzed data.

Current role of offshore wind energy and potential for development

Currently, EU MS and United Kingdom (UK) have a total of around 32 GW of installed offshore wind farm capacity provided by approximately 6,300 turbines. The European leader in offshore wind farm development in Europe has for years been the UK, which has 13.7 GW of installed wind farm capacity provided by more than 2,700 operating turbines. The 11 EU MS that have managed to start generating electricity from offshore wind farms have 3,549 turbines with a total capacity of around 18 GW.

The EU target for the installation of offshore wind farms is currently set at 60 GW by 2030 and 300 GW by 2050 (EC, 2020). The EU identifies the capacity to install offshore wind farms as crucial to achieving the targets set in the European Green Deal. In order to accelerate the development of this energy sector, initiatives dedicated to two seas have been set up: the North Seas Energy Cooperation (NSEC) and the Baltic Energy Interconnection Plan (BEMIP). Individual EU countries set their own targets for the installation of offshore wind farms, which in total exceed the common EU target. Table 1 shows the targets of individual EU MS and UK that still seems to play an important role in achieving the final outcome of the European energy transformation and climate neutrality.

Table 1. Current status of offshore wind energy in EU MS and UK and adopted installation target by 2030

Country	Number of turbines installed (units) at the end of 2022	Actual installed capacity (GW) at the end of 2022	Planned capacity target by 2030 (GW)
Belgium	399	2.23	5.8
Denmark	648	2.47	12.9
Finland	11	0.04	2.0
France	81	0.48	5.2
Germany	1,556	8.11	30.0
Ireland	7	0.03	7.0
Italy	10	0.03	0.9
Netherlands	739	4.53	21.0
Portugal	3	0.03	9.0
Spain	1	0.05	3.0
Sweden	80	0.19	4.0
Poland	0	0.00	5.9
Lithuania	0	0.00	1.4
Latvia	0	0.00	0.4
Estonia	0	0.00	1.2
Romania	0	0.00	0.5
Greece	0	0.00	2.0
Total at national level of EU Member States	3,549	18.18	111.2
European Union	**3,549**	**18.18**	**60.0**
United Kingdom	2,766	13.70	50.0

Source: modified after Díaz and Guedes Soares (2020); Musial et al. (2022).

After the outbreak of war in Ukraine, in August 2022, eight EU Baltic Sea countries signed a joint declaration in Marienborg to install 20 GW of capacity in the Baltic Sea by 2030 (EU BSG, 2022). The associated countries have also declared a plan, based on the NSEC initiative, to install 76 GW of capacity by 2030 and 260 GW by 2050 (NSEC, 2022). Of the NSEC countries, Belgium, Denmark, Germany and the Netherlands may be the leaders in offshore wind development, having announced a plan to install 150 GW of capacity by 2050 (ED, 2022). The assumed targets for offshore wind farm installations announced by the three European agreements, independently of the target set by the European Commission, are summarised in Table 2.

The presented targets for the installation of offshore wind farms in EU MS, in addition to access to offshore space, also require supply chain capacity to access the products and services needed to meet the growing installation targets. While interest in the supply chain for renewables has been the subject of research for years (Wee et al., 2012), the study of the supply chain for offshore wind farms, does not appear to have been widely undertaken in the literature (Poulsen & Lema, 2017). This issue has received attention in recent years, due to the rapidly increasing installation pipelines of offshore wind farms, which require access to components at a specific time in order to effectively manage the supply chain (Irawan et al., 2018). One indicator for the supply chain is the number of wind turbines planned for installation by 2030, in order to estimate the scale of demand that developers with projects in Europe will submit in the coming years.

Table 2. Installation targets of offshore wind energy joint transnational agreements

Transnational Agreement	Signatory States	Actual installed capacity (GW) at the end of 2022	Planned capacity target 2030 (GW)	Planned capacity target 2050 (GW)
The Marienborg Declaration signed by BEMIP Members	Poland, Germany, Denmark, Sweden, Finland, Lithuania, Latvia, Estonia	2.6	20	–
The Esbjerg Declaration	Belgium, Denmark, Germany, the Netherlands	15.2	65	150
North Seas Energy Cooperation	Belgium, Denmark, Germany, Netherlands, France, Ireland, Luxembourg, Norway	15.8	76	260
European Union	**European Commission**	**18.18**	**60**	**300**

Source: EU BSG (2022); EC (2020); ED (2022); NSEC (2022).

Methods

The aim of this paper is to provide answers to the research questions posed, namely: 1. What resources are required to meet the goals of installing offshore wind power in Europe by 2030, and how are they to be measured? 2. How to measure the importance of offshore wind energy for the European energy transition up to 2030?

In order to find possible answers, appropriate research methods and data on offshore wind energy development in Europe were selected. Data on existing wind farms as well as individual governments' plans for offshore wind farm development over a specific timeframe, expressed in terms of so-called offshore wind farm installation targets, were used. The source of information on existing wind farms was the database from the 4C Offshore portal (4C Offshore, 2023). As the individual EU countries create their own policies for offshore wind farm development, so-called interim targets were used, whereby common target dates were set in order to be able to make projections for reduction in greenhouse gas emissions and the offshore spaces needed to be developed to meet the targets.

The possibility to develop offshore wind farms requires the availability of a significant amount of offshore space. As offshore wind energy grows, the average value of offshore space and the installed capacity of a single wind farm increases (Bilgili & Alphan, 2022). The selection of the offshore spaces that will enable the allocation of offshore wind farms lies within the scope of the maritime spatial plans prepared by individual countries (Zaucha et al., 2020a). The selection of space for the development of offshore wind farms is crucial in terms of the attractiveness of realizing investments in a given area, due to distance from the shore, windiness, water depth, distance from the installation port and service port (Przedrzymirska et al., 2021). When designating areas for the development of offshore wind farms, planners must take into account the need to limit other economic activities, such as fishing and other social and economic activity accompanying the addition of a new dimension to the maritime space (Ciołek et al., 2018; Zaucha, 2018). The preparation of maritime spatial plans requires taking into account multiple — often conflicting — interests and finding solutions that will most effectively realize them mutually (Zaucha et al., 2020b). The efficiency resulting from the construction of offshore wind farms in offshore spaces can be measured by the relation of the designated space to the expected renewable energy production, which influences decarbonization and increased energy security.

The maritime spatial plans of EU MS were analyzed. According to the analysis, the value of marine space designated for offshore wind farm development in the EU is 55,816 km^2. Table 3 presents the value of areas designated for offshore wind energy development together with the share of the given space form in the total value of the maritime spatial development plan in the exclusive economic zone of the country.

The countries' maritime spatial plans, which determine what space will be allocated for offshore energy development, were also analyzed. The maritime spaces designated for offshore wind energy development were reviewed on a European scale. The table does not include the offshore areas designated for offshore wind farm development in countries that have not yet adopted an offshore spatial plan.

Table 3. Areas designated for offshore wind power development

Country	Area designated for offshore wind farm development (km^2)	Offshore exclusive economic zone allocation for construction of offshore wind farms (%)
Belgium	519	15
Denmark	11,000	10
Finland	3,500	4.3
France	12,000	2.3–3.5
Germany	8,400	15
Ireland	1,000	0.2
Italy	No applicable maritime spatial development plan	–
Netherlands	3,400	5.9
Portugal	3,203	–
Spain	5,000	0.46
Sweden	1,400	1
Poland	3,600	12
Lithuania	644	9.4
Latvia	300	1
Estonia	1,850	5
Romania	No applicable maritime spatial development plan	–
Greece	No applicable maritime spatial development plan	–
European Union	**55,816**	

Source: EC (2023b).

In order to determine the potential assumed efficiency of offshore utilization, 87 European existing or planned offshore wind projects were analyzed. The analyzed projects were connected to the grid after 2019 or are planned to be connected to the grid before 2030. Consequently, projects with a total planned connection capacity of 113,913 MW, which have been or are planned to be built over an area of 19,728 km^2, were screened. The projects vary significantly in terms of the expected efficiency of installing offshore wind farm capacity in space; from 1.2 MW/km^2 (lowest space factor) to 18.8 MW/km^2 (highest space factor). This analysis covers the timeframe up to 2030 and therefore also applies to projects at an early stage of development, including potential installed capacity, in line with the set targets of the MS. On the basis of the analyzed data on project assumptions, the possibility of installing an average of 5.77 MW of capacity per 1 km^2 of offshore space in European marine waters was assumed. The maritime spatial plans of EU countries that have published such plans have also been analyzed.

The capital expenditure required for the construction of offshore wind farms was determined on the basis of the selected technology, using the offshore wind farm construction cost allocation model prepared by the UK Department for Business, Energy and Industrial Strategy (Freeman & Blanch, 2021). Different capital expenditures were assumed depending on the chosen foundation technology. The analysis covers projects using different types of foundations: bottom-fixed and floating. Fixed foundation technology (monopiles) was adopted as typical for wind farms installed in Europe by 2030 (Díaz & Guedes Soares, 2020), with the exception of: France, Portugal, Italy, Greece and Spain, which are focusing on the development of floating offshore wind. The following parameters were assumed for wind farms installed with monopiles in water depth up to 25 meters: distance from operations and maintenance port: 40 km; average wind speed at 100 meters above water level: 9.4 m/s and CAPEX is assumed €1992 per installed MW. When the wind farm is installed on water depths between 25 and 60 meters, the foundation technology might be monopile or jacket and the CAPEX is assumed as €2126 per installed MW.

The feasibility of floating offshore wind technology in Europe by 2030 was also taken into consideration. It was assumed that 100% of the planned installed capacity for France, Portugal, Spain, Greece and Italy will be using semi-submersible technology by 2030 and UK will add another 1.2 GW. This assumption is based on the countries offshore wind development strategy and their natural conditions, primarily water depth. This could result in 20,713 MW of new installed floating offshore wind in Europe by 2030. Average parameters for floating wind technology were assumed as following: water depth: 60 meters and above; distance from O&M port: 40 km; average wind speed at 100 meters above water level: 9.7 m/s.

Table 4. Assumptions for determining the amount of capital expenditure (CAPEX) depending on the technology adopted

Assumptions	**Bottom-fixed (Monopile)**	**Bottom-fixed (Monopile or Jacket)**	**Semi-submersible (Floating)**
Water depth	up to 25 m	between 25 and 60 m	above 60 m
Distance from O&M port	40 km	40 km	40 km
Turbine size	18 MW	18 MW	18 MW
CAPEX breakdown: (€000s/MW)			
Project development	96	98	134
Turbine	925	925	947
Tower	81	81	155
Support structure	203	254	715
Array cables	26	26	31
Installation	149	209	97
Transmission supply and installation	379	391	442
Construction phase insurance	43	46	58
Construction contingency	91	97	123
SUM	**1,992**	**2,126**	**2,702**

Source: own calculation based on information from Innovation Impact on Levelized Cost of Energy Model (Freeman & Blanch, 2021).

On the basis of the adopted technological assumptions, the amount of investment necessary to bear the costs of construction of offshore wind power plants was determined, with a breakdown into individual components. The development of floating offshore wind technology was supposed to occur mainly in France, Portugal, Spain, Italy and Greece (water depth of more than 60 metres). In the other countries, the predominance of the use of monopiles or jackets to attach wind towers the seabed was presumed. Table 4 presents the financial data used for estimation of the construction costs of offshore wind power plants.

The increase in installation targets for offshore wind farms requires supply chains to adapt to meet new requirements. The number of turbines installed has been considered as one of the indicators relevant to shaping the supply chain for offshore wind in the EU and the UK. In order to estimate the demand for the number of turbines installed in Europe, a forecast of the growth in the generation capacity of a single turbine was executed (Bilgili & Alphan, 2022). An increase in the value of the installed capacity of a single turbine also implies a higher generation potential per km^2 of marine space (Fig. 2). Projections of installed turbine capacity were based on contracts concluded by offshore wind farm developers with turbine manufacturers and announcements by developers regarding the assumed installed turbine capacity.

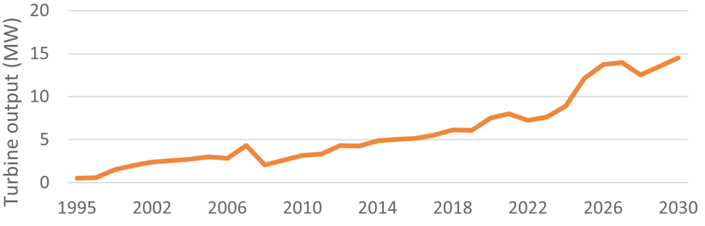

Figure 2. Average installed capacity per turbine in European offshore wind farms (EU and UK)
Source: modified after Bilgili and Alphan (2022).

Energy production from offshore wind farms depends on factors such as nominal power, hub height, rotor diameter, and windiness (Arrambide et al., 2019). Limitations in turbine availability (due to maintenance and breakdowns) and losses at different stages of energy transmission affect the energy actually delivered to the system. Table 5 presents the assumptions used to calculate the power generated from offshore wind farms installed in Europe. They are based on the information from the Innovation Impact on Levelized Cost of Energy Model (Freeman & Blanch, 2021).

Table 5. Assumptions made for the calculation of actual delivered electricity from offshore wind farms

Gross energy production	**4,906 (MWh/MW/year)**
Gross load factor	56%
Wind farm availability	95.6%
Aerodynamic array losses	6.1%
Electrical array losses	1.0%
Blockage effect	1.0%
Other losses	1.9%
Net load factor	48.3%

Source: Levelized Cost of Energy Model (Freeman & Blanch, 2021).

According to an assumed net load factor of 48.3%, 4,234 MWh is generated annually from every 1 GW of installed capacity of offshore wind farms.

Based on data on planned offshore wind farm installations, an analysis was made of the potential to reduce carbon emissions by changing the energy generation technology. The analysis was carried out in one of three possible scenarios depending on the original source of energy production to be replaced by offshore electricity generation. Data was taken from available studies, and emissions were assumed to be 16 gCO_2/kWhe for an offshore wind farm over its entire operating phase (including material generation and construction, operations and decommissioning phases) (Kaldellis & Apostolou, 2017). Assumptions for the value of carbon emission reductions are presented in the case of moving away from coal-fired, gas-fired and nuclear generation. Figure 3 shows the lifecycle carbon footprint for the compared power generation technologies: coal fired and natural gas-fired, nuclear, and offshore wind. According to the assumed values, offshore wind is the least carbon-intensive source of power generation among those analyzed, second only to onshore wind (Kaldellis & Apostolou, 2017).

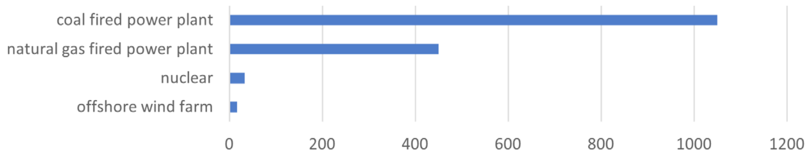

Figure 3. Comparison of the emissivity of electricity by generation source
Source: modified after Kaldellis and Apostolou (2017).

In line with the assumed difference in carbon intensity, a reduction greenhouse gas emissions was calculated in the case of replacement of electricity generation by offshore wind farms. In the case of replacement of electricity generation by offshore wind farms, a reduction of 4.38 Mt CO_2 per year was assumed for each gigawatt of installed capacity, which is a greater reduction than the International Energy Agency's figure of 3.5 Mt CO_2 per year (IEA, 2020). Similarly, based on the assumptions made, a reduction of 1.84 Mt CO_2 per year was calculated for the replacement of gas-fired power plants and 0.07 Mt CO_2 per year for the replacement of nuclear power plants. In order to obtain the results of the reductions in greenhouse gas emissions in the EU resulting from the installation of the assumed offshore wind farm capacities, a source substitution structure was assumed for the period 2019–2021, with the reduction in energy production coming most from gas-fired power plants (50%), nuclear power plants (35%) and, to the least extent, coal-fired power plants (15%) (Moore et al., 2022).

To determine the share of offshore wind energy in the EU energy mix, an increase in energy demand in the EU of 1% per year was assumed. According to Eurostat, electricity production in the 27 EU countries was 2.911 TWh in 2021 (Eurostat, 2023b). An average increase in energy production between 2022 and 2030 of 1% per year was assumed.

The construction of offshore wind farms makes it possible to achieve the energy transition and to reduce the carbon footprint of electricity generation in Europe. The construction of offshore wind farms requires a commitment of resources in the form of financial outlays and the designation of offshore space for the construction of offshore wind farms, as well as the capacity of the supply chain to ensure the availability of components for offshore wind farm installations (Freeman et al., 2019).

An area of 55,816 km^2 earmarked for offshore wind development could allow up to 323 GW of installed capacity to be realised, which would allow the EU target of installing 300 GW of offshore wind farms by 2050 to be surpassed. The designation of such areas for offshore wind energy development may therefore provide a rationale for assuming that the installation target for offshore wind energy in Europe might be surpassed as well. This is also indicated by the declarations of individual MS. The countries of the North Seas Energy Cooperation group have made a commitment to installing a total of 260 GW of offshore wind capacity by 2050, which is almost 87% of the EU target (EC, 2020; NSEC, 2022). Full utilization of the available offshore space requires a number of conditions to be met, among them: availability of capital, a supply chain capable of responding to market demand, available infrastructure, and many others.

To calculate the capital expenditure required to meet the installation targets for offshore wind turbines in each country, the capacity installation targets declared by each country were adopted. The cost of the capital expenditure was assumed in accordance with the assumptions presented in the methodology chapter. The capital expenditure was deemed to be €1992/MW installed capacity for bottom-fixed turbines in water depth up to 25 metres; €2126/MW in water depth between 25 and 60 metres, and 2702 €/MW capital expenditure for floating offshore-wind turbines (above 60 metres water depth). Based on the offshore wind auctions and water depths, the installation of floating-type turbines was assumed for France, Portugal, Spain, Italy, Greece and partly in UK. The amounts of capital expenditure (CAPEX) to meet the targets for installing offshore wind farms by 2030 are shown in Table 6.

Table 6. Projected investment in offshore wind farm projects by country

Country/Area	Planned capacity yet to be installed in order to meet the 2030 target (MW)	Forecasted installation cost (€ per MW) based on the technology adopted	Capital expenditure required to develop planned capacity in order to meet the 2030 target (€ billion)
Belgium	3,574	1,992	7.12
Denmark	10,427	1,992	20.77
Finland	1,956	2,031	3.97
France	4,718	2,702	12.75
Germany	21,890	2,031	44.46
Ireland	6,975	2,031	14.17
Italy	870	2,702	2.35
Netherlands	16,473	1,992	32.81
Portugal	8,975	2,702	24.25
Spain	2,950	2,702	7.97
Sweden	3,809	2,031	7.74
Poland	5,900	2,031	11.98
Lithuania	1,400	2,031	2.84
Latvia	400	2,031	0.81
Estonia	1,200	2,031	2.44
Romania	500	1,992	1.00
Greece	2,000	2,702	5.40
SUM for EU MS	94,017	-	202.83
United Kingdom	36,300	2,031 – bottom fixed 2,702 – floating offshore wind	97.28

Source: own calculations based on country declarations on the installation target for offshore wind energy and Innovation Impact on Levelised Cost of Energy Model (Freeman & Blanch, 2021).

On the basis of the assumptions made, the total investment for the realization of offshore wind farms was estimated to be up to €202.83 billion to meet the installation targets of individual EU MS. The UK's capital expenditure could reach the level of €97.28 billion. In the scenario of the most dynamic growth in installed capacity in Europe (EU and UK), the total investment in offshore wind farm construction could amount to €300 billion by 2030, in order to meet the stated targets of installing offshore wind capacity. The source of funding for offshore wind farm projects developed in Europe is private capital, which finances the project at different stages depending on the nature of the investment instrument. At the initial stage of a project, the development work typically is covered by the developer and then financed by private investors depending on their risk exposure strategy. Apace with the development of offshore wind technology, the value of the investment in a single project is increasing despite a reduction of Levelized Cost of Electricity (LCOE) indicator due to an increase in the average installed capacity per project (Rubio-Domingo & Linares, 2021; Shields et al., 2021a). There has also been a decline in expected returns on offshore wind farm investments over the past decade, due to the maturity of the sector and better risk identification. Depending on the stage of investment in a project, expected rates of return can range from 5% internal rate of return for projects in the operations phase, to 25% internal rate of return for projects in the early development phase, prior to permitting (Guillet, 2022).

Realizing such a rapid increase in the value of installed offshore wind capacity, however, requires not only capital investment, but also a prepared supply chain that is able to meet market demand (Poulsen & Lema, 2017). European offshore wind farms are dominated by turbines manufactured by three manufacturers: Siemens Gamesa, Vestas and General Electric. Historically, a maximum of around 500-600 turbines per year have been installed in Europe. In order to meet the installation targets, around 9,830 turbines will need to be installed between 2023 and 2030, most of which might be installed after 2027 due to the early stage of development of wind farm projects that plan to be online by 2030. This implies a dynamic, exponential increase in demand for turbines, wind towers, access to port facilities' services and installation vessels and crews, cables and all the components required to install offshore wind farms. As a result of the analysis of the installation plans of individual EU countries and the UK, and assumptions on the increase in the value of a single turbine's capacity, a forecast for the number of installed turbines in Europe has been prepared (Fig. 4). The available data shows approximately 6,300 in operation in Europe at the end of 2022. According to the forecast, a total of 16,130 turbines could be in operation at the end of 2030.

Achieving the planned capacity targets for offshore wind farms in Europe requires the installation of an additional 9,830 turbines between 2023 and 2030. However, this implies a significant development of the supply chain in Europe (Poulsen & Lema, 2017). Due to the relatively early stage of most European projects that are expected to contribute to the 2030 installation scenario, the installation of most turbines will fall between 2028 and 2030, a period that coincides with a very busy period of offshore wind development also outside Europe, including in the United States (US). The management of the European supply chain has its own characteristics because, despite expressing common targets through the regions, individual countries pursue their own policies to support the offshore wind industry and are responsible for preparing installation plans, auctioning space for wind farm development and adapting infrastructure. Like the US and the UK, the EU needs a common vision for offshore wind development to ensure that installation targets can be met and that the energy transition can be achieved. The US and UK are developing offshore wind with extensive use of the local supply chain (Allan et al., 2020; Shields et al., 2021b). The EU has put forward the Green Deal Industrial Plan for the Net-Zero Age as its response to the global supply chain situation for the renewables sector (EC, 2023a). One of the targets of the program is to mobilize a large pool of national and EU funds through the Recovery and Resilience Facility, Horizon Europe and the Just Transition Fund, among others (EC, 2023a). The current production capacity of offshore wind farm turbines in Europe is around 9.5 GW per year, and could reach 11.5 – from 2024, thanks to the work of the new turbine factory (Hutchinson & Zhao, 2023). The development of local supply chains can significantly contribute to the installation targets of offshore wind farms, but in the context of the assumed timeframe, the current stage of industry readiness may not be sufficient. Figure 5 shows the annual value of new offshore wind installations in Europe versus the capacity of European turbine manufacturing plants. The graph shows a possible lack of access to European-made turbines from 2027 if investments in increased turbine manufacturing capacity are not undertaken.

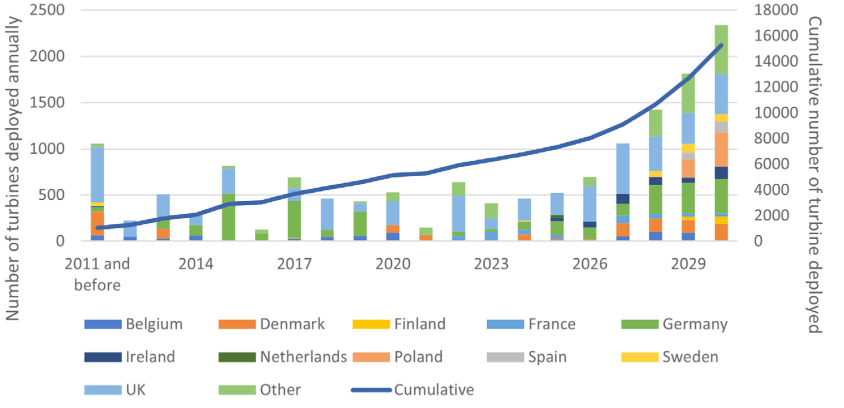

Figure 4. Forecasted number of offshore wind turbines deployed in Europe
Source: 4C Offshore (14.02.2023).

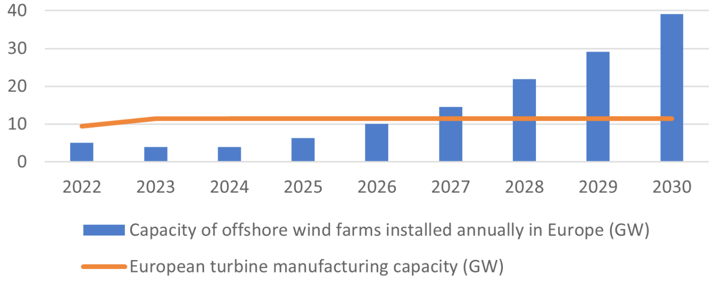

Figure 5. Annual installation of offshore wind turbines in Europe between 2022 and 2030 in relation to supply chain capacity
Source: annual new installation targets stated by EU MS (Hutchinson & Zhao, 2023).

Offshore wind farm developers have to use the principle of economic efficiency in their investment and supplier selection decisions, which does not always mean choosing a local supplier as the best option (van der Loos et al., 2022). One of the prerequisites for the development of an industrial base for realizing the energy transition with offshore wind energy is a long-term and credible plan for the development of this sector, which will allow private investors to commit resources to undertake capital expenditure. A significant investment risk for the offshore wind industry is the variability in component demand that results from overlapping investment plans of different offshore wind projects, while at the same time the need to maintain generation capacity during periods of reduced activity and market interest. The above considerations also apply to the necessary port infrastructure, installation vessels and personnel to cope with both installation ambitions and technological advances that require the adaptation of vessels and technical infrastructure.

Currently, the EU's energy mix is based primarily on the combustion of fossil fuels (coal and gas) and the production of energy by nuclear power plants. Of renewable energy, which accounts for almost 46% of EU energy production, wind and hydro are the most important (Eurostat, 2023a). Among wind power, onshore wind is dominant, but, with ambitious installation targets, the importance of offshore wind could increase in the coming years. Based on the assumptions made about the potential for offshore wind energy production in Europe, the annual value of electricity production in the EU was calculated. In 2021, the value of electricity generated by offshore wind farms will only allow 3.5% of the EU's energy needs to be met. The enormous potential of offshore wind farms to reduce the need for imported energy resources will make it possible to produce around 457 TWh of electricity from offshore wind farms by 2030, provided the targets are met (Table 7). This implies the possibility to increase the importance of offshore wind energy to around 14.4% of the EU energy mix.

Table 7. Electricity production from offshore wind farms installed in the EU

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Offshore wind generation (TWh)	66.7	78.5	86.7	99.6	118.6	148.4	219.6	321.2	457.1

Source: own calculations based on: EU MS installation targets.

In order to estimate the generation potential for one square kilometer of offshore space, the possible electricity production from a theoretical 5.77 MW turbine installed under European conditions was calculated. Based on the assumptions made, the potential to generate 24,430 MWh of electricity on an annual basis was calculated from each kilometer of offshore wind space where offshore wind farms are located. The indicated value refers to new wind power plants with the high efficiency and effectiveness assumed for offshore wind farms installed after 2022. The projected value can serve as an element of the evaluation of spatial rents resulting from the use of space for a given type of activity and thus allow for the inclusion of indicators related to sustainable electricity generation in the management of marine space (Gilek et al., 2021).

Another indicator is the possibility of reducing carbon dioxide emissions due to the transition from energy production based on the current energy mix to the replacement of conventional sources of electricity generation by offshore wind farms. Based on the assumptions made, the annual and cumulative reduction in greenhouse gas emissions due to the replacement of power stations (according to the adopted methodology) by offshore wind farms was calculated. The annual reduction in carbon dioxide emissions in the EU, resulting from the installation of offshore wind farms, amounted to approximately 36.6 Mt in 2022, and could be as much as 184.6 Mt in 2030. The cumulative reduction in greenhouse gas emissions, due to the installation of 115 GW of offshore wind power, could amount to 886.7 Mt.

The expected value of reduction in greenhouse gas emissions from the construction of an offshore wind farm in an area of one square kilometer is 9,235 tons per year, for the assumptions made (Fig. 6).

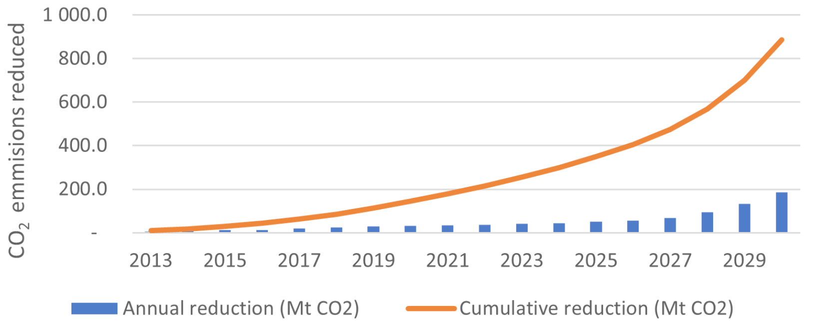

Figure 6. Reduction in carbon dioxide emissions in Europe due to the installation of offshore wind farms, under the assumed scenario of installing new plants by 2030
Source: own calculations based on: EU MS installation targets (Kaldellis & Apostolou, 2017).

Discussion and conclusion

The calculations made show the potential of offshore wind energy to meet the targets set in the European Green Deal and REPowerEU strategy. European countries undertook a significant increase in the installation dynamics of offshore wind farms, following energy crisis in Europe. However, it should be borne in mind that such a significant acceleration of the energy transition based on offshore resources must not violate planning processes for marine spaces.

Most EU countries have already adopted Maritime Spatial Plans that provide for the allocation of significant marine areas for offshore energy development. At the same time, increasing the efficiency of space use, thanks to technological advances including the rapid increase in the size of a single turbine installed at sea, will allow countries to make even better use of marine space for energy purposes. On many occasions, it may turn out that the generation potential of specific offshore areas is higher than the planners had assumed.

Many of Europe's offshore wind farm projects are currently in the early stages of development, which requires going through a process of permitting, environmental impact assessment and environmental clearance. This multi-year process is important as it allows potential conflicts of interest to be identified and managed at an early stage and allows the work started at the spatial planning stage to continue. The identification of a given marine space as a space with potential for offshore energy development also determines the possibility of developing the local economy and community, changing its character and carrying both potential benefits and costs (Laskowicz, 2021). Adequate management of the marine space at the stage of its inclusion in the spatial development plan and then through continued dialogue between different interest groups is important for the feasibility of offshore wind farm projects, with an appropriate level of public acceptance (Lamy et al., 2020). The changes brought about by offshore energy transformation requires working with local communities and local economic actors to increase public acceptance of the changes (Haraldsson et al., 2020). Suitable communication and community education can serve to engage communities in offshore energy development (Ciołek et al., 2018) and transform the local economy, which in coastal areas is currently focused on tourism and fishing (Szejgiec-Kolenda et al., 2018). Some of the elements that influence perceptions of offshore wind energy development are distance from the shore, environmental impact, landscape pollution (Gee & Burkhard, 2010; Sonnberger & Ruddat, 2017). Stakeholders can expect solutions to mitigate the negative impacts of offshore wind development (Johansen & Emborg, 2018). Some of the potential economic benefits may be subject to distribution with stakeholders through, the involvement of local communities and businesses in the supply chain for the project, which results in job creation and economic benefits (Chen et al., 2015; Weig & Schultz-zehden, 2019).

It may be important for a sound planning process to be able to use measurable indicators to quantify the consequences of decisions in terms of giving space a specific character. The development of offshore wind energy translates into concrete changes in social, environmental, economic, energy and climate terms. This article presents a proposal for measuring indicators that can be used to shape offshore space and climate policy. Through historical data and assumptions, values for electricity production and carbon emission reductions in the EU are presented both holistically and universally per square kilometer of maritime space. Using these indicators, maritime space planners can enter numerical values for these values into decision-making models with greater precision.

In addition to providing adequate marine space suitable for offshore energy development, it is necessary to create a supply chain capable of responding to the demand expressed by the EU's climate policy targets. The projections presented provide an indication of the demand for turbines over time to 2030. While turbines are an important component in determining the amount of investment in the overall project, there are a number of elements that need to be integrated into the supply chain to enable the ambitious targets to be met. One of the identified bottlenecks relates to grid connections and availability of specialized installation vessels (Gatzert & Kosub, 2016). Further challenges will arise during the maintenance and operations phase of offshore wind farms, due to the need for sufficient trained personnel and crew transfer vessels (Ren et al., 2021).

However, it should be borne in mind that the indicators analyzed in this article only cover a slice of the reality shaped by offshore wind energy development. The analysis of the necessary resources and potential effects for the construction of offshore wind farms can be extended to include numerous indicators, including employment, impact on economic development, geographical location of costs and benefits, environmental impact, parameterization of conflicts of interest, and others. There are also studies on the impact of changing the nature of marine and coastal areas on values beyond measurable indicators, related to cultural or even emotional impacts, among others (Zaucha & Pardus, 2019). These aspects can further research on indicators describing offshore wind development.

Faced with an energy crisis in Europe, EU countries have resorted to a consistent climate policy, aiming to accelerate the energy transition based on renewable energy sources. Offshore wind energy is an excellent addition to the EU's energy mix, which today in terms of renewables is mainly focused on onshore wind and hydro. Technological developments, greater cost efficiency (per LCOE) and increased production capacity of offshore wind farms make it an attractive form of energy generation for EU countries. By using green hydrogen production with electricity generated from offshore wind farms, it is possible to eliminate variability in energy access. One potential solution for providing continued access to low-carbon energy is the production of hydrogen through electrolyzers working with large-scale floating offshore wind projects (Ibrahim et al., 2022).

The research shows the potential for offshore wind farms to also work with other forms of power generation, such as floating solar photovoltaic (López et al., 2020) and tidal turbines (Nasab et al., 2020). There are also many multi-use options for offshore wind turbine installations, such as aquaculture (van den Burg et al., 2017; van den Burg et al., 2020), tourism (Glasson et al., 2022) and recreational fishing (Hooper et al., 2017). Additional opportunities for offshore energy to coexist with other activities can positively influence the efficiency of marine space use (Przedrzymirska et al., 2021). Individual countries independently create policies for the management of multiple marine activities in offshore windfarm areas, which affects the availability of marine areas for fishing, between other activities (Schupp et al., 2021). With the development of offshore wind turbine technology and the possibility of using floating offshore wind turbines, new sea spaces can be utilized for the production of renewable energy. This will further increase the importance of offshore wind energy in building energy security in Europe.

This article presents calculations of spatial and capital resources for the implementation of EU climate policy targets that are given independent shape by the individual countries of the European Community. The development of the energy transition in different countries points to certain factors that cause some countries to adapt renewable energy generation better than others (Ćetković & Buzogány, 2016). Among European countries, the leader in offshore wind development is the UK, which, based on an offshore wind support scheme and the promotion of local content, has created an efficient supply chain for offshore wind (Higgins & Foley, 2014). Decarbonization of the energy system in Europe is a long-term process and the announcement of installation targets for offshore wind turbines in individual countries is only the first step towards achieving it (Victoria et al., 2020). EU MS have not been dynamically developing offshore energy production over the past few years, although the example of the UK shows that it has been possible to create the conditions for the development of this sector. The current dynamic changes in installation plans and the adoption of offshore spatial plans, juxtaposed with the possibilities of installing turbines in these spaces, show that there is a very high potential for energy production in European offshore areas. Offshore wind energy has for years been seen as a potential source of low-carbon electricity that can be cost-effective and have a positive impact on energy security (Esteban et al., 2011). However, it was only the energy crisis in Europe, that led to significant increases in national offshore wind installation targets. The timing of the installation targets set by European countries overlap with each other and with the dynamic development in the US and Asia. Through the loss of the last few years in offshore wind development and the supply chain for the sector, it can be very challenging for Europe to reach the installation targets set, proving that energy and climate policies should be planned for the long term (Victoria et al., 2020).

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Economic Aspects of Marine Spatial Planning: The Case of Offshore Wind Farms in Poland

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Abstract

Spatial rent (annuity) makes it possible to estimate the economic value resulting from the use of space for a given type of activity. This article provides calculations of spatial rent in regard to offshore wind energy development and proposes a data-driven approach for optimizing spatial management strategies, ultimately contributing to more informed decision-making processes in marine spatial management. It analyses seven projects that could be developed in the Polish part of the Baltic Sea as part of Poland's energy transition. The article employs a robust methodology that integrates technoeconomic analysis and financial forecasting to calculate spatial rent by discounting net cash flows. The calculations are carried out for two windiness scenarios, with the results of the weighted average annual energy production ranging from 38.02 GWh/km^2 to 40.56 GWh/km^2. Such energy production could yield an annual spatial rent of 10.72 million €/km^2 to 13.30 million €/km^2.

Keywords

offshore wind, spatial rent, green deal, energy transformation

Introduction

The European Union (EU)'s energy policy is one of the pillars of the entire community and is integral to shaping the social and economic development of the continent. For decades, the EU has consistently pursued a plan to decarbonize the energy sector, aiming to reduce electricity generation from coal and other fossil-fuel-fired power plants in favour of sustainable renewable energy. The contributions of individual EU countries have been planned by setting specific targets for reducing carbon dioxide emissions and increasing the production of energy from renewable sources. In pursuing their aims, EU countries have simultaneously been leading the way in reducing energy dependence on fossil fuels, including fossil fuels from Russia. However, as a result of the military conflict in Ukraine in February 2022, European countries faced the new challenge of having to immediately address energy supply constraints and energy price fluctuations.

In Poland, the milestones for developing offshore wind energy as part of the energy transition were the establishment of an offshore spatial development plan (*Regulation of the Council of Ministers of April 14, 2021 on the Adoption of the Spatial Development Plan of Internal Sea Waters, Territorial Sea and Exclusive Economic Zone in the Scale 1:200 000*, 2021) and the passing of a special act to promote offshore wind energy (*The Act on Promoting Electricity Generation by Offshore Wind Farms*, 2020), guaranteeing that developers offtake energy at a certain price. These two documents provide the foundation for determining the economic viability of a project in relation to the area of offshore space required for its implementation. Although the development of offshore wind energy in Poland was planned even before Poland's accession to the EU, adjusting legislative and economic frameworks was necessary (Beurskens & De Noord, 2003; Stryjecki, 2009). Economic assessment is an essential part of the analysis of the investment process for renewable energy sources, as it provides the grounds for justifying the action in a free market economy. Investors need to receive a return on the capital investment that is adequate to compensate the risks incurred (Dopierała et al., 2022). Investors are thus incentivized to make investments, ensuring that the energy transition targets set by countries at the local and EU/international levels are met. In 2020, the EU set, as part of its renewable energy strategy, a target for offshore wind energy development of 60 GW by 2030 and 300 GW by 2050 (European Commission, 2020a). However, in

2022, with the outbreak of war in Ukraine, individual EU countries reacted strongly and decided to increase the targets for offshore wind installations (North Sea Governments, 2022; NSEC, 2022). The development of this form of renewable energy production, in addition to the possibility of curbing carbon dioxide emissions, is also an opportunity for Poland and Europe to reduce their dependence on imports of energy resources and to improve their energy security.

The surge of interest in offshore wind farm investment in Europe has also drawn attention to the aspect of marine space utilization. The maritime spatial development plan adopted by the Polish government in 2021 is meant to enable the development of offshore energy in designated areas; specifically, 2,310.81 km^2 are designated where offshore wind energy development is permitted (*Regulation of the Council of Ministers of April 14, 2021 on the Adoption of the Spatial Development Plan of Internal Sea Waters, Territorial Sea and Exclusive Economic Zone in the Scale 1:200 000*, 2021). These areas represent 7.6% of the total area covered by the Polish Maritime Spatial Plan. An integral part of maritime governance is the management of conflicts of interest, which, with the emergence of new maritime activities and increased use of marine space, may require trade-offs (Zaucha, 2019).

This work investigates a specific dimension of energy transition, namely offshore wind development in Poland. A certain challenge for undertaking a study in this area is the early stage of said development in Poland: At the time of preparing this article, none of the proposed projects have started offshore construction. However, it should be kept in mind that spatial planning, which determines the feasibility of investment and energy transition by identifying space for development, takes place at an early stage, where the range of available data on specific projects is limited and information gaps exist (Zaucha, 2018). This study assessed the economic value of building offshore wind farms by taking into account spatial considerations. Critical elements of the decision-making process regarding the siting of wind farms in the Polish coastal zone and the electricity they generate have already been analysed (Ziemba, 2022). Offshore wind farms are key to meeting the EU's renewable energy development targets set by the Green Deal (European Commission, 2020a). However, a comprehensive economic, legal, and environmental framework is necessary for their realization (Adamiec, 2023). To mitigate financial risks, various support mechanisms can be used, such as contracts for difference, feed-in tariffs, tax policies, and subsidies, among others (DeCastro et al., 2019). Further, spatial planning can determine the economic value resulting from, among other things, the use of specific marine areas (Zaucha et al., 2020).

This study aimed to provide a tool for enhancing the spatial planning process through the consideration of the specific economic value of the sea space allocated to renewable energy, namely offshore wind energy (OWE) spatial rent[1] (annuity), which is mainly derived from OWE financial benefits. Similar attempts have been made in the literature for determining the economic value of other maritime activities, such as fishing, for which a contribution margin has been estimated (Psuty et al., 2021). The need to develop economic tools for more accurate decision-making in marine spatial planning development has been identified by various researchers (Psuty et al., 2021; Surís-Regueiro et al., 2021; World Bank, 2022; Zaucha et al., 2020).

Theory

The sustainable use of marine spaces remains the subject of many scientific and practical studies (Gilek et al., 2021), which have concluded that their use is conditioned by the preservation of the natural capacity of marine resources to reproduce and the possibility of the coexistence of a wide range of human activities that do not conflict with each other and with the natural marine environment (Morf et al., 2019; Turski et al., 2018). The sustainable use of marine spaces is one of the key challenges facing modern maritime spatial planning in the face of the increased intensity of activities carried out on the seas (Nash et al., 2020).

Each of the sea areas that make up the EU maritime economy has distinct characteristics. The seas that make up the EU maritime basins are divided into Northern Waters (Atlantic Ocean, North

[1] The term 'spatial rent' is used in this paper instead of the concept of 'annuity' to follow the original terminology proposed by Ricardo (Ricardo, 1821).

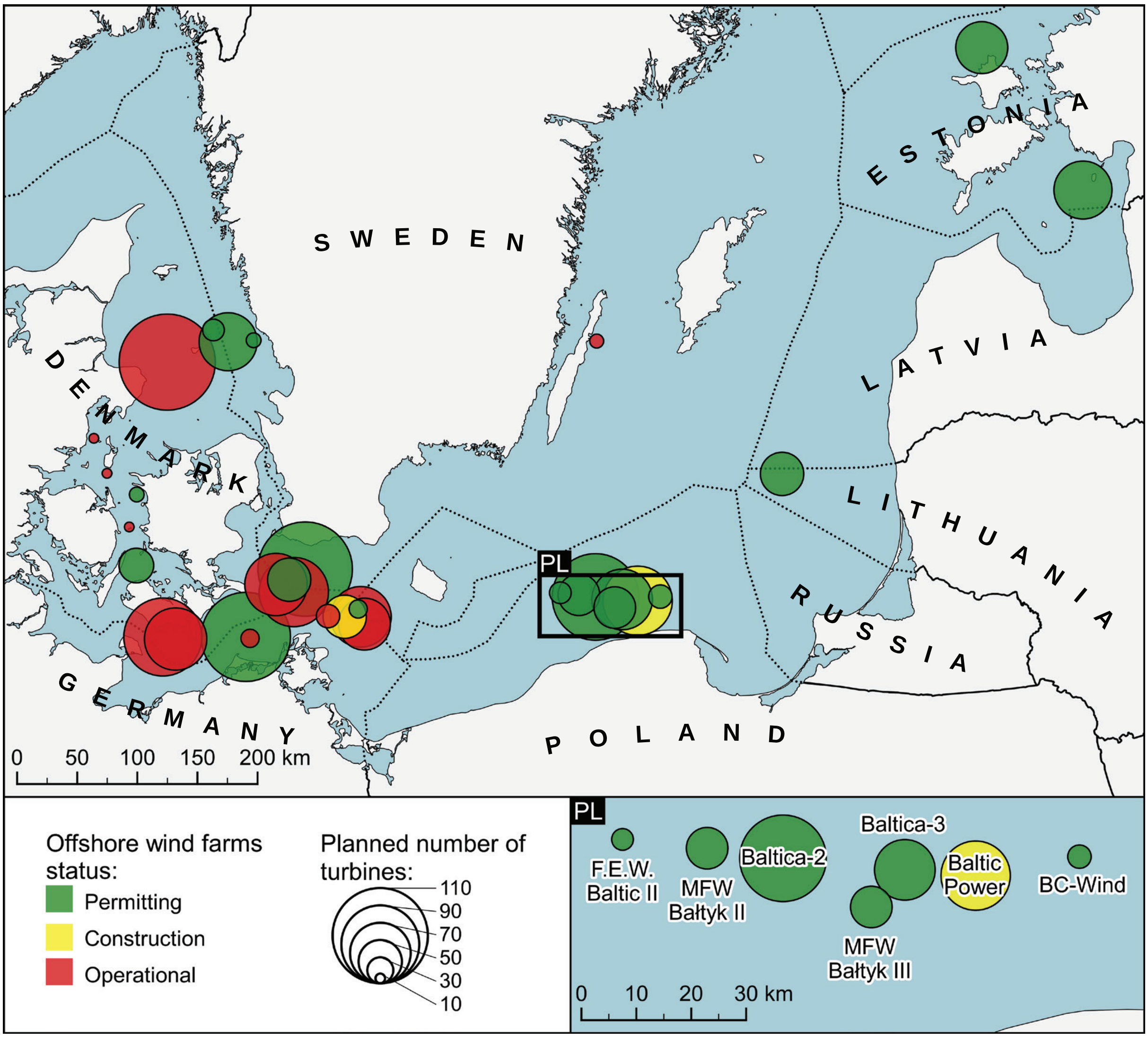
Sea, Baltic Sea) and the Mediterranean (Mediterranean, West Mediterranean, Adriatic-Ionian Sea, East Mediterranean, Black Sea). Each of these basins represents huge potential for the installation of offshore wind turbines for the production of renewable electricity, but this sector of the maritime economy currently represents a small fraction of the added value generated. Coastal tourism represents the largest sector of the EU maritime economy, both in terms of gross value added and employment (European Commission, 2020b). Previous studies on the sectoral development of the EU's sea basins have revealed the potential for increasing the efficiency of spatial development through multiple use, but they have not made use of specific calculations of financial indicators. Using OWE as an example, this article proposes a solution for comparing the economic benefits of implementing a specific activity in marine areas (Przedrzymirska et al., 2021). Table 1 presents the current marine energy potential and its technical installation potential. Not all countries developing OWE in the listed maritime areas are part of the EU, as the leader in offshore wind development in the North Sea is the United Kingdom.

Table 1. Utilization of offshore wind potential in European waters in relation to estimated technical capacity

Sea Basin	Current installed offshore wind capacity [GW]	Installation target [GW]	Total technical potential for offshore wind installation [GW]
North Sea	27.9	150 in 2050	1948
Mediterranean Sea	0.1	-	1,646.2
Black Sea	0	-	453
Baltic Sea	3.32	19.6 in 2030	93.5
Atlantic Ocean	2	-	-

Sources: Hahmann et al. (2023), European Commission (2019), Staschus et al. (2020), The World Bank Data Catalog (Retrieved from: www.datacatalog.worldbank.org)

While the construction of offshore wind farms is part of the EU's energy strategy, the significant impact of such projects on the entire 'blue economy' sector should not be overlooked (European Commission, 2023). The complexity of this sector means that assessing its individual components is not straightforward and that the sector needs to be considered holistically. To do this, it is necessary to obtain the right data to enable effective decision-making and impact monitoring (Burgess et al., 2018). The need for a socioeconomic assessment is part of the trend towards the quantification of the phenomenon that is captured by the term blue economy. Individual studies have examined selected geographical areas and specific activities in the maritime sector (Fernández-Macho et al., 2015; Kwiatkowski & Zaucha, 2023; Mogila et al., 2021; Psuty et al., 2021). There have been also some attempts to estimate the benefits of maritime spatial plans. For instance, Surís-Regueiro et al. (2021) proposed a methodology for estimating the total (induced and indirect) economic effects—specifically, for the blue economy—related to maritime spatial plans by making use of counterfactual scenarios for the planned marine areas (Surís-Regueiro et al., 2021). Offshore wind development is of vital importance for the European blue economy, as new investments in offshore renewable energy can contribute to job creation and improve energy security, thereby enhancing the resilience of the European economy (IRENA, 2017, 2020). The development of OWE necessitates the implementation of effective decisions regarding the allocation of new marine spaces to facilitate the advancement of new investments (European Commission, 2018). However, to date, no universal method has been devised for the quantification of the economic benefits of the development of a particular maritime activity in relation to the space it occupies. This poses a major challenge for maritime spatial planning, which can be based on subjective judgements and captured by well-organized marine stakeholders. The approach proposed in this paper can contribute to building a tool for maritime spatial planning decision-makers by providing for a clear assessment of the economic impact of planning decisions. In response to the need to develop a universal method for determining spatial rent, a method for calculating the spatial rent resulting from the use of marine space in the Polish Baltic Sea zone for the development of OWE is proposed herein.



Map 1. Location of offshore wind farms in the Southern Baltic Sea

Source: Map created by Krystian Puzdrakiewicz based on data provided by the author, 2024.

Spatial rent can shape spatial development and influence the desire to maximize the efficiency of resource allocation. Positive rent motivates sea users to allocate certain resources to a given area. In the long run, activities with higher rents can be expected to displace activities with lower rents. Consequently, the ability to tally and compare the rents resulting from different activities may make it possible to predict conflict dynamics and space use processes. In the Baltic Sea, the development of OWE displaces fishermen's access to the fishing areas and also reduces the availability of shipping routes due to the size of the expected installations (Zaucha et al., 2020). The amount of the expected rent varies depending on the factors that determine the efficiency of the space used for a given activity; in the case of offshore wind farms, these are mainly windiness, water depth, distance from land, and distance from port.

The Baltic Sea has the potential to make a significant contribution to the EU's energy policy goals within a few years. As shown in Table 1, the Baltic Sea could reach an installed capacity of almost 20 GW by 2030 (EU Baltic Sea Governments, 2022), of which 5.9 GW would be wind farms installed in the Polish Baltic Sea zone. Map 1 shows the location of existing and planned offshore wind farm projects in the Baltic.

Meeting the target of installing almost 20 GW of capacity in the Baltic Sea before the end of this decade means that the number of sited turbines must be doubled from the current 720 to around 1,500 turbines in 2030. In addition to the installation of the turbines, the construction of offshore wind farms requires a cable connection between the towers and the transmission station and the laying of submarine cables for the export of energy to land. The pace and size of investment are not without impact on the Baltic Sea ecosystem and have certain consequences, both positive and negative (Galparsoro et al., 2022). The development of offshore wind farms takes place in successive stages, which are characterized by various environmental, social, and economic impacts. The external effects of an offshore wind farm at different stages are taken into account at an early stage of marine spatial planning (Bailey et al., 2014).

The impact of offshore wind farm development on the environment should be considered in light of the phase of the investment cycle and technology (Mauricio Hernandez et al., 2021). Particularly intense local effects occur during the construction and decommissioning phases due to the noise and vibrations associated with offshore activities (Galparsoro et al., 2022). Research indicates the presence of both positive and negative aspects of offshore wind farm development. Among the negative environmental aspects, birds whose migration corridors intersect with the locations of wind farms may come under particular pressure (Adamiec, 2020; Snyder & Kaiser, 2009). However, upon observing fish species, researchers have noted that certain ones derive benefits from the effects of artificial reefs (Hooper & Austen, 2014). The structures of wind farms may also influence potential social conflicts including fishing activity and landscape disturbances, which are especially significant concerns for coastal areas focused on tourism (Biniek, 2021; Voltaire et al., 2017).

While the benefits stemming from the energy security and low carbon footprint of electricity production associated with renewable sources are widespread, the potential negative social and environmental effects are primarily observed locally. Developers of offshore wind farms are required to prepare an Environmental Impact Assessment (EIA) document in order to apply for necessary permits (Adamiec, 2023). The EIAs for Polish investments anticipate minimal negative environmental impact, and the plans for locating individual farms are designed to mitigate potential threats, such as by preserving migratory corridors for birds (Bednarska et al., 2017). The actual impacts of the planned investments centred in the Baltic Sea environment and potential conflicts are challenging to estimate due to the lack of existing installations (Biniek, 2017).

Material and methods

A spatial rent is a monetary expression of the benefits derived from the use of a given space (Zaucha et al., 2020). Determining the value of spatial rent allows an objective estimation of the economic benefits provided by a given economic activity in a given area (Zaucha, 2019). Therefore, in order to estimate the spatial rent for the offshore wind farms planned in the Polish Baltic Sea zone, it is necessary to estimate the financial values of the investment. Based on the available knowledge on modelling the costs and financial flows resulting from offshore wind farm operation, a financial model was developed for seven Polish projects, covered by a support mechanism guaranteeing a minimum price for energy consumption (Judge et al., 2019; Kaiser & Snyder, 2013; Castro-Santos et al., 2018). A challenge for the determination of the spatial rent of the planned project is the lack of accurate data on the costs of the implementation of the various stages of an offshore wind farm. In this study, seven projects with a total installed capacity of 5.9 GW were analysed. All projects are expected to be connected to the national grid by 2028, according to the developers' plan. Table 2 shows the projects analysed along with their basic technical characteristics.

Table 2. Offshore wind farm projects

Name of project	Developer	Planned generation capacity (MW)	Assumed number of turbines	Offshore wind farm area (km^2)	Distance from shore (km)
Baltic Power	PKN ORLEN, Northland Power	1,200	80	131	39
Baltica 3	PGE, Ørsted	1,045	70	131	25
Baltica 2	PGE, Ørsted	1,498	100	189	30

Table 1. – cont.

Name of project	Developer	Planned generation capacity (MW)	Assumed number of turbines	Offshore wind farm area (km^2)	Distance from shore (km)
Bałtyk III	Polenergia, Equinor	720	48	116	23
Bałtyk II	Polenergia, Equinor	720	48	121	37
BC-Wind	Ocean Winds	399	27	91	23
F.E.W. Baltic II	RWE	350	25	41	46
TOTAL	-	5,932	398	820	-

Source: own elaboration, based on developers' plans.

The technical assumptions adopted in the model can have a significant impact on offshore wind energy production and consequently affect the financial performance of the projects analysed (Monforti & Gonzalez-Aparicio, 2017; Mora et al., 2019). To calculate the spatial rent, assumptions were made regarding: technical solutions of offshore wind farms, construction and operating costs, production capacity and revenues generated from the sale of electricity. Recent years have been characterized by high dynamics of technical development of offshore wind energy, including a significant increase in the capacity of a single turbine (WindEurope Business Intelligence, 2022). The capacity of a single turbine was assumed to be 15 MW, according to the first tenders awarded by developers with projects in Poland. In order to estimate the possible spatial rent depending on wind power, spatial rent calculations were adopted based on two different average wind power scenarios for the projects analysed. On the basis of wind measurement data, wind speeds of 9.5 m/s were assumed for Scenario 1 and 10.5 m/s for Scenario 2 (Boniecka et al., 2016) due to the installation of the turbines at a height of approximately 150 m. The capacity factor was assumed to be 60% in Scenario 1 and 64% in Scenario 2, respectively (Valpy et al., 2017; Vestas Wind Systems A/S, 2023). The calculation methodology used in this document is based on certain simplifications and assumptions, including the determination of the capacity factor. This parameter is derived from technical specifications provided by turbine manufacturers. Research by Sobotka et al. (2019) analysed the actual performance of a 400-MW offshore wind farm and revealed a lower capacity factor for 8-MW turbines. This means that actual energy production and the resulting revenue may differ from the values assumed in the model, particularly due to differences in geographic conditions at different sites. The amount of energy produced is subject to regional variations due to wind conditions in different offshore areas (Boniecka et al., 2016). In addition, different technical solutions may be employed to account for various factors such as water depth, soil conditions, and other site-specific conditions (Ziemba, 2022). These considerations emphasize the complexity of predicting wind energy production in different environments. If current trends continue, the construction cost of offshore wind farms will decrease in the coming years (Rubio-Domingo & Linares, 2021). For the projects analysed, the investment cost for the construction of an offshore wind farm was assumed to range from 2,292 €/kW to 2,736 €/kW and 33.7 €/kW in annual operating expenditures (IRENA, 2022). A 25-year wind farm lifespan and decommissioning costs of 211 €/kW were assumed (Judge et al., 2019). The projects analysed were subject to a support mechanism, which consists of guaranteeing a fixed minimum energy offtake (€68 per MWh) in order to reduce market risk (*The Act on Promoting Electricity Generation by Offshore Wind Farms*, 2020). In this way, investors can plan for the revenue generated by the projects. Assumptions were made according to available sources and studies by other authors (Rubio-Domingo & Linares, 2021; Ziemba, 2022). A weighted average cost of capital of 7.6% was used, higher than in Germany, the Netherlands, or Denmark (Rubio-Domingo & Linares, 2021). The model also assumed a government concession fee of PLN 23,000 (€4,845). Because of different financing models for offshore wind farm investments, equal shares of debt capital and equity were assumed (Lam & Law, 2018).

Calculations were made in Excel using formulas that recalculate the financial parameters of each of the seven projects analysed. Certain technical and financial assumptions were made, as shown in Table 3.

Table 3. Assumptions adopted for calculation of spatial rent for offshore wind farm projects located in Poland

Category of assumption	Parameter	Assumption made
Technical	Wind speed—SCENARIO 1	9.5 m/s
Technical	Wind speed—SCENARIO 2	10.5 m/s
Technical	Turbine size	15 MW
Technical	Capacity factor—SCENARIO 1	60%
Technical	Capacity factor—SCENARIO 2	64%
Technical	COD year	2027/2028
Technical	Operations and maintenance lifetime	25 years
Financial	CAPEX per kW	€2,292–€2,735
Financial	OPEX yearly per kW	€33.7
Financial	Decommissioning per kW	€211
Financial	CfD Rate/MWh	€68 (EURPLN = 4.70)
Financial	Inflation rate estimation	2.5%
Financial	Weighted average cost of capital	7.6%
Financial	Concession fee	€4,945 (EURPLN = 4.70)
Financial	Discount rate	6.0%
Financial	Share of equity and debt	50% equity, 50% debt

Source: Rubio-Domingo and Linares (2021); Ziemba (2022).

The development of offshore wind energy in Europe, mainly in the United Kingdom but also in other countries, including the Baltic Sea Basin, provides data for estimating the cost of generating 1 kWh of energy from offshore wind farms and the value of energy production from a 1 km^2 offshore wind farm (Boniecka et al., 2016). These estimated data may constitute a significant supplement to the existing studies on the determinants of spatial development of maritime areas, both Polish and European, which, to the author's knowledge, have not performed economic analysis as an element of the study of conditions.

However, estimating the external costs resulting from the construction of offshore wind farms remains a difficulty (Ladenburg & Lutzeyer, 2012). The decision to allocate certain marine spaces for a particular activity may result in other activities having to be abandoned. In the case of offshore wind farm development, one of the potential external costs may be a reduction in the ability to develop fisheries in wind farm areas (Hooper & Austen, 2014; Stelzenmüller et al., 2016). Apart from the impact on fisheries, the development of offshore wind farms in the Baltic Sea may affect tourism, which is an important part of the economy of coastal regions. The construction of offshore wind farms may affect the attractiveness of tourist regions due to the industrialization of the landscape (Biniek, 2021; Voltaire et al., 2017). Table 4 presents an analysis of the potential benefits and threats resulting from the construction of offshore wind farms in the Baltic Sea (Laskowicz, 2021).

Table 4. Externalities arising from offshore wind farm development at different stages

Life stage of an offshore wind farm	Activity	External costs
Development	Survey of areas for the construction of offshore wind farms	Increased intensity of maritime space exploration; possible conflicts with fishing industry
Construction	Transport and installation of offshore wind farm components	Possible risk to marine mammals and fish from noise pollution

Table 4. – cont.

Life stage of an offshore wind farm	Activity	External costs
Construction and operation	The need to maintain safety zones during construction and operation	Restricted access to fishing grounds
Operation	Rotor blade movement	Threat to birds
Construction and operation	Industrialization of the landscape	Threat to tourism and cultural identity of coastal residents
Development, construction, and operation	Adaptation of port infrastructure	Capital expenditure required to adapt port infrastructure; adaptation of significant land areas required
Operation	Operation and maintenance of farms during operation	Necessary maintenance of infrastructure related to transmission provision, including cables and transformer stations; risk of accidents and spills of hazardous substances
Decommissioning	Removal of offshore wind farm features and restoration of the natural environment	Risk to fish and marine mammals from demolition work; risk of disturbance to wildlife habitats

Source: own elaboration.

The benefits and risks listed are not always possible to include in an economic calculation due to the lack of a methodology to estimate the costs or profits arising from phenomena that co-occur in the different phases of an offshore wind farm. This study estimated the spatial rent resulting from the possibility of building offshore wind farms in marine areas, and the purpose of presenting the calculations for the spatial rent resulting from the construction of offshore wind farms is to provide an economic rationale for decisions regarding the management of marine space.

Results

Results were obtained for two different scenarios, varying in terms of the efficiency of the wind turbines. The operating efficiency of wind turbines depends on a number of factors, including the location of the turbines and the technical efficiency of the equipment, but a key factor is the wind (Ziemba, 2022). Table 5 presents the financial outlay required to achieve the assumed generation capacity and the expected values of electricity production from the assumed projects. Also presented is the value of the electricity generated from the use of 1 km^2 of offshore space dedicated to the construction of an offshore wind farm and the unit cost of electricity generation.

Table 5. Electricity production of Polish offshore wind farm projects by 2028 under two production efficiency scenarios

Capacity factor	Name of project	Planned generation capacity (MW)	CAPEX m (€)	Annual energy production (GWh)	Area (km^2)	Annual energy production per km^2 (GWh/km^2)
60%	Baltic II	350	802	1,840	41	44.87
	Baltic Power	1,200	3,163	6,307	131	48.15
	Baltica 2	1,498	4,099	7,874	189	41.66
	Baltica 3	1,045	2,859	5,493	131	41.93
	Baltic II	720	1,650	3,784	121	31.28
	Baltic III	720	1,650	3,784	116	32.62
	BC WIND	399	915	2,097	91	23.05
	Total for Scenario 1	5,932	15,138	31,179	820	Weighted average: 38.02

Table 5. – cont.

Capacity factor	Name of project	Planned generation capacity (MW)	CAPEX m (€)	Annual energy production (GWh)	Area (km²)	Annual energy production per km² (GWh/km²)
64%	Baltic II	350	802	1,962	41	47.86
	Baltic Power	1,200	3,163	6,728	131	51.36
	Baltica 2	1,498	4,099	8,398	189	44.44
	Baltica 3	1,045	2,859	5,859	131	44.72
	Baltic II	720	1,650	4,037	121	33.36
	Baltic III	720	1,650	4,037	116	34.80
	BC WIND	399	915	2,237	91	24.58
	Total for Scenario 2	5,932	15,138	33,257	820	Weighted average: 40.56

Source: own study based on prepared financial model and assumptions shown in Methodology section.

The capital expenditure for the construction of the seven projects analysed according to the model will amount to €15,138 million. Turbines with a total generating capacity of 5,932 MW will be installed over an area of 820 km^2, which will generate between 31,179 GWh and 33,257 GWh of electricity annually, depending on the actual windiness. The average annual electricity production from 1 km^2 of sea space will range from 38.02 GWh/km^2 to 40.56 GWh/km^2.

The level of energy consumption in Poland has been more or less constant for more than a decade. In 2010, the level of energy consumption was about 150 TWh, and in 2021 the value will exceed 174 TWh (Polish National Grid, 2022). The construction of seven offshore wind farm projects with an installed capacity of 5.9 GW could translate into production of between 31 TWh and over 33 TWh per year. The expected year for this phase of offshore wind development to reach full capacity is 2028. This means that in 2030, when a demand of 198.8 TWh is projected (Polish National Grid, 2020), offshore wind could meet around 16.5% of the national electricity demand. Table 6 presents the financial indicators together with an estimate of the spatial rent for offshore wind projects.

Table 6. Results of financial model for offshore wind farms with estimation of spatial rent

Capacity factor	Name of project	Planned generation capacity (MW)	Total discounted net cash flows (million €)	Total undiscounted net cash flows (million €)	IRR (%)	Spatial rent based on discounted net cash flows (€ million/km²)
60%	Baltic II	350	614	2,539	11.67	14.97
	Baltic Power	1,200	1,649	8,089	9.88	12.93
	Baltica 2	1,498	1,920	9,874	9.43	10.16
	Baltica 3	1,045	1,339	6,888	9.43	10.22
	Baltic II	720	1,262	5,223	11.67	10.43
	Baltic III	720	1,262	5,223	11.67	10.88
	BC WIND	399	700	2,895	11.67	7.69
	Total for Scenario 1	5,932	8,790	40,732	-	Weighted average: 10.72
64%	Baltic II	350	734	2,824	12.65	17.91
	Baltic Power	1,200	2,131	9,066	10.79	16.27
	Baltica 2	1,498	2,466	11,093	10.32	13.05
	Baltica 3	1,045	1,720	7,739	10.32	13.13
	Baltic II	720	1,510	5,809	12.65	12.48
	Baltic III	720	1,510	5,809	12.65	13.02
	BC WIND	399	837	3,219	12.65	9.20
	Total for Scenario 2	5,932	10,908	45,559	-	Weighted average: 13.30

Source: own study based on prepared financial model and assumptions shown in Methodology section.

Through the data analysis, the financial efficiency of the individual projects was determined and compared with the data on the maritime space used for the project. The prepared model demonstrated the high financial profitability of the planned projects, with the internal rate of return ranging from 9.43% to as high as 12.65%. The spatial rent resulting from the construction of offshore wind farms in the Polish Baltic Sea zone was calculated, and depending on the analysed project and the adopted wind scenario (rate of capacity factor), the expected spatial rents were found to range from 7.69 to 17.91 million €/km^2. The weighted average spatial rent was found to be €10.72 million/km^2 in Scenario 1 and €13.30 million/km^2 in Scenario 2.

Conclusion and policy implications

For the model, this study assumed a relatively high capacity factor, which contributed significantly to the high expected spatial rent values based on discounted net cash flows. Discounted net cash flows are essential due to the long operating life of offshore wind farms and the need to account for changes in capital value over time. As a result of installing offshore wind farms with a capacity of 5.9 GW in an area of 820 km^2, the potential to generate 31–33 TWh of energy per year was assumed. Such energy production, assuming the guaranteed energy prices in the differential mechanism, would allow for high rates of return and space rents that are not achievable for other marine activities. Research on the economic value of marine space use has been conducted by Psuty et al. (2021) for the fisheries sector and by Czermański et al. (2024) for the shipping sector. Studies on the economic viability of marine space use differ in methodology, so a direct comparison of spatial rent results is not possible; nevertheless, previous work provides a basis for assessing the economic efficiency of the activities conducted. Based on differences in the expected spatial rents depending on the type of activity, decisions on marine spatial management and guidelines for mitigating potential conflicts of interest arising from the displacement of more profitable activities by those generating lower spatial rents can be made.

The development of offshore renewable energy requires significant capital investment and extensive marine space utilization. The deployment of offshore wind farms has local and global environmental and social impacts, with most of the adverse effects concentrated locally. However, quantifying such externalities within an economic modelling framework is challenging due to the lack of reliable data on the specific impacts, some of which are inherently subjective and lack quantifiable parameters for description. Another crucial aspect in managing the decision-making process regarding the development of activities in specific areas is the need to mitigate potential conflicts of interest arising from other functions. Alternative uses of space must be integrated into the economic calculus governing decisions on spatial functions, as such alternatives are a fundamental component in the overall assessment of the economic viability of an activity.

An important element of offshore development decisions, especially in the context of offshore renewable energy, is the time dimension of the decision. Due to the high financial costs of building an offshore wind farm, projects with a long lifecycle are likely to have a payback period of 25 to 30 years. After this period, developers, depending on the approvals obtained, may decide to extend the life of the project in question for a further period by, for example, using new turbines embedded in the existing space. In practice, this means that the decision to authorize the construction of offshore wind farms has a large temporal impact, as an investment in infrastructure that constitutes some kind of interference with the environment will remain in the offshore space for at least 30 years, and once the infrastructure is built, it is in practice impossible to change the use of the space.

Some of the parameters that influence the economic evaluation of an offshore wind farm project are shown in Table 3. There are nine effects listed that can be analysed from an economic perspective, and attempts have been made to do so in scientific studies (Aitken, 2010; Lamy et al., 2020; Laskowicz, 2021; Smythe et al., 2020; Varela-Vázquez & Sánchez-Carreira, 2017). To date, however, no integrated tool has been proposed to provide for comprehensive economic assessment of a project. The proposed tool, which aligns the economic benefits of offshore wind farms with the marine spatial area, represents a step towards making planning decisions based on economic data. Financial models prepared by developers take into account only the financial aspect of the investment, are undertaken by the investor, and are based on an analysis of a narrow slice of reality, which has a direct impact on financial flows for the investor. In practice, various types of costs may not be included in the economic calculation and are borne by other users of the neighbouring space or entities excluded from the use of the space intended for OWE development. The calculations conducted in this study also do not fully cover all elements. Due to numerous limitations, only selected data were analysed, whose quantification and incorporation into the model were feasible. Numerous external costs were not valued for the purposes of this study, but they may impact both the profitability of the investment itself and the assessment of the justification for maintaining such high spatial rents generated by offshore wind farms. Certain external costs, such as potential negative impacts on the environment or landscape or economic changes in coastal municipalities, may influence the economic assessment of marine spatial utilization (Dorrell & Lee, 2020; Zaucha, 2018). Thus, further work on OWE spatial rent should focus on internalizing the aforesaid external costs and benefits. The literature on this is vast but still hardly conclusive (Kwiatkowski & Zaucha, 2023; Laskowicz, 2021).

The overintensive use of marine space for energy can cause social conflicts (Alexander et al., 2013). Considering the economic conditions of a project already at the space planning stage can help identify potential conflicts of interest and estimate their economic value. The use of spatial rents can therefore help manage, avoid, or mitigate potential conflict altogether. It is necessary to consider the justification for imposing an obligation on developers of offshore wind farms to prepare, in addition to EIA documents, an analysis of the investment's impact on potential socioeconomic conflicts and possible mitigation measures, including potential compensation for specific interest groups, such as for the fishing industry due to the loss of opportunity to exploit fisheries (Hooper & Austen, 2014). The calculation of opportunity costs can provide a basis for dialogue between the various parties to a conflict and rationalize the interests of both parties. Relying on reliable and credible data can also provide a starting point for further economic calculations, which would be applied at the stage of developing the legal and institutional framework for OWE. Incorporating spatial rent calculations can enrich the comprehensive evaluation of investment profitability, particularly regarding government-granted energy offtake price guarantees. In addition, it is essential to recognize that the construction of offshore wind farms yields various benefits, the distribution of which should be accounted for in studies addressing the economic dimensions of marine space utilization (Allan et al., 2020; Connolly, 2020).

The seven wind farm projects analysed in this article located in Poland have a minimum offtake price mechanism granted, but in Europe, projects are increasingly being developed on a so-called 'zero-subsidy' basis—that is, on fully commercial terms. Individual countries extract various contributions, including royalties, taxes and other outlays, from offshore wind farm developers as a condition for the permission to use the space and develop projects. Some of the contributions are intended as a kind of compensation for the distribution of benefits resulting from the construction of offshore wind farms and are directed to a precisely defined group of recipients—for instance, through the direct mechanism of opportunities for business participation in the project for residents and entities of coastal regions or through funding for environmental protection in a given area (Adamiec, 2023; Gorroño-Albizu et al., 2019).

The elements of compensation for possible losses resulting from OWE development vary from country to country, including within the EU. Some of them are mandatory in character and are precisely calculated by the organizer of the tender for access to sites for the construction of offshore wind farms, while at other times, developers take it upon themselves to establish relationships with specific interest groups. Developers actively pursue substantial support for the implementation of OWE projects, recognizing that proceeding with an investment amidst unresolved conflicts of interest could severely hamper or, in severe cases, entirely derail project development. Therefore, developers are prepared to incur the cost of managing the distribution of economic benefits by committing resources and capital in order to build or maintain public acceptance at key points.

On the one hand, the implementation of the goals established in the Green Deal policy brings benefits to society as a whole through access to secure renewable energy and offers the possibility of independence from fossil fuels; on the other hand, it brings some challenges. Basing decisions on the use of marine space for the implementation of the energy goals set out in the Green Deal can contribute to more efficient management of marine space and, as a result, measurably help to achieve the energy goals, especially in regard to the construction of OWE, which is an important element of the Polish and EU energy strategies.

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Article

The Perception of Polish Business Stakeholders of the Local Economic Impact of Maritime Spatial Planning Promoting the Development of Offshore Wind Energy

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Abstract: The recently adopted maritime spatial plan for Polish sea waters promotes offshore wind farm (OWF) development. The study's identification of the local municipalities affected by offshore development was based on the plan's provisions. Through the analysis of the plan and literature findings, both positive and negative impacts of future OWF development were identified and examined. Such an analysis seems to be a precondition for the more active engagement of local stakeholders in the debate on the ways in which to best utilize the new opportunities created by the plan and cope with the threats resulting from maritime spatial planning (MSP). The key impacts recognized by the local business stakeholders have been related to landscape pollution and fishing limitations. Stakeholders less frequently have noticed positive impacts of MSP such as development of a new form of tourism. Up to this point, small municipalities have not undertaken sufficient action, and there is a lack of communication between developers, marine planners and coastal communities. Planners have not assessed the impact of their plan on local economic development. The proposed remedies cover standard actions related to communication, education and dialogue, but in addition to that, a consolidated action of local municipalities on how to capitalize on OWF development has been proposed. The first step proposed is preparation of a joint strategy by coastal municipalities addressing this issue.

Keywords: maritime spatial planning; offshore wind development coastal municipalities; Poland; social acceptance

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1. Introduction

Maritime spatial planning (MSP) is considered a relatively fresh territorial governance mechanism [1]. The sea represents a new domain of spatial planning, and the ambition of MSP is to link the spatial development of sea and land [2]. According to the EU MSP directive [3], until March 2021, the entire sea space under the jurisdiction of EU countries should be covered by maritime spatial plans. In many countries, MSP is driven by global concerns, including, among others, climate change. Resultantly, vast sea areas in EU territory have been allocated for offshore energy generation [4]. Undoubtedly, such a spatial decision will influence development on land. However, this development runs a risk of failure if it disregards the needs and concerns of the local population and if local stakeholders are unaware of the opportunities and threats related to MSP. Thus, MSP should be accompanied by actions taken at the local level, as in the case of Agenda 2030 [5]. In this context, local leadership and the local public choice process, i.e., a proactive attitude shown by the local administration [6], are of utmost importance. Yet, in many MSP cases, these elements are absent and MSP remains a top-down process [7].

The Polish maritime spatial plan was adopted in May 2021. More than 8% of Polish sea areas are allocated to offshore energy. According to the Polish National Energy Strategy, by 2030, there will be approximately 5.9 GW and by 2040, between 8 and 11 GW capacity installed at offshore wind farms [8]. This offshore boom partially stems from the recently enforced policy inhibiting the construction of wind farms on land as a result of several negative externalities, such as landscape pollution, impact on the health of local citizens, etc. One of the reasons behind the setback was the implementation of the 10H rule, which requires a minimal distance, from the wind device to the nearest building or natural protection areas, of at least ten times the height of the device [9]. Such a policy shift is expected to become a game-changer, shifting the production of wind energy from land to sea.

The problem is that the economic impacts of MSP have never been addressed, systematically, on a local scale. Moreover, overshadowed by more significant impacts, e.g., those linked to climate change, several others have been forgotten entirely. Yet, such "hidden" impacts will appear at separate geographical scales and with different time lags. For instance, as MSP remains the responsibility of Poland's national government, in preparing the key local assumptions, the local and even regional consequences have not been considered carefully. Consequently, without the proactive approach of the stakeholders affected by them, the local or regional impacts would remain unclear. However, the time lag between the adoption of the maritime plans and their actual results renders those stakeholders falsely calm and unaware. They are unable to estimate or make an informed guess on the goods and bads resulting from MSP development. Without previous relevant experience, they lack sufficient knowledge and know-how regarding the essence and magnitude of these impacts that influence their welfare. Thus, they may remain unprepared and unable to take part in policy discussions, and, when the impacts appear, it may prove too late to require an overhaul of the policy set-up. Such a turn of events will negatively influence development at a local scale.

Resultantly, this paper aims at identifying the aforesaid MSP impacts (related to offshore energy) at a local scale and mapping the local business stakeholders' perception of them (in Poland). It suggests and tests a structured approach for fulfilling these objectives. Local scale is defined in terms of the proximity to offshore wind farms (coastal areas neighboring farms) and the scale of the business operations of the enterprises (local businesses).

This paper is a Polish contribution to the ongoing discussion of the various impacts of MSP and OWF development. The majority of these investigations have been done at a macro and meso-scale, e.g., the research of Jenniches, Weig and Schultz-Zehden, Aitken and Kannen and Ratter, among others [10–13]. The problem is that, with the exception of Jenniches, who demonstrated how to measure the regional economic and environmental impacts of terrestrial wind energy development by taking into consideration the differences in the environmental and socioeconomic structure among the regions/territories affected [10], these studies were not spatially explicit. A number of studies that focus on the local stakeholders' perceptions of OWFs or MSP exist as well. For instance, Kermagoret et al. examined stakeholder perceptions of the social, ecological and economic impacts of OWFs on the local communities of the Bay of Saint-Brieuc in France [14]. Similar studies have been conducted at a meso-scale [15]. However, these studies focused mainly on the identification of perceptions and the acceptance mechanisms. The added value of this paper consists of linking these two different perspectives: the one related to the stakeholders' minds and the one concentrating on local territorial development. The logic is the following: the mapping of perception informs public choice, public choice influences market decisions, inducing development at a local scale, and this changes the attitudes of stakeholders accordingly, providing a feedback loop in the entire process.

2. Research Strategy, Methods and Setting the Scene

The following research strategy was adopted in this paper. Firstly, based on the literature review, the positive and negative economic impacts of OWF development at a local scale were identified. Secondly, relevant local business stakeholders in Poland potentially affected by OWF development were pinpointed and their stakes analyzed. The selection of stakeholders was based on their input in the local development (representativeness of the economic structure of the local areas analyzed). Stakeholder mapping allowed for the distilling of OWF impacts that are relevant for key local stakeholders driving local development. Then, this information was used for conducting in-depth interviews which led to the identification of the local stakeholders' awareness regarding the risks and opportunities created by OWF development, as well as to the assessment of their level of preparedness.

Finally, the stakeholders' opinions and knowledge were juxtaposed with the experiences of other countries in which offshore wind farms are operating on a large scale. All these factors served the aim of formulating conclusions on the necessary steps that would lead to local coastal communities in Poland being better prepared to more vigorously exploit the benefits of offshore wind farm development and mitigate or adapt to impacts that negatively affect the area's welfare. The methodological scheme is presented in Figure 1.

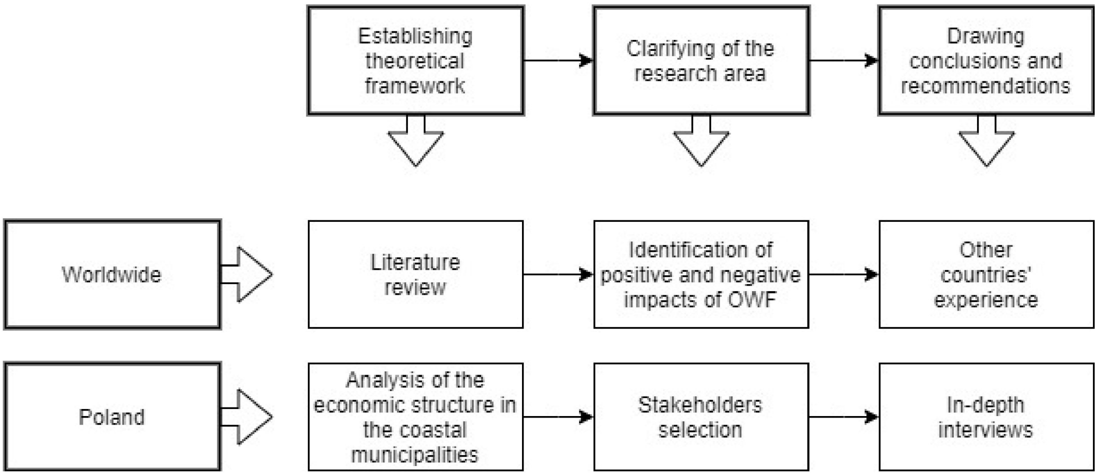

Figure 1. Methodological scheme.

2.1. Good and Bad—Literature Review and Theoretical Framework

The relevant literature demonstrates that, despite the careful engagement of stakeholders, offshore wind farm development still brings both benefits and burdens. The most thoroughly researched negative impact at the local scale, extensively discussed even before the deployment of OWF installations, has been the aesthetic issue [16], otherwise referred to as landscape industrialization. According to the study conducted by Sullivan et al. in 2011 in the Irish Sea and North Sea (on 11 offshore facilities that varied from 80 m to 126 m in rotor diameter size), in different weather conditions, moderately sized (in terms of number of turbines) offshore wind facilities may be visible from distances exceeding 35 km. Smaller wind facilities were judged to be easily visible at distances of 22–25 km [17]. Since the research, the dimensions of installed offshore facilities increased and can be more than double the size of the facilities observed in 2011, the GE's Haliade-X with its 220 m rotor diameter representing such an example. Alongside the number of turbines and OWF area, the study on the efficiency of European offshore wind farms counts the distance to shore as one of the key factors determining landscape pollution. For the purposes of assessing the impact score, the distance from shore ranging between 20–30 km is scored as 3 (where 5 is the maximum score and 1 is the minimum score for a distance exceeding 40 km) [18]. Landscape industrialization may result in a significant welfare loss [19]. According to Gee, the threat to the open horizon posed by the presence of an offshore wind farm could produce feelings of anxiety among people emotionally tied to the sea [20]. Other key problems prominently highlighted in the relevant literature concern the visual impact of OWFs on the recreational demand for the beach. Voltaire et al. conducted a wide survey among Catalonian tourists to estimate the loss in prosperity that may result from a shift in beachgoer behavior [19]. The study proved that the potential economic loss in touristic regions is significant but depends on the distance to shoreline and density of turbines within one project [19]. While researching public acceptance of OWFs, Roddis et al. also acknowledged that visual pollution may impact local tourism (including employment) and the price of local property [21] as well. The potential negative impact of Southern England's Navitus Bay offshore wind farm on the landscape represented one of the reasons for its rejection [18]. This effect on the landscape was also the reason for Polish legislators banning offshore wind farms in Polish territorial waters (up to 12 miles from the shore) [22].

Another important negative impact is related to the permanent exclusion of other sea sectors (exclusion effect). As navigation barriers, farms may cause diversions of shipping (rerouting): "Diversion can lead to following problems for the shipping sector: (1) Increased time and fuel spent, more greenhouse gas emissions, higher wages for the crew; (2) Financial penalties from the charter; (3) Higher insurance costs due to riskier routes; (4) Compliance with national and international law. Some countries have areas where certain restrictions apply, such as PSSAs in the Baltic; (5) In the case of short sea shipping, longer transit times may make short sea services unable to compete with land-based transport services" [23]. By the same token, fishing can be banned in the OWF areas or at least regulated. The restriction of fishing leads to conflicts with the fishing industry [24]. The exclusion of areas from fishing directly translates to a loss in the fishers' revenue, particularly for small-scale fisheries. OWFs might also exclude mining and the placing of communication cables in areas that belong to the farms.

The construction of OWFs may also result in new and direct negative impacts on sea environment and ocean functioning. The ecological risks of OWFs were identified by Roddis et al. [21], as well as in numerous other studies [25–27]. In particular, serious concerns have been raised in terms of the well-being of mammals and migrating birds. A number of researchers have also discussed [27] the possible implications of energy withdrawn from the OWF area (sea air) and the shape of the seabed undergoing a change that may alter existing sea currents and, subsequently, sediment transport, resulting in coastal erosion. The same authors have also identified various chemical risks related to the intensification of oil spills that occur from OWF construction and maintenance, leaks of ammonia (working fluid in a closed OWF system), toxic for sea species, leaching of toxic compounds from anti-fouling paints that are used to minimize the biological fouling of pillars. Finally, electromagnetic fields around transmitting cables and other facilities could compromise the navigation of species sensitive to electro- or magnetic fields, primarily fish [28].

Direct costs (direct effect of OWFs) are imposed on other sectors as well. In the case of OWF semi-closure, negative impacts on the fishery sector may include: accidental damage and ship strikes, snagging fishing gears and obstruction of navigation routes to and from fishing grounds [29]. Fishers' concerns are also related to water cables disrupting fishing efforts. Furthermore, OWFs may limit leisure tourism (e.g., sailing) [18] and discourage sailing through OWF areas, as well as reduce navigation safety in general [30].

Finally, several authors identified social and distributional justice as an issue. Kannen and Ratter focused on the high uncertainty that stems from social and ecological impacts, characterizing marine planning as "planning under uncertainty" [13]. The usually top-down and centrally supported OWF location processes that affect local societies may threaten the latter's integrity and normal functioning. If such processes radically change the social set-up by introducing new and powerful actors, they create an additional burden rather than an opportunity [31].

However, the list of positive impacts is long as well. The most prominent are direct ones concerning the creation of new local jobs and employment opportunities (a direct effect of OWFs). According to official estimates, the investment could generate more than 70 thousand jobs in Poland and a PLN 15 bln inflow to the central budget before 2030 [32]. Maintenance and service, responsible for nearly 19% of the total cost, form the largest part of cost breakdown in OWF investment. Operations including compensation payments, training, onshore and offshore logistics and health and safety inspections are responsible for 9.3% of the total investment [32]. The value of maintenance and services needed to support Polish offshore farms over the years will amount to approximately PLN 4 bln and operations another PLN 2 bln. The local companies could benefit greatly since all these services can be provided locally. Local port facilities can offer room for the providers of these services. Thus, sectors that are traditionally linked to local economy, such as the fishery sector, for instance, but seaport services and their infrastructure could also be potential beneficiaries. They can be included in the offshore wind farm supply chain. Additionally, farms could become a suitable place for the development of mariculture activities, facilitating the further diversification of the local economic base. There will be a multiplication effect as well. New employment will increase the demand for local goods and services, at least partially driving up the demand for goods and services offered in local stores and other service facilities. Moreover, due to an increase in income tax revenues, partially acquired from municipal budgets (at least in Poland), a portion of these benefits will be channeled into the budgets of local coastal municipalities. Power connectors, from the sea to national grid, will be located near the shore as well, providing additional income from property tax. Richer local communities will be able to better support local development.

Landscape industrialization may have some positive implications as well. OWFs could attract tourists interested in visiting the farms, allowing for the development of new forms of tourism, e.g., recreational boating or short sea-touring [33] operated by local companies.

The environmental benefits are related mainly to the climacteric ones [31]. Access to clean energy would improve the image of local tourist places and attract new tourists and inhabitants. OWFs have numerous positive impacts on marine and coastal habitats (habitat effects). For instance, the farms may act as artificial reefs. Research has shown that artificial reefs may exert a restorative effect on degraded natural habitats [25]. The macroalgal habitat in the Korean peninsula, created from artificial reefs, represents such an example. OWF pillars could offer new opportunities for mussels and benthic species. The result is increased biodiversity but also an improved ecological situation of sea waters stemming from the filtrating services provided by shellfish. The enrichment of biodiversity could provide an opportunity for recruiting commercially valuable marine species, a byproduct recognized as the "reef effect", identified in the North Sea [34]. A sheltering effect is a yet another benefit [28]. Because of the restriction of navigation or fishing within the farms, larger-scale OWF areas will act as maritime protected areas. "Thus, they may serve as recruitment sources for the adjacent fishing areas" [27]. As a result, fishers will be granted access to more abundant fish stock in the long run [35]. However, one should note that, while the artificial reef may stimulate some species, it may adversely affect others [36]. However many of these ecological benefits could also translate into additional economic ones, as in the case of fisheries or by attracting tourists and new inhabitants. For example, an artificial reef may attract divers and result in the development of local diving companies [35].

The social benefits are related mainly to the support of weak social groups. As proved by the research, many groups of fishers are content with receiving compensation for restrictions in access to the fishing grounds. A number of authors [35] also mention modernization opportunities, i.e., the inflow of new know-how, better prospects for the development of local start-ups due to increased awareness on a local scale and an improved local economic situation (i.e., diminishing outflow of young, well-educated people, inflow of top specialists, etc.).

All the impacts identified in this section are summarized in Table 1. They are grouped according to the well-known energy trilemma, which refers to the trade-offs between economic impacts, environmental impacts and social/civic impacts [37].

Table 1. OWF positive and negative impacts on a local scale.

Type of Impact	Source of Impact	Negative	Positive
Impact on local economic development	Landscape industrialization	Discouraging beachgoers and other types of coastal tourists Negative impact of a decrease of local tourism on other local industries Reducing prices of coastal real estate	Attracting new tourists interested in seeing OWF Positive multiplication effect from local tourism to other local industries
	Exclusion effect	Higher costs of navigation, diverting navigation from local ports near OWF Closing traditional fishing grounds and impeding access to functioning ones	Increasing abundance of commercial fish species (sanctuary effect)
	Direct effect	Baltica 3 Accidental damage and ship strikes, snagging fishing gears Discouraging leisure tourist sailing within OWF Negative effect on navigation safety	New jobs in maintenance and operation of OWF and in mariculture, new services in local ports Increased budgets of the local communities
	Habitat effect		Increasing abundance of commercial fish species due to increased biodiversity. Cleaner sea waters attracting new tourists and inhabitants Attracting new tourists for diving in OWF area
Impact on environment	Habitat effect	Changing composition of species	Cleaner sea waters Increased biodiversity
	Direct effect	Risk of erosions Risk of chemical pollution Direct threats to migrating birds, mammals and some fish species	
Impact on local social well-being and decision-making process	Landscape industrialization		Feeling of anxiety among people emotionally tied to the sea
	Social effect	Political encroachment compromising social justice	Opportunity for modernizing coastal societies Support for weak social groups

2.2. *Stakeholder Mapping—A Short List of OWF Impacts*

In order to establish a link between the perceptions of local stakeholders of OWFs and the process of local development, the economic structures of the local areas affected by OWFs were analyzed first. On this basis, the relevant group of stakeholders, i.e., those driving local economic development, was identified.

OWF farms will be located primarily in the north-central part of the Polish sea waters. Based on the proximity to OWF investments, 8 municipalities were identified as areas locally impacted by OWF development: Darłowo, Postomino, Ustka, Smołdzino, Łeba, Choczewo, Krokowa and Władysławowo.

Table 2 presents the basic characteristics of the selected municipalities, thus providing a general overview; they have low population density and are short in resources when compared to bigger urban agglomerations. The number of inhabitants of the 8 municipalities combined is less than 40% of Gdynia's population (244 thousand inhabitants) and less than 20% of Gdańsk's (559 thousand inhabitants).

Table 2. List of the 8 municipalities and their basic characteristics. Source: own study based on Statistics Poland data.

Municipality	Number of Inhabitants	Area (km^2)	Urban Density	Budget (PLN Thousand)	Seaport
Władysławowo	15,388	42	366	98,908	Yes
Krokowa	10,816	214	51	69,812	No
Ustka city	15,367	10	1537	92,562	Yes
Ustka rural municipality	8339	227	37	51,153	No
Darłowo rural municipality	7949	269	397	64,893	Yes
Darłowo city	13,695	20	51	81,045	No
Postomino	6891	227	30	51,176	No
Choczewo	5495	183	30	29,734	No
Łeba	3675	15	240	29,738	Yes
Smołdzino	3398	260	13	16,479	No

According to the research of Szejgiec-Kolenda et al., maritime economy has been developed intensively only in certain areas of the Polish coast [38]. In general, the area surrounding the Gulf of Gdańsk is more developed than the northern coast, in which the eight selected communes are located [38].

As presented in Figure 2, the tourism sector plays a key role in the economy structure [38] of small coastal communities. In the latter, many individuals earn a living from their privately owned guesthouses, run as family businesses. During the 3-month summer season, touristic coastal cities are inundated by crowds of visitors, leading to seasonal profits for the habitants, revenues that constitute the main source of total annual income. In 2019, more than 600 thousand tourists visited the abovementioned 8 municipalities [39]. The statistics are drawn from official data which may not necessarily reflect reality as it does not include zones that are not officially registered. As such, the numbers in reality may be greater. For instance, on Booking.com, the total number of advertisers is much higher than in the official statistics. Table 3 presents a comparison of each municipality's basic data on tourism with the data collected from Booking.com. The data show the level of entrepreneurship in tourism as well as the sector's vast importance for coastal municipalities. According to official statistics, these municipalities have a combined number of 740 accommodation facilities, while Booking.com data indicate a higher number of more than 1200 facilities.

Table 3. Tourism in coastal communities. Source: my own study based on the maritime economy statistical data of 2019 and my research on Booking.com (accessed on 26 April 2020).

Municipality	Number of Accommodation Facilities (2019)	Number of Accommodations (2019)	Number of Tourists Annually (2019)	Number of Accommodation Facilities According to Booking.com (2020)
Władysławowo	349	17,410	255,318	566
Łeba	137	10,703	121,815	267
Krokowa	62	2245	17,752	8
Ustka	72	7085	58,171	293
Darłowo	67	6932	81,031	108
Postomino	33	4837	63,864	93
Choczewo	18	496	5414	11
Smołdzino	2	89	NA	10

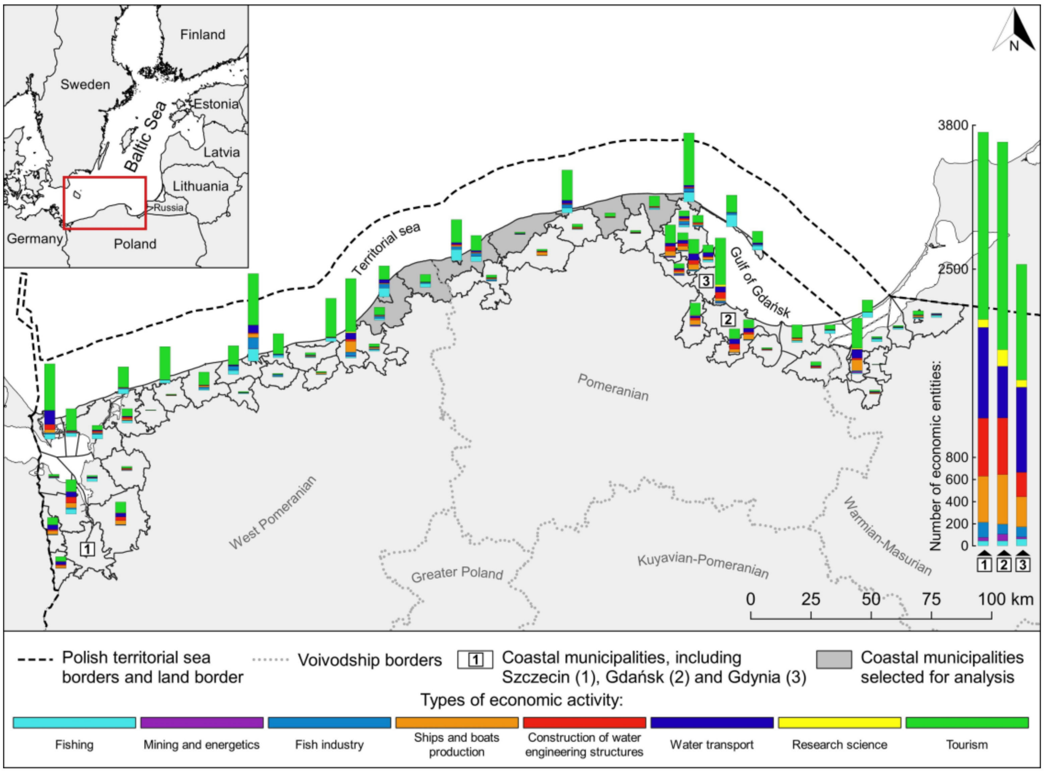

Figure 2. Number of maritime economy entities in coastal communities in 2016. Source: own study based on Statistics Poland data.

The fishery sector in Poland is under significant pressure, following numerous regulations and limitations on catches, such as the establishment of quotas on the latter. Fishers have become more skeptical and wary of any new limitations placed on their fishing areas [40]. This situation has resulted in a steep decline in fishery fleet as well as in an overall decline in this particular sector of the local economy. However, it has also made fishers sensitive to OWF development [40]. Water transport plays a relatively important role in the economy of several of these municipalities. Four (4) municipalities have one seaport each within their territory, while the municipality of Ustka has two. According to existing analyses, the port of Ustka is the most suitable for servicing OWFs [41].

In conclusion, tourism, fishery and water transport are the main engines of development for these municipalities, which offer the largest rent from marine space utilization to their citizens [42]. Therefore, the perception of the OWF impact on local development was conducted on the basis of the opinions of stakeholders from these sectors.

In line with the above analysis, all impacts have been selected from a literature review that is relevant to these key economic sectors, or drivers of local development, in the investigated area. This selection is presented in Table 4.

Table 4. OWF positive and negative local economic impacts for discussions among local stakeholders.

Impact	Tourism	Fishery	Water Transport
Positive	Attracts new tourist interested in OWF	Increases abundance of commercial fish species (sanctuary and habitat effects)	New services in local ports
	Creates new types of jobs related to the maintenance and operating of OWF, development of mariculture, development of new types of tourism (diving, OWF sea-touring, etc.) and development of ports. Presents the opportunity to modernize coastal societies. Supports weaker social groups.		

Table 4. *Cont.*

Impact	Tourism	Fishery	Water Transport
Negative	Discourages beachgoers and other types of coastal tourists due to landscape industrialization	Closes traditional fishing grounds and impeding access to the functioning ones. Causes accidental damage and ship strikes, snagging fishing gears.	Increases navigation costs, diverting navigation from local ports near OWF. Diminishes the number of leisure tourists sailing through local ports (making stop-over there).
	Encourages political encroachment compromising social justice (uncertainty)		

3. Engagement of Stakeholders in Policy Processes in Poland

Wind farms have been introduced to Polish maritime areas by two parallel efforts. The first one was related to maritime spatial planning while the second was of a sectoral character.

In Poland, OWFs were mentioned for the very first time in 2011 in strategic documents. Though the pilot plan for the Middle Bank was of an informal character, it clearly signaled the possibility of the emergence of OWFs. This document has not been widely discussed, however, and has thus remained known only among planning professionals. In 2016, the Study of Conditions of Spatial Development of Polish Sea Areas [41] was prepared by order of the Polish Maritime Administration. In this document, one chapter was devoted to the development of OWFs in Polish marine areas. Subsequently, the Maritime Authorities compiled the Polish maritime spatial plan, reserving marine space for a minimum of 11 GW of offshore wind energy, a figure that totals 8% of Polish marine areas, approximately 2342 km^2 [22]. Figure 3 presents the areas designated for OWF deployment (14.E, 43.E, 44.E, 45.E, 46.E, 53.E, 60.E), the small coastal municipalities selected for the present research, the vessel routes and the catches within the area.

The abovementioned study and plan were both subject to numerous discussions. The plan could be accepted or rejected, but, if rejected, it was required that the reasons must be clearly specified and posted on the official Maritime Administration website. OWF developers actively participated in this process. Local business stakeholders (fishers, representatives of tourism industry) were active as well, but, surprisingly, they raised only a few concerns regarding OWFs. Fishers, on the other hand, feared a potential exclusion effect as well as the creation of barriers to their traditional fishing ground. A separate meeting was organized to reach an agreement between fishers and OWF developers concerning the placement of fishing restrictions during construction and the operation of farms. Other local businesses highlighted conflicts related to the construction of a nuclear power plant, gas pipelines and typical tourist infrastructure (marinas, piers, seaside boulevards, etc.). However, the most active here were local authorities. The latter were solely concerned with the development of the tourism sector while neglecting any other opportunities for development that were provided by the plan [22]. Landscape pollution went unmentioned during public debates and public hearings. Discussions on local ports were limited to the topics of exclusion effects, such as the limited access of ships from the northern direction due to OWF construction, but only a small number of port authorities were really active. Current research from the Maritime Institute in Gdańsk and Södertörn University in Stockholm on the social sustainability [43] of Polish maritime spatial planning indicates that the low participation of local stakeholders may be partially due to communication barriers and low awareness of the plan's consequences on their welfare.

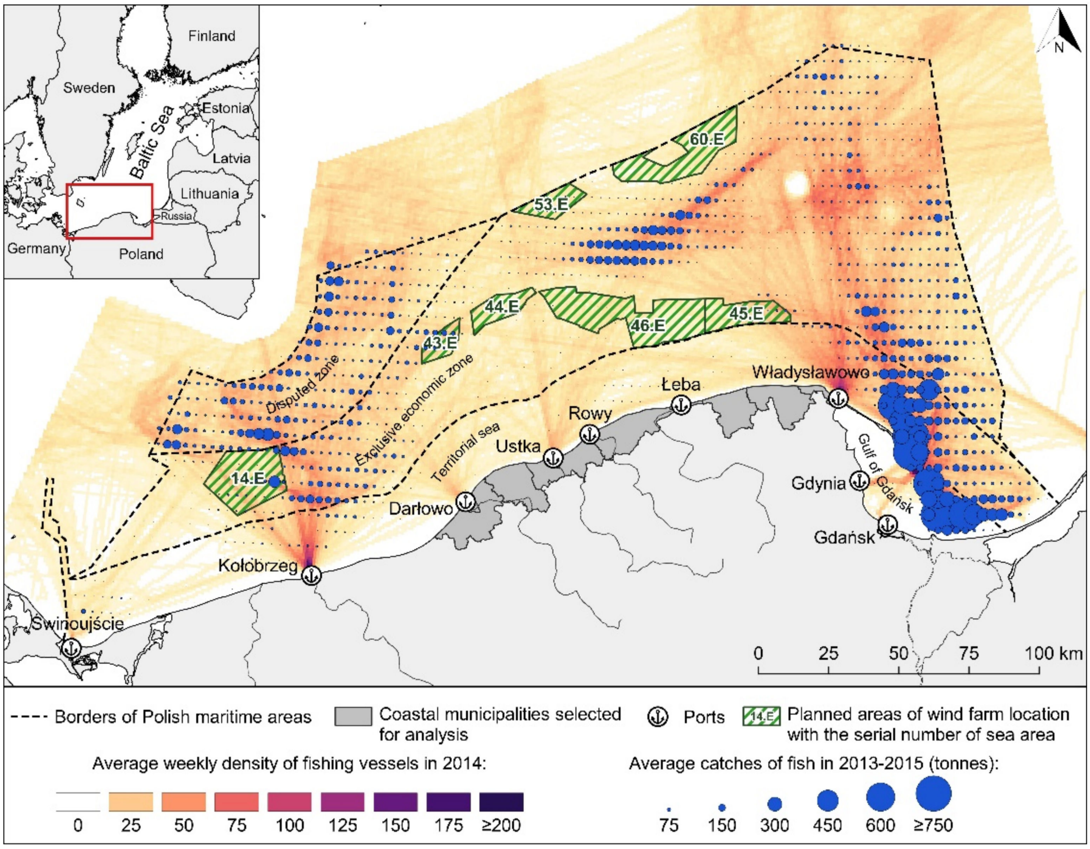

Figure 3. Average weekly density of fishing vessels and average volume of catches in the area of future OWF projects. Source: own study based on data shared by Maritime Office in Gdynia and HELCOM.

Several sectoral actions have been launched in tandem. Since 2012, the OWF sector has undertaken numerous efforts to provide information on OWF deployment (various activities of Polish Offshore Wind Energy Society (PTMEW), e.g., Offshore Academy). One of the most important was the PTMEW project, where public participation in the development of sea area plans was implemented under the program "Citizens for Democracy". It was designed to stimulate public discussion and involve key local stakeholders in the introduction of OWF to Polish marine areas. It was composed of various informational meetings in selected seaside urban centers, which took the form of seminars with the participation of local community representatives, OWF industry and the maritime administration. However, it seems that these efforts had a limited impact on the attitude of local stakeholders, who seemed to mix up various sea governance processes. For instance, they saw maritime spatial planning as being in the interest of OWF developers [44]. The OWF sector has also successfully lobbied for the support of Polish key decision-makers. On January 2021, after two years of discussions and various draft proposals, the Polish special offshore bill [45] was adopted by the Parliament. It provides numerous supportive measures aiming at the enhancement of offshore energy investments. The bill also contains several so-called local content rules, based on the UK's solutions, in order to support local businesses [46]. It requires investors to describe their planned investment with Polish entities [45]. However, the bill does not provide specifications for the location of the entity; thus, the only requirement regarding the entity is its registration or the registration of one of its branches in Poland. There is no differentiation among contractors with regards to their location. The entire economy is perceived as a whole, without lending the local perspective more prominence. It seems that the preparation of the bill failed to profoundly engage local business stakeholders. The national public administration and the representatives of the OWF sector were the dominant actors in the preparation process of the bill. No local consultations were offered, and no local effects (except some positive direct ones) were considered.

4. Polish Stakeholders' Perception of Impacts and Proposed Ways of Coping with Them

In order to gauge the complexity of the current perception of OWFs and their potential effects on coastal municipal economies, six representatives from local businesses and four others from the public administration sector, within the municipalities under investigation, were interviewed via in-depth semi-structured interviews. One respondent represented the tourism sector, four the fishery sector, one the offshore sector, two came from local governments, and two from national agencies. The interviews were conducted in the period of 21 October to 26 November 2020.

The interviewees were asked about the general impact of OWF development as well as the key impacts identified in this research. The interviews were conducted, transcribed and analyzed by coding the key elements [47].

The results, using a modified Likert scale, are presented in Figure 4. The respondents could express their level of endorsement by selecting one of five possible statements: "strongly agree", "agree", "neutral", "disagree" or "strongly disagree". Because of the relatively small number of interviews (10), the results may not be considered as representative but may offer new insights into the issues under investigation. Among the respondents, there was a strong agreement regarding OWFs' significant impact on the economies of the affected coastal municipalities (Figure 4). The majority of responses pointed to a positive impact with no clear opinion among the respondents on the potential negative impact (Figure 4).

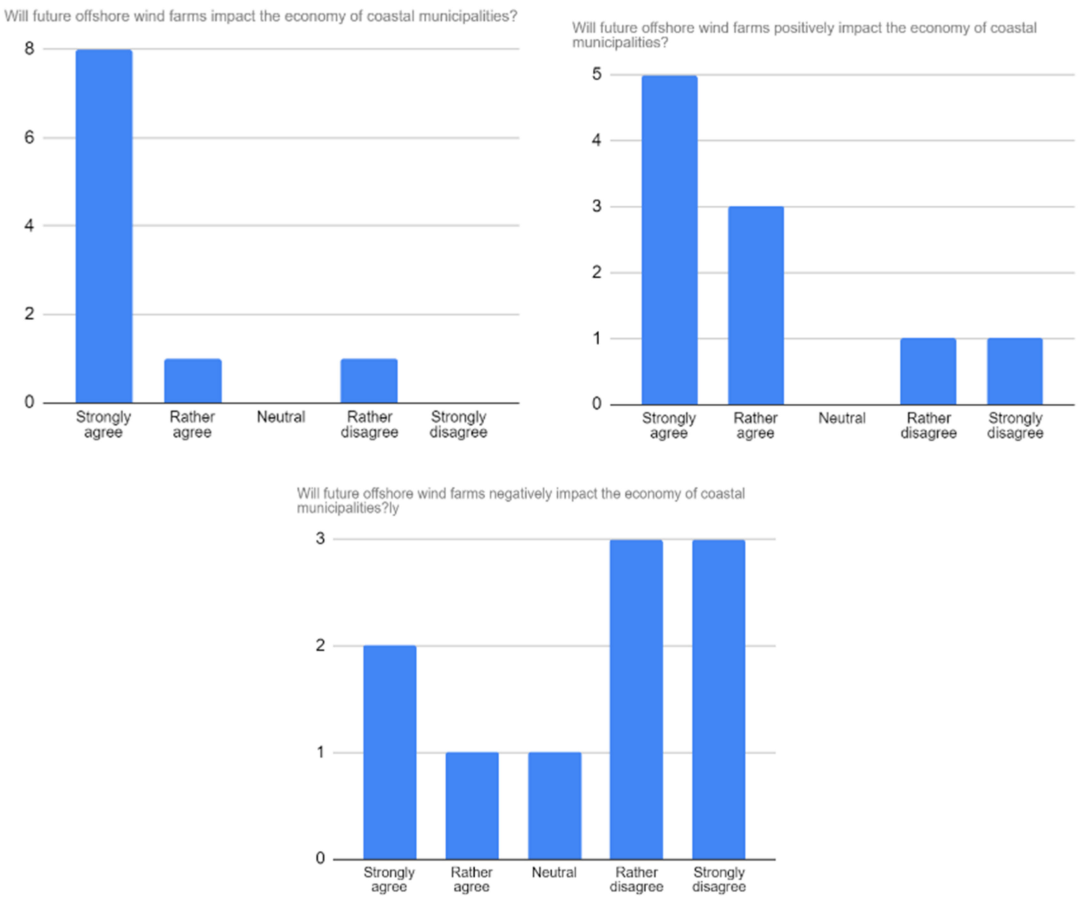

Figure 4. Results from interviews with stakeholders measured by Likert's scale. Own research.

The respondents were asked six open-ended questions regarding their awareness of the impact of OWF projects on local business stakeholders. The three main topics were discussed intensively by all respondents, who expressed clear opinions on the negative and positive impacts of OWF development as well as potential coping mechanisms.

Major concerns among respondents regarding the negative impact on the local economy included specifically landscape pollution and possible restrictions to the fishing industry. Thus far, developers have failed to properly and directly address any expected impact on the landscape, leading to confusion and very disparate opinions among locals: "In terms of imagery, these windmills make a macabre impression on me" (local business) versus "it seems to me that they add a certain charm and modernity" (fisherman). Among locals, the landscape is perceived as valuable due to their emotional bond to the seascape and the touristic sector. This further supports concerns regarding fisheries: "When it comes to Łeba, the fishermen are the most affected, because windmills will take these areas from us" (fishermen). There is a general consensus among fishermen on their compensation expectations due to restrictions in fishing zones: "And it is definitely about compensation, fishermen count on it, everything is taken from us—fishermen, we use it and we have income from it. When one fishery limits the catch or closes it, we lose the income" (fishermen). Fishers are willing to relinquish fishing areas in exchange for proper compensation: "If there will be compensation, everyone will forget about these restrictions in fisheries" (fishermen). There are positive opinions as well, though not expressed by fishers themselves: "Paradoxically, it may be that natural reefs are formed between these windmill poles and there will be more of these fish" (public authority).

Businesses seem to be distrustful of investors, something which may cause potential obstacles in terms of the businesses' participation in the distribution of potential benefits. However, expectations on potential benefits from OWF development are still popular among respondents: "The local government should act in the direction that there should be as many benefits as possible for local societies" (local business).

Uncertainty and lack of trust in political decisions, i.e., fear of political encroachment, is a key concern among respondents. The low level of information on potential business opportunities and the necessary requirements to win a contract create anxiety among fishermen: "Here, only tiny units could be used, (. . .) But other activities are more like dreams. Łeba will not benefit from it, Ustka—more likely, it has greater depths in port and if there are no Poles, they will take Danes or Germans who already have experience" (fishermen). "People in all seaside towns don't know what's going to happen, and lack of knowledge is the worst" (fishermen).

Most of the respondents confirmed being aware of future OWF development: "So far it was all held back, in the realm of dreams, and now I can see that there is a sharp acceleration" (public authority). However, poor communication between stakeholders is noticed: "Misinformation, we don't know if this will have an impact on fish populations or port traffic, so people are careful" (fishermen). The results in Table 4 reveal that, out of several positive impacts collected, local stakeholders recognized only two of them, related to artificial reefs and fishers' support (weak social group). With the exception of one navigation-related impact, negative ones were more easily recognized. Local public authorities seem to be unaware of them.

As far as remedies are concerned, local business representatives expressed apprehension regarding the improvement of knowledge: "Investor companies should begin actively operating in local communities. In order to build a positive image of these enterprises, (. . .) and show what the benefits for the region will be" (local business). However, others oppose this idea: "The commune should act, make people aware, but not through the investor who will butter us up" (fishermen); "It's obvious that the investor will strongly encourage OWF development and will show only its positive aspects (. . .) and will not disclose what threatens us" (fishermen); and "they may tell us what will be convenient for them" (fishermen). Therefore, many interviewees emphasized the role of local government as a mediating agent between locals and investors, but this role could prove difficult since the problem is highly complex and small communes may lack competences. Respondents do not feel confident in their own representatives' abilities to create fair round-table discussions: "This local government is here to work for our benefit, our society, and I am afraid it is not being done the way it should" (local business). Until now, commitment and cooperation among local governments on that issue have not been observed; on the contrary, some signals indicate that municipalities compete with each other. One interlocutor noticed: "Unfortunately, these local governments do not cooperate. They compete, which is very bad" (public authority).

To conclude, these opinions create the impression that local business stakeholders expect two things: a more democratic dialogue with the OWF sector and the local government's proactive engagement, e.g., sharing and building knowledge on the local impacts of OWFs and assisting local business stakeholders in aforesaid dialogue. Such a partnership between local businesses and local public choice processes should improve local level preparedness.

5. Coping with Negative Impacts—Existing International Experience

In order to prepare local business stakeholders for a proactive attitude toward OWF-related MSP impacts, the existing international experience suggests applying the dialogue process (social learning), in which developers and maritime administration communicate directly with the locals [13]. Yet, due to an asymmetry of power, this is not an easy task. In general, the integration of local stakeholders in maritime spatial planning is considered to be a complex and demanding task [48]. Public spaces, policy round tables and educational programs are required in order to fill the knowledge gap and prepare the actors to participate in the process [49]. Several analyses exist of the methods of engaging local stakeholders in the processes bridging MSP and local development [32]. Participative governance is of utmost importance [50]. Maritime administration should pay more attention to the distribution of goods and bads stemming from MSP [50]. Another highly significant aspect is the support of local stakeholders, specifically the facilitation of their networking by the local public administration for the purposes of building their preparedness and strengthening their negotiation and bargaining power. The German experience best illustrates this idea. In order to offer all the functions demanded by offshore wind operators, under the LO-PINOD framework, a few German ports in Schleswig-Holstein created a common strategy in response to an OWF project located in their vicinity [50]. Such a strategy allowed them to coordinate their actions and devise an offer of becoming an attractive partner for OWF developers [51]. By joining forces and creating a cluster, German municipalities used their assets, close location and an improved lack of strong infrastructure. Coordinated actions undertaken by regional ports let them lobby using one, stronger voice, which expressed the common goal. The German case is an example showing that the cooperation of a few small seaports can become effective but needs to be established deliberately.

6. Ways Forward—Recommendations for Public Choice Processes

The analysis of the three topics raised by the interviews yielded several additional solutions for improving the preparedness level of coastal municipalities. The most important seems to be multi-level governance, i.e., the consolidated action of local municipalities possibly facilitated by an upper level of governments, NGOs and academia. The experience of other countries may inform this type of governance. There is much space to improve and create a platform of cooperation between coastal municipalities so that they may use a collective voice in ensuring the upholding of their self-interests. Such cooperation could continue to evolve organically in a cluster of offshore wind farms, by offering a wide range of services for OWF investors and operators.

The first step entails a common strategy among coastal municipalities on how to capitalize on OWF development and prevent any risks stemming from the process. The strategy should address the identification of business opportunities, an analysis of OWF-related risks and opportunities for locals, the conscious development of new competencies and necessary infrastructure and the collection of convincing evidence on potential OWF-related tourism and fishery losses. In order to ensure the necessary synergies as well as counterbalance the economic power of OWF developers (the overhauling of the strategy building process by the vested interests), this strategy should be jointly developed by all affected coastal municipalities.

Secondly, this strategy should become a vehicle of communication between local communities and OWF developers. The municipalities should communicate their expectations to the developers. This would greatly improve the level of trust and understanding between these small coastal municipalities and investors. In addition, the participation of a social intermediary, such as an NGO or scientific organization, would also prove helpful. Proper preparation for these discussions and provision of credible evidence is of the utmost importance. The failure to take these preparatory steps during consultations with fishers, on various planning documents, is partly to blame for this group's dissatisfaction with the process of marine governance in Poland [44].

Thirdly, the strategy should inform the negotiation of the Polish Offshore Sector Deal, a declaration of good practices and intentions designed to support the national offshore sector. Unfortunately, small coastal municipalities do not seem to have actively participated in the process. The appointment of a dedicated plenipotentiary to represent the interest of coastal municipalities at the national level would be beneficial to counterbalance that of the government and business sector. This plenipotentiary may build an institutional framework that will serve to connect the presently scattered municipalities with multinational institutions, which are currently not addressing the issue of cooperation at the local level.

Finally, this strategy can serve to raise the awareness of local populations on the risks and opportunities of OWF development, a challenging task if one wants to avoid further antagonizing local societies. Similar issues to the maritime spatial planning process may arise, such as the fear of furthering the legitimization of OWF development through participation. This issue must be addressed through the introduction of political trade-offs of cost and benefits, based on the identified conflicts by stakeholders [52].

7. Conclusions

The present paper has a twofold objective. The first aim is to identify the potential socioeconomic effects of the development of OWF-related MSP for small coastal municipalities in Poland and the specific conditioning factors. The second aim is to examine the perception of small coastal municipalities and investigate potential methods of increasing their benefits, while preventing risks, from the new types of maritime spatial development as well as propose effective policy and research measures that may lead to an improvement in the level of their preparedness. As far as the second objective is concerned, one can conclude that despite the visible acceleration of MSP in Poland and the indisputable fact that this process will impact coastal communities and their economies sooner rather than later, local societies are simply not prepared to meet the challenge. The main challenges are related to communication, a mismatch in popular knowledge (problems with knowledge integration) and a lack of leadership in structuring the coastal municipalities' response to MSP results, i.e., OWF development. Thus far, the minimal necessary level of trust among the affected actors has not been reached and there is no clear strategy on how to proceed. The clear risk here is that, in the absence of a proactive approach from local communities, the potential benefits may be either reaped by international actors or be divided in an ad hoc manner under the surveillance of the well-organized marine sectors. However, one should note that the current research revealed some limitations of the approach applied. They were related to:

- Data deficits: a lack of credible and recent data on catches (artisanal fishery) and tourism creating problems in assessing the real trade-offs related to OWF development in Poland.

- The small number of stakeholders who participated in in-depth interviews: for many of the individuals approached, the subject was entirely new and they were unwilling to express their opinions. This may create a research bias in the obtained results.

Finally, this paper reveals several important tasks for the research community. In order to facilitate the preparedness of coastal societies for the new forms of offshore development as well as equip them with the necessary skills and information that will increase their engagement in decisions on strategic trade-offs, new knowledge and know-how are necessary. The following tasks should be encouraged:

- More in-depth research on various economic, environmental and social consequences of MSP, with a particular focus on OWF;
- Systematic measurement of offshore spatial rent from various maritime uses;
- Organized pressure on improving the collection of available offshore economic data by specialized statistical agencies and launching the collection of data that are not systematically compiled, particularly data relevant to coastal tourism;
- Inventing and testing simple, user-friendly communication of research results that may be of interest to local communities;
- Participating in and facilitating dialogue between coastal communities and business entities in relation to MSP and the development of terrestrial territory;
- Analyzing and disseminating relevant experience from other countries and similar processes.

Neglecting the crucial role and importance of local stakeholders in MSP may become an obstacle rather than an opportunity. Close cooperation between the local government and non-government organizations is required at this juncture in the MSP process. The inclusion of third parties in this process is necessary for creating a suitable platform for democratic discussion without the risk of impartiality. A commitment to better education, information flow and other activities that will lead to an increase in social participation is an investment for a successful long-term relationship with the local community.

The current research should be continued and deepened in the following directions:

(1) The present study should ideally be succeeded by a survey on the perception and preparedness of stakeholders in the small coastal municipalities related to OWF development. This would result in obeying more rigorous standards of representativeness and a more reliable picture of what stakeholders know in fact on the OWF impact (assessment of the stakeholders' knowledge of OWF impact on local development).

(2) Existing databases of Polish enterprises should be used to identify the potential beneficiaries of offshore energy development that can be part of the value chain of the Polish OWFs (as suppliers). The international experience in this field should be investigated, and in-depth interviews with stakeholders should follow.

(3) Finally, in-depth interviews should be conducted with a variety of local stakeholders in order to identify the level of social acceptance, among small coastal communities, of offshore wind farm development. A screening of the general public's opinion is of key importance in this case.

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Spatial distribution of economic benefits from offshore wind development: case studies of Poland and the United Kingdom

Przestrzenna dystrybucja korzyści ekonomicznych z rozwoju morskiej energetyki wiatrowej: studia przypadku Polski i Wielkiej Brytanii

Abstract: This paper compares Poland, an emerging offshore wind market, with the United Kingdom, the European leader in the sector, to explore how economic benefits from offshore wind are distributed spatially. The Spatial Economic Benefit Analysis (SEBA) method was applied and refined by integrating an economic dimension, enabling the estimation of contract values and their geographical allocation. The study covers 18 projects, linking supply chain actors with contract packages to assess spatial concentration. Results show that supply chains tend to cluster: in the UK, a mature industrial belt has developed around the southern North Sea, spanning the British, Belgian, Dutch and Danish coasts, serving both British and international markets. In Poland, Tier 1 contracts are largely secured by foreign firms, though domestic actors are visible in coastal and metropolitan clusters. With further offshore wind development in the Baltic Sea, Poland could play a central role in a regional supply hub, provided policy frameworks are strengthened to support local content.

Keywords: offshore wind, local content, spatial distribution, supply chain, coastal regions, SEBA.

Zarys treści: Artykuł porównuje Polskę, wschodzący rynek morskiej energetyki wiatrowej, z Wielką Brytanią, będącą europejskim liderem w tym sektorze, w celu zbadania przestrzennego rozkładu korzyści ekonomicznych wynikających z rozwoju morskiej energetyki wiatrowej. W badaniu zastosowano metodę Spatial Economic Benefit Analysis (SEBA), rozszerzoną o wymiar ekonomiczny, co umożliwiło szacowanie wartości kontraktów i ich alokację geograficzną. Analiza objęła 18 projektów, łącząc podmioty łańcucha dostaw z kontraktami w celu identyfikacji koncentracji korzyści ekonomicznych. Wyniki wskazują, że łańcuchy dostaw mają tendencję do tworzenia klastrów: w Wielkiej Brytanii powstał dojrzały pas przemysłowy w południowej części Morza Północnego, obejmujący wybrzeża brytyjskie, belgijskie, holenderskie i duńskie, obsługujący rynek brytyjski i globalny. W Polsce kontrakty Tier 1 w dużej mierze realizują podmioty zagraniczne, choć widoczna jest aktywność krajowych firm w klastrach nadmorskich i metropolitalnych. Wraz z dalszym rozwojem morskiej energetyki wiatrowej na Bałtyku Polska może odegrać kluczową rolę w tworzeniu regionalnego hubu dostaw, pod warunkiem wzmocnienia ram politycznych wspierających local content.

Słowa kluczowe: morska energetyka wiatrowa, local content, dystrybucja przestrzenna, łańcuch dostaw, regiony nadmorskie, SEBA.

Introduction

Europe's transition to renewable energy and enhanced energy security has been significantly bolstered by the expansion of offshore wind development, particularly in reducing reliance on fossil fuels. The United Kingdom leads Europe in this sector, with 52 operational offshore wind farms representing over 15.9 GW of installed capacity (The Crown Estate, 2025). In contrast, Poland is embarking on its offshore wind journey, with its first 1.2 GW offshore wind farm (OWF) scheduled for grid connection in 2025 and an ambitious target of nearly 6 GW installed capacity by the end of 2030 (Adamiec, 2023). While offshore wind implementation is crucial for energy security and the transformation of Europe's energy mix, it also raises important socioeconomic considerations regarding the distribution of economic benefits, especially concerning local content creation (Glasson et al., 2022; van der Loos et al., 2022).

This paper examines the spatial economic benefits of offshore wind projects in Poland and the UK, comparing supply chains at different stages of development and their regional distribution. The study assesses the contribution of domestic companies to offshore wind through products and services, while also analyzing the regional location of supply chain activities to capture spatial patterns. The comparative perspective between the mature UK market and the emerging Polish case highlights differences in supply chain configuration and the factors shaping these patterns. (World Bank Group, 2021).

Examining the spatial patterns of economic benefits from offshore wind farms, with a comparative focus on the Polish and British contexts, constitutes a relevant research challenge. There is still a gap in the literature on sectoral distribution and the identification of potential clusters of maritime activities in renewables. The task is particularly difficult in countries at an early stage of development: in Poland, with no operational offshore wind farm in the first half of 2025, the sector is still emerging, but expected to expand rapidly in the coming years (Adamiec, 2023). Consequently, this study should be understood not only as an ex-post assessment of existing spatial patterns in a mature market such as the UK, but also as a forward-looking attempt to explore potential trajectories of offshore wind sector development in Poland with the UK as a reference.

The growth of offshore wind energy creates new types of economic activities, but its effects are unevenly distributed, depending on supply chain structures and the capacity of domestic firms to participate (Biniek, 2017). Essentially, this involves determining whether the economic advantages generated remain localized to coastal regions, extend nationally, or reach beyond to areas furnishing the necessary spatial and infrastructural resources for offshore wind energy development (Saunders et al., 2020). This research seeks to geographically address these benefits through a detailed analysis of supply chain localization and regional economic integration within the offshore wind sector in Poland and UK (Kosek et al., 2025; Stebbings et al., 2020).

In this context, the concept of local content, understood as the proportion of national and regional entities participating in offshore wind projects, encompassing the supply of components, engineering services, logistics and operational and maintenance activities, becomes critically important. Van der Loos et al. (2022) argue that local content is an outcome of the interactions between public policies, industrial strategies and global value chains, which rarely facilitate complete localization. Therefore local governments are looking for strategies to maximize the local economic benefits from such projects, even though they might initially be limited in contexts with scarce pre-existing industrial capabilities (Allan et al., 2020). Local governments play a pivotal role in shaping the economic landscape for offshore wind development by establishing legal and financial conditions necessary to attract investment. Governments can also influence the geographical distribution of these benefits by encouraging the localization of supply chain activities and nurturing regional industrial growth (Kahouli & Martin, 2018; Poulsen & Lema, 2017).

This complexity necessitates a granular examination of supply chain structures to accurately assess the degree of local economic integration and identify opportunities for enhancing domestic participation. This paper seeks to provide a comprehensive understanding of how varying sector maturity and industrial capabilities in Poland and the UK influence the spatial patterns of economic benefits, particularly focusing on the extent to which local content is fostered.

The offshore wind supply chain is not static - it evolves alongside the maturity of the sector and the policies supporting its growth. The UK case demonstrates that a well developed supply chain, reinforced by the Offshore Wind Sector Deal, can gradually increase the share of local content with the ambitious target set at 60% by the end of 2030 (UK Government, 2025). In contrast, Poland, while only beginning its offshore wind development, can draw on the UK's experience in shaping sectoral agreements and mapping supply chains (*Offshore Wind Sector Deal*, 2021). The juxtaposition of Poland and the United Kingdom reflects the intention to compare offshore wind supply chains at very different stages of maturity. In the UK, more than 25 years of development have established the country as a European leader and a reference point for actively shaping supply chains with significant domestic participation (UK Government, 2025). Poland, by contrast, has not yet commissioned a single offshore wind farm, but aims to become a regional leader with up to 18 GW of capacity planned by 2040 (Ministry of Climate and Environment, 2021).

This study addresses the challenge of assessing spatial economic benefits in a sector that is still in early phase. The novelty of the approach lies in applying and adapting the Spatial Economic Benefit Analysis (SEBA) tool to measure the potential impacts of offshore wind development at a stage when no operational capacity yet exists in Poland. By geolocating supply chain actors and linking them with estimated contract values, the method enables an ex-ante assessment of how the sector may evolve. The analysis quantifies the participation of domestic companies in the offshore wind supply chain and interprets it in relation to key factors shaping its structure and regional distribution. In doing so, the paper proposes a framework for assessing the economic impacts of industries in formation, offering insights into current conditions and future trajectories.

Theoretical background

The Blue Economy has been increasingly recognized as an important driver of regional development, generating both direct and indirect spillover effects across multiple sectors of the economy (Czermański et al., 2024; Jenniches, 2018; Zaucha, 2018). Land-sea interactions (LSI) provide a useful analytical perspective for understanding how maritime activities are linked to inland economic structures (Kidd et al., 2019; World Bank, 2022; Zaucha, 2019).

Evidence from Poland demonstrates the scale and uneven distribution of such impacts: the national blue economy was estimated at EUR 12.9 billion, with an output multiplier of 1.86, meaning that each euro invested generated an additional 0.86 euro in other sectors (Mogila et al., 2024). While over 75% of direct effects are concentrated in coastal regions, indirect and induced benefits also allocate to central and southern regions, reflecting strong interregional linkages and the role of manufacturing and services. These findings highlight the clustered yet interconnected nature of the blue economy and underline the need for methodological approaches capable of capturing not only sectoral, but also spatial dimensions of its development. This perspective is especially relevant for emerging maritime industries such as offshore wind, where direct local economic effects remain largely unmeasured.

The economic benefits of offshore wind energy are increasingly recognized as crucial not only for regional development, but also the social acceptance within the local community. However, how these benefits are spread across different locations depends on several factors. These include the maturity of the domestic offshore wind sector, the capacity of local supply chains and the implementation of public policies that promote local content (Sylvest, 2020; World Bank Group, 2021).

Jenniches (2018) emphasizes that the regional economic effects of renewable energy technologies, including OWF, are significant in terms of job creation, gross value added (GVA) and the development of local industrial ecosystems. The job creation effect is widely recognized in the literature with several different approaches to better estimate the number of jobs created from the wind energy development (Aldieri et al., 2020; Kahouli & Martin, 2018). Although offshore wind investments generate benefits such as new jobs, existing methodologies do not allocate them geographically. Moreover, economic outcomes extend beyond direct and indirect employment effects. The input-output (I-O) methodology is commonly used in order to better understand the blue economy sector (Mogila et al., 2021). In the context of offshore wind development there has been an I-O model created by Allan et al. (2020). According to the study, for the UK offshore wind sector, each £1 million spent locally can generate over £1.5 million in GVA and create more than 10 full-time equivalent (FTE) jobs, but this multiplier effect depends strongly on the level of local content and the geographical distribution of suppliers (Allan et al., 2020).

Economic benefits derived from offshore wind energy manifest not only offshore, but also and frequently more significantly, onshore. The deployment of new OWF projects necessitates complementary onshore activities, including installation, logistics, maintenance and infrastructure management, which collectively stimulate demand for local goods and services (Díaz & Guedes Soares, 2020). This connection is captured by the concept of land-sea interactions, which, according to Kidd (2019), have both functional and institutional aspects, making them vital for effective spatial and economic planning (Tocco et al., 2024).

Local content could be classified as an economic outcome of land-sea interactions, as the distribution of benefits depends on the location of installation ports, manufacturing facilities, transmission networks and operation and maintenance centers (Glasson et al., 2022; van der Loos et al., 2022). These elements give rise to specialized offshore wind service hubs, around which investments and employment opportunities tend to concentrate (Markard & Petersen, 2009; Poulsen & Lema, 2017). This spatial clustering facilitates the emergence of specialized skills and infrastructure, further reinforcing regional economic development (Junqueira et al., 2021). The economic impact of increasing local content in offshore wind developments has been less widely studied, yet it remains a crucial factor in maximizing the benefits for the host economy (Allan et al., 2020).

In assessing the economic benefits of OWFs, the concept of local content is of central importance. This term refers to the share of national or regional companies and resources in the delivery of offshore projects, but its definition is neither standardized nor universally applied in the international context. BVG Associates (2015) proposed a comprehensive methodology for measuring local content in the UK offshore wind sector, based on the valuation of contracts, tier-level supply chain segmentation (tiers 1-3) and geolocation of suppliers. While local content is recognized on the national level within the country's economy, there is currently lack of standardized methodology to assess the distribution on the regional level.

Furthermore, the capacity to retain economic value within a region is significantly influenced by the availability of port infrastructure, industrial facilities and a skilled workforce equipped to support offshore projects (Crowards et al., 2023). Consequently, less developed markets typically exhibit a greater dependence on foreign suppliers and expertise. As the sector matures and consistent new investments enable private capital to fund supply chain infrastructure in a particular region, the proportion of local content tends to increase (World Bank Group, 2021).

In the UK, socio-economic impacts of offshore wind are assessed through mandatory Supply Chain Plans, which commit developers to domestic value creation and are later verified against contracting outcomes and achieved local content (Glasson et al., 2022). In Poland, although developers must submit Supply Chain Plans under the CfD scheme, these contain no binding local content requirements and follow no unified methodology. As a result, data on domestic participation are self-declared, unverified and fragmented, with no national database for tracking economic impacts such as job creation or gross value added.

There is growing academic interest in measuring the spatial distribution of economic benefits from offshore wind energy (OWE). For this purpose, Weig and Schultz-Zehden (2019) proposed the Spatial Economic Benefit Analysis (SEBA), which integrates quantitative and spatial analyses to localize economic gains. SEBA provides a useful framework for assessing spatial impacts of offshore wind projects, particularly in emerging markets such as Poland.

The SEBA methodology links supplier locations, business activities and contract values to represent economic benefit flows spatially. It has been applied to offshore wind and other maritime sectors such as fisheries, oil and gas, seabed mining, tourism and shipping, demonstrating its value as a planning tool within Maritime Spatial Planning (Weig & Schultz-zehden, 2019). Its pioneering application to the German offshore wind sector revealed coastal concentration, inland industrial linkages and the international nature of supply chains, while also showing that ownership structures affect domestic participation. However, its broader use remains limited by scarce economic data. Addressing this gap, the present paper applies SEBA in an ex-ante perspective to offshore wind in Poland, in comparison with the mature UK market.

Materials and methods

The aim of this study was to examine the spatial distribution of economic benefits from offshore wind energy (OWE) development in Poland and the United Kingdom by analyzing supply chain value and its distribution. This study refines the SEBA methodology by identifying specific companies within offshore wind supply chains and estimating the value of contracts for individual projects. This makes it possible to link economic value to spatial patterns and to improve the analysis of regional economic impacts. The enhanced method also supports a more reliable assessment of local content, providing a basis for policy discussions on how to strengthen domestic participation in offshore wind development (Allan et al., 2020).

This research addresses a knowledge gap by integrating a detailed mapping of supply chain actors in Poland and the UK. The methodological framework was structured in three stages. Stage 1 examined the spatial location of offshore wind farms and service ports. Stage 2 analyzed the set of contracts that could be identified within the supply chain of each individual project. Stage 3 extended the analysis to the broader geographical distribution of entities across the entire offshore wind sector, providing the structural context for understanding supply chains. The analytical tool was refined in line with the direction proposed by Weig and Schultz-Zehden and this modification represents a significant improvement of SEBA. In this revised framework, contract values were not only mapped spatially, but also linked to their estimated economic weight, allowing for a more precise assessment of capital flows and their territorial footprint within national and regional economies (Weig & Schultz-zehden, 2019).

First, offshore wind farms in Poland and the United Kingdom were identified for analysis. The selection aimed to include relatively recent investments that could provide insights into the current status of both markets. The projects examined represent four different stages of development: (1) development phase, when preparatory work is undertaken; (2) pre-construction phase, preceding the start of offshore works; (3) construction phase, when installation activities at sea are ongoing; and (4) operational phase, when the wind farm is fully connected to the grid. The decommissioning phase was not considered within the scope of this study.

In 2021, Poland introduced a new support mechanism in the form of Contracts for Difference (CfD), which compensates the gap between the market electricity price and the fixed strike price of approximately EUR 72/MWh. All seven projects that successfully secured Polish CfD support were included in the study. The Polish projects selected for analysis are presented in Table 1, together with their basic characteristics. The expected Commercial Operation Date (COD) was estimated based on the announcements by Ministry of Climate and Environment. A key feature of the analysis is the identification of the designated operations and maintenance (O&M) port, which represents a major center of economic benefits throughout the O&M phase of the project (Kaiser & Snyder, 2013; Kosek et al., 2025).

Table 1. Polish offshore wind projects selected for the analysis
Tabela 1. Polskie projekty morskiej energetyki wiatrowej wybrane do analizy

Project	Total Power (MW)	Developers	Status	COD	Operation& Maintenance Port
Baltic Power	1140	PKN ORLEN, Northland Power	Under construction	2026	Port of Łeba
Baltica 2	1498	PGE, Orsted	Pre-construction	2027	Port of Ustka
Baltica 3	1045	PGE, Orsted	Pre-construction	2030	Port of Ustka
Bałtyk II	720	Equinor, Polenergia	Pre-construction	2027	Port of Łeba

Bałtyk III	720	Equinor, Polenergia	Pre-construction	2027	Port of Łeba
BC-Wind	399	Ocean Winds	Development	2027	Port of Władysławowo
F.E.W. Baltic II	350	RWE Renewables	Development	2030	Port of Ustka

Source: Current offshore wind farm projects, (Ministry of Climate and Environment, 2025), access 31.08.2025

By the end of 2024, a total of 52 offshore wind farms were in operation in the UK, with a combined capacity of almost 16 GW (The Crown Estate, 2025). For the purpose of this analysis, eleven of the most recent projects were selected. The selection focused primarily on projects commissioned in 2023 or later, as well as those currently under construction or in the development phase. The UK projects selected for the analysis, together with their basic characteristics, are presented in Table 2.

Table 2. UK offshore wind projects selected for the analysis
Tabela 2. Projekty morskiej energetyki wiatrowej w Wielkiej Brytanii wybrane do analizy

Project	Total Power (MW)	Developers	Status	COD	Operation& Maintenance Port
Dogger Bank A	1200	SSE Renewables, Equinor, Vårgrønn	Under construction	2025	Port of Tyne
Dogger Bank B	1235	SSE Renewables, Equinor, Vårgrønn	Under construction	2026	Port of Tyne
Dogger Bank C	1218	SSE Renewables, Equinor, Vårgrønn	Under construction	2027	Port of Tyne
Hornsea 3	2852	Ørsted	Development	2028	Port of Grimsby
Berwick Bank	4100	SSE Renewables	Development	2030	East Lothian
Sofia Offshore Wind Farm	1400	RWE Renewables	Under construction	2026	Port of Grimsby
East Anglia 3	1400	ScottishPower Renewables	Under construction	2026	Port of Lowestoft
Neart na Gaoithe	450	EDF Renewables, ESB	Operational	2025	Eyemouth Harbour
Inch Cape	1080	Red Rock Power, ESB, SDIC	Under construction	2027	Port of Montrose
Seagreen	1075	SSE Renewables, TotalEnergies	Operational	2023	Port of Montrose
Moray West	882	Ocean Winds	Under construction	2026	Buckie Harbour

Source: Offshore Wind Report 2024 by The Crown Estate UK (2025)

In total, 18 offshore wind farms with a combined capacity exceeding 22,7 GW were selected for analysis. Each project was mapped and associated to its operations and maintenance (O&M) port.

The second stage of this research involved identifying entities participating in the supply chains of the analyzed wind farms and where possible, allocating the value of their contracts. Supply chain plans, the 4C Offshore database and public announcements were reviewed to obtain information on awarded contracts. Each supplier was geolocated according to its registered headquarters. Estimated contract values were assigned exclusively to Tier 1 suppliers responsible for complete component or service packages. Due to limited transparency and the scarcity of publicly available financial data on value of service or component delivery, the methodology developed by BVG Associates was adapted. This approach made it possible to assess contract values for identified suppliers using Levelized Cost of Energy (LCOE) benchmarks.

The Levelized Cost of Energy (LCOE) represents the constant unit cost of electricity that equalizes the present value of all costs with the present value of electricity produced over the lifetime of a project, using a given discount rate (typically the Weighted Average Cost of Capital, WACC). Expressed in today's prices and excluding tax and inflation, it reflects the lifetime average cost of electricity generation. LCOE is widely employed to compare the economic performance of different generation technologies and locations (Johnston et al., 2020).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t *- Investment expenditure in year* t

M_t *-Operation, maintenance and service expenditure in year* t

E_t *-Energy generation in years* t

r *- Weighted Average Cost of Capital (WACC)*

n *– number of years*

The cost of each offshore wind farm was estimated using BVG Associates' assumptions on the expected Levelized Cost of Energy (LCOE). The average investment cost was set at EUR 2,737,000 per MW of installed capacity (CAPEX), with an annual average operating expenditure of €97,800 per MW (OPEX) (BVG Associates, 2025).

Costs were disaggregated by category and the estimated value of each category was used to approximate the contract value of the corresponding supply chain package. Developers typically contract Tier 1 suppliers for main components and services, who then subcontract to Tier 2 and Tier 3 firms. As detailed cost data are available primarily for Tier 1, values were estimated mainly at this level and to a lesser extent for lower tiers, which were mapped, but only partially quantified.

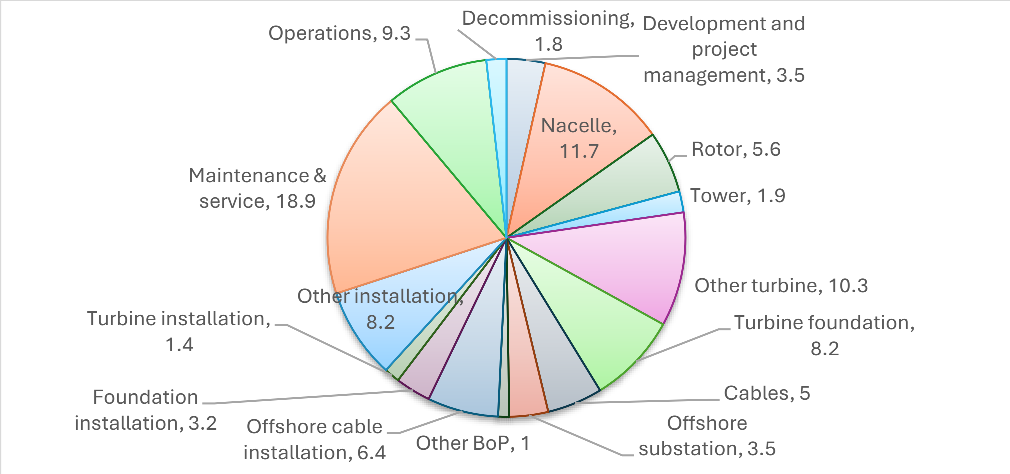

Figure 1. Contribution of each major cost element to levelized cost of energy (LCOE), based on BVG Associates (2025).

Rycina 1. Udział najważniejszych elementów w całkowitym koszcie energii (LCOE), na podstawie BVG Associates (2025).

The SEBA methodology was refined by adding a value-based dimension to the spatial mapping of supply chain actors. As shown in Figure 1, the largest costs relate to turbines and installation, with turbine manufacturers also holding long-term service contracts, concentrating both CAPEX and OPEX in a few firms. For geographical allocation, operational expenditures were assigned to the location of the service port. This refinement allows the method to capture not only the territorial distribution of suppliers, but also the concentration of economic value among specific actors and regions.

Stage 3 extended the analysis beyond project-specific supply chains to capture the wider industrial context. Companies active in the offshore wind sector were identified through industry databases: in Poland from marinepoland.com and in the UK from the Offshore Renewable Energy Catapult's 'wind' database, filtered to include firms with revenues above EUR 10 million. Each company was geolocated by its registered address, producing datasets of about 280 entities in Poland and 400 in the UK. This allowed the creation of maps to analyze spatial concentration and identify potential regional clusters of offshore wind activity.

Results

The spatial-economic examination of the offshore wind energy sector in Poland and the United Kingdom, employing an enhanced SEBA methodology, shows distinct patterns in sectoral concentration and the distribution of economic value. The findings encompass four analytical layers: the location patterns of all identified sectoral entities within analyzed economies, the mapping of contracted suppliers for representative offshore wind projects, the estimated economic value of Tier 1 contracts and a cross country comparison of structural and geographic characteristics.

First step for the analysis is the location of the selected offshore wind farms in Poland and UK. The territorial distribution of the polish offshore wind farms is presented on Figure 2.

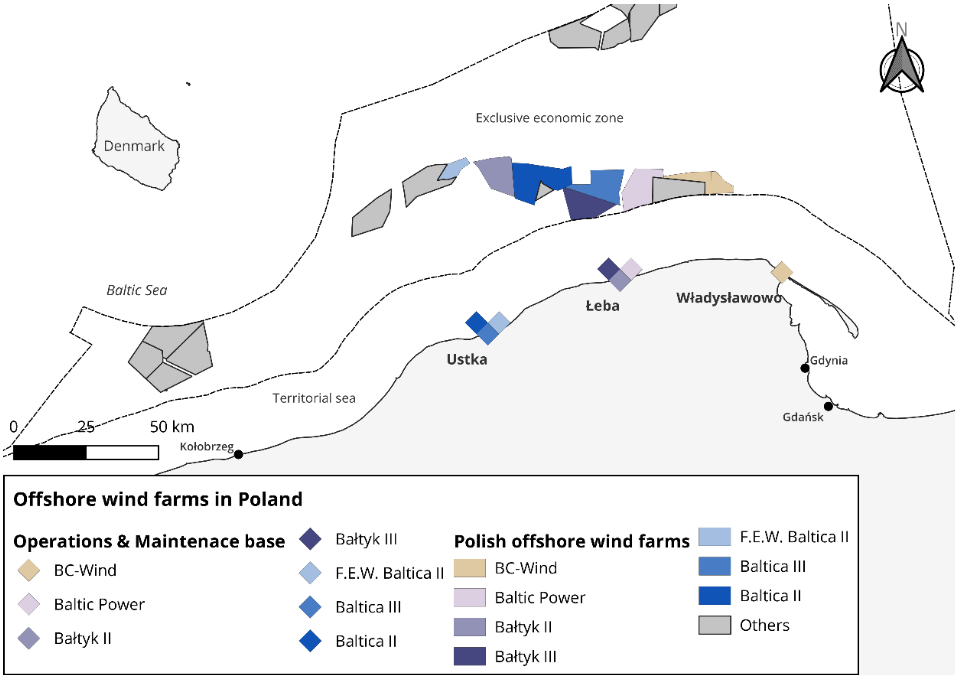

Figure 2. Polish offshore wind farms location based on Spatial Information System of the Maritime Administration (SIPAM), www.sipam.gov.pl, access 01.08.2025.

Rycina 2. Lokalizacja polskich morskich farm wiatrowych na podstawie Systemu Informacji Przestrzennej Administracji Morskiej (SIPAM), www.sipam.gov.pl, dostęp 01.08.2025.

In Poland, the planned offshore wind farms are located within the Exclusive economic zone of the Baltic Sea, in the corridor north of Łeba and Ustka, about 20–30 km offshore. The location reflects favorable wind conditions, shallow depths of 20–50 meters and short transmission distances, which reduce costs of cabling and grid connection. From the perspective of logistics, the main installation ports are Gdańsk and Gdynia, both equipped with infrastructure for handling and pre-assembling large turbine components such as nacelles, towers and foundations.

For the long-term operational phase, dedicated operations and maintenance (O&M) ports have been assigned to specific projects. Among them, Ustka and Łeba play a pivotal role: each has already been designated as the base for three offshore wind farms and this number may increase with further projects in the future. Władysławowo is also preparing to host one project, while additional capacities may emerge as the sector grows. On the map, projects marked in grey indicate early-stage developments not included in this analysis. Each analyzed project has been assigned a colour, which also corresponds to its designated O&M port marked with the same colour in the legend.

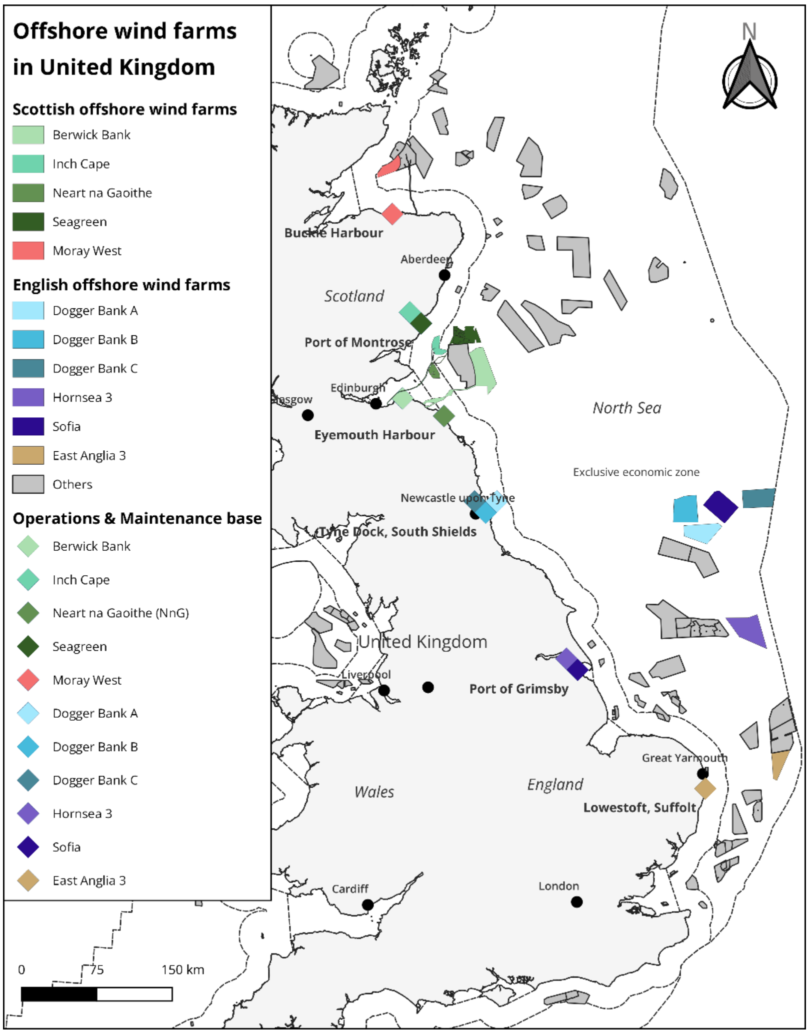

Figure 3. UK offshore wind farms location based on the Offshore Wind Map, www.thecrownestate.co.uk and Crown Estate Scotland Spatial Hub, www.crown-estate-scotland-spatial-hub-coregis.hub.arcgis.com, access 01.08.2025.

Rycina 3. Lokalizacja morskich farm wiatrowych w Wielkiej Brytanii na podstawie Mapy Offshore Wind, www.thecrownestate.co.uk oraz Crown Estate Scotland Spatial Hub, www.crown-estate-scotland-spatial-hub-coregis.hub.arcgis.com, dostęp 01.08.2025

Figure 3 shows that offshore wind farms in the United Kingdom tend to form several distinct clusters rather than being evenly distributed across the North Sea. These clusters reflect both favourable environmental conditions and areas designated by administrative decisions such as Crown Estate leasing rounds.

Three major offshore wind zones can be identified in UK. The first is in Scotland, where projects such as Seagreen are located further offshore in the northern part of the North Sea. The second is the Humber region in central-eastern England, around Grimsby, which serves as the main base for large-scale developments including Hornsea and Dogger Bank. The third is situated off the southern coast near Suffolk, where the East Anglia projects are concentrated. Each of these clusters is supported by dedicated operations and maintenance (O&M) ports, creating regional service hubs. This spatial pattern highlights the maturity of the British offshore wind sector, where emergence of several maritime clusters.

Stage 2 of the analysis focused on the value of contracts allocated within the supply chains of the selected offshore wind projects. Figure 4 and 5 present the spatial distribution of suppliers linked to the analyzed farms. Each project is shown with a distinct colour, corresponding to its supply chain, while the size of circles reflects the estimated value of the awarded contracts. This visualization illustrates both the geographical spread of contractors and the relative scale of their participation.

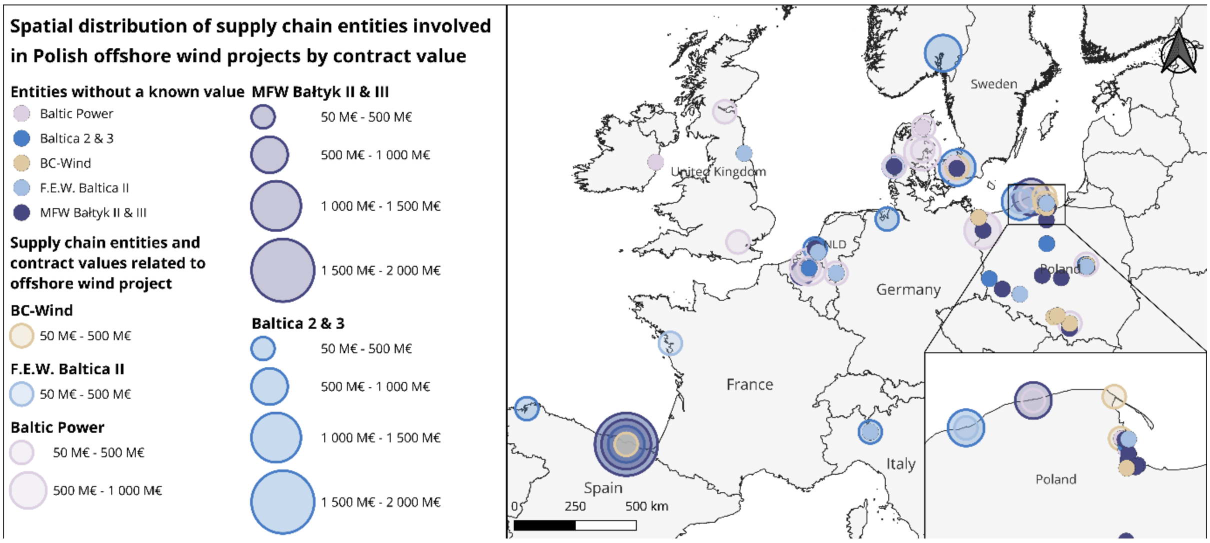

Figure 4. Spatial distribution of selected Polish offshore wind projects' supply chain, based on 4C Offshore (*4C Offshore.com*, 2025) database and public data published by offshore wind project developers.

Rycina 4. Dystrybucja geograficzna analizowanych polskich projektów morskiej energetyki wiatrowej, na podstawie bazy danych 4C Offshore (*4C Offshore.com*, 2025) i danych opublikowanych przez deweloperów morskiej energetyki wiatrowej.

The map highlights the significant role of foreign suppliers, particularly in turbine procurement and maintenance. Turbines for all Polish projects are supplied exclusively by Vestas and Siemens Gamesa, which results in a strong concentration of contract values around their headquarters: in northern Spain for Siemens Gamesa Renewables and in Denmark for Vestas. In contrast, Polish firms are primarily engaged as subcontractors, which is reflected in their lower contract values. Their activity is nonetheless visible in the form of a regional cluster in northern Poland, with concentrations in coastal areas and around designated service and installation ports. This suggests that while international firms dominate the most capital-intensive packages, domestic suppliers are beginning to establish a foothold within the supply chain, especially in activities directly linked to port infrastructure, local support services, operations and maintenance (O&M).

Stage 2 of the analysis for the United Kingdom focused on the distribution of supply chain entities and their contract values (Figure 5). As in the Polish case, each project is represented with a distinct colour and the size of the circle reflects the estimated value of the corresponding Tier 1 contract.

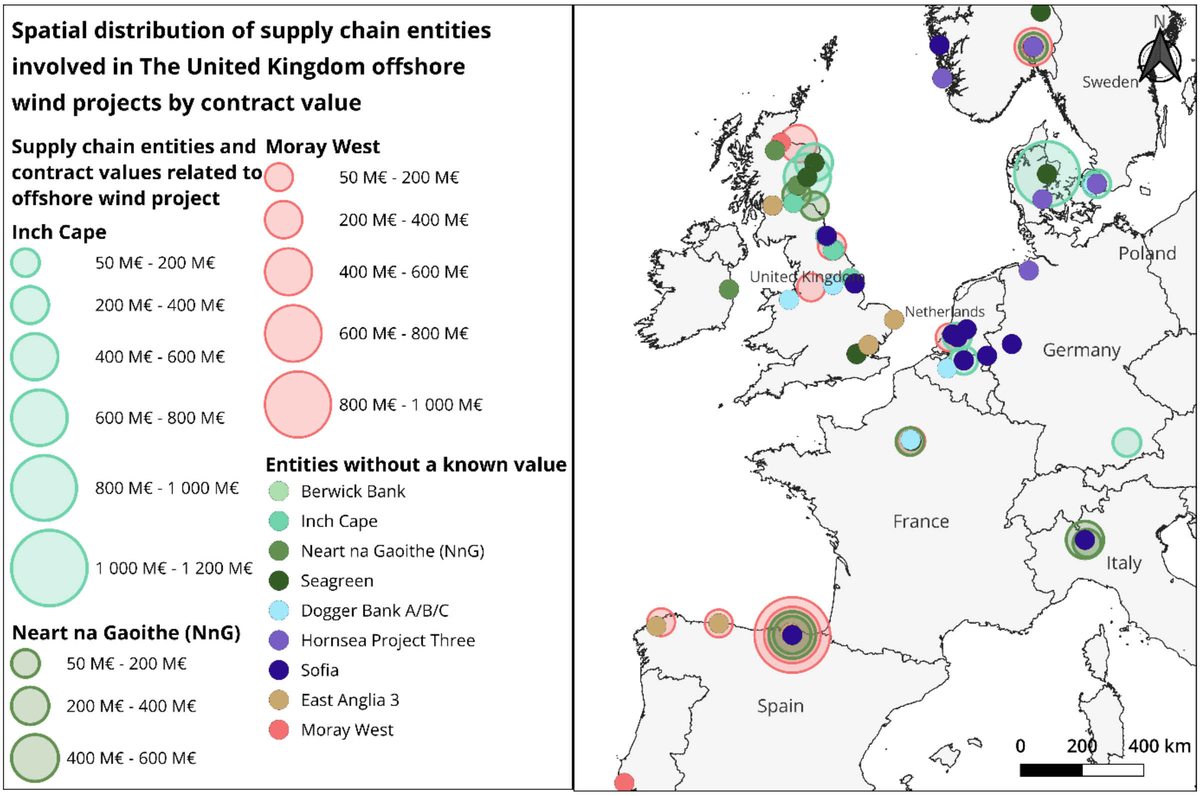

Figure 5. Spatial distribution of selected UK offshore wind projects' supply chain, based on 4C offshore database (*4C Offshore.com*, 2025) and data published by offshore wind project developers.

Rycina 5. Dystrybucja geograficzna analizowanych polskich projektów morskiej energetyki wiatrowej, na podstawie bazy danych 4C Offshore (*4C Offshore.Com*, 2025) i danych opublikowanych przez deweloperów morskiej energetyki wiatrowej.

The map again confirms the dominance of turbine manufacturers Vestas and Siemens Gamesa Renewable Energy, whose headquarters in Denmark and northern Spain concentrate the largest contract values. Both companies supply turbines for UK projects, which is why their headquarters appear clearly on the map as major contract locations. At the same time, the UK case is characterized by a substantial involvement of domestic companies. A dense concentration of suppliers can be observed along the British coastline, particularly in regions adjacent to the major clusters of offshore wind farms. This suggests the emergence of regional supply chain clusters that mirror the geographical distribution of wind farm projects themselves. In addition, clusters of Dutch and Belgian firms extend the spatial footprint of the supply chain across the southern North Sea. Together with British and Danish suppliers, they form a continuous industrial belt around this maritime area, which effectively functions as an integrated supply chain hub for the offshore wind sector.

The Stage 2 analysis highlighted both the international dimension of supply chains and the visible presence of domestic firms, particularly in coastal regions. These findings illustrate how contract allocations shape the geography of offshore wind development, but they do not capture the full sectoral potential. Therefore, Stage 3 examines the wider offshore wind industry in Poland and the UK, mapping companies that could become part of project supply chains as the sector continues to expand.

Further analyze considers the wider geography of the offshore wind sector in Poland beyond the contracts already awarded. Figure 6 presents a heatmap based on 280 entities identified from the industry database. The map highlights patterns of geographical concentration by marking locations with a high density of firms active in the offshore wind supply chain. This visualization makes it possible to identify regional clusters and to distinguish the main centers of activity within the national context.

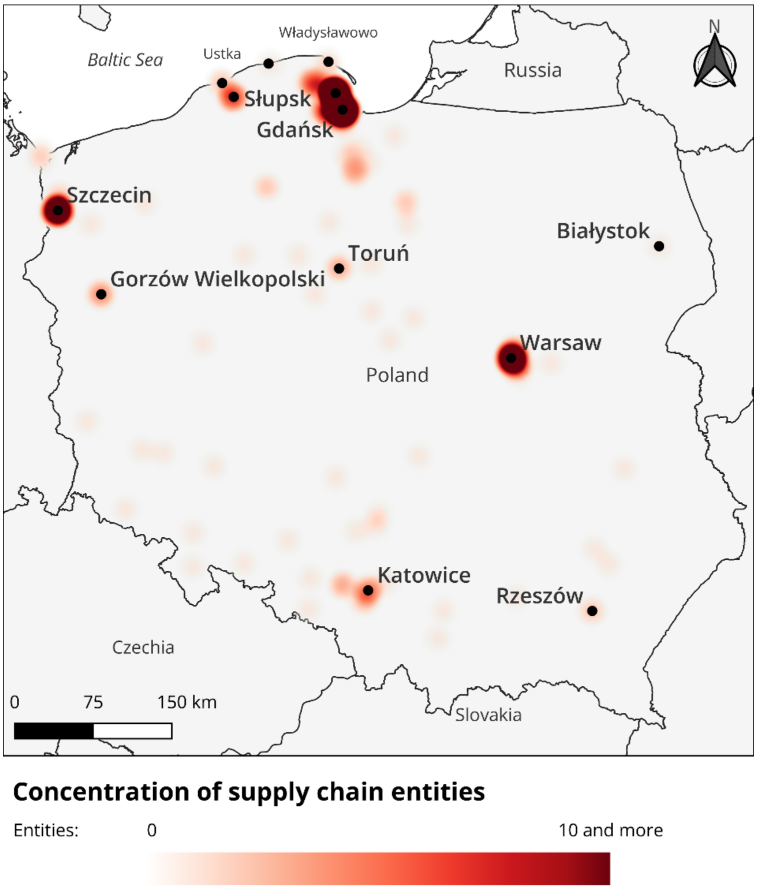

Figure 6. Spatial distribution of Polish offshore wind sector supply chain based on marineportal.com offshore companies database, access 01.08.2025.

Rycina 6. Dystrybucja przestrzenna polskiego łańcucha dostaw dla morskiej energetyki wiatrowej na podstawie bazy danych firm branży offshore według marineporta.com, dostęp 01.08.2025.

Three such centers stand out. The Pomeranian region in Gdańsk forms the dominant hub, concentrating shipyards, fabrication facilities and the two installation ports. The West Pomeranian region in Szczecin builds on shipbuilding traditions and its proximity to German and Danish markets. A third hub is the Mazovian region (Warsaw), where company headquarters, engineering consultancies and financial services are located. Additional smaller clusters appear in Lower Silesia (Katowice) linked to component manufacturing. This spatial distribution reveals a division between coast and inland: maritime regions provide industrial and port capacities, while Warsaw entities - project management and financing. Together, these centers outline the structural basis for further growth of local content by embedding offshore wind into both coastal industry and national economic networks.

Stage 3 for the United Kingdom is based on 405 identified companies active in the offshore wind sector. Figure 7 presents their spatial distribution as a heatmap, highlighting the areas of highest concentration.

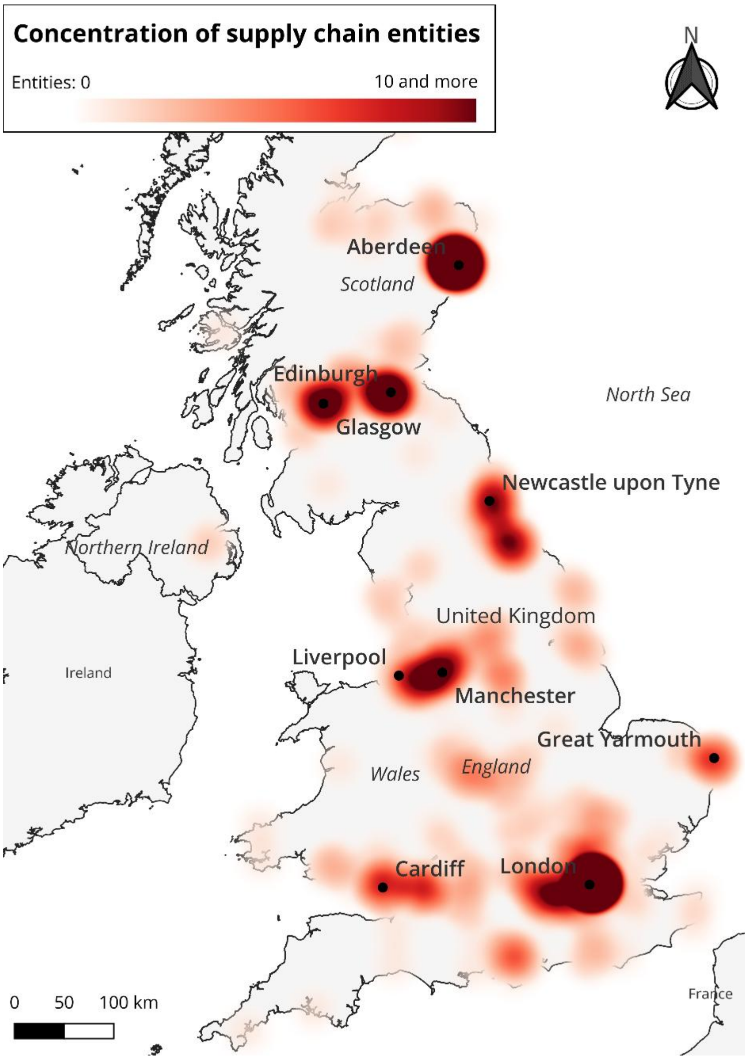

Figure 7. Spatial distribution of UK offshore wind sector supply chain, based on UK Offshore wind directory (ORE Catapult, 2025) offshore companies database, access 01.08.2025.

Rycina 7. Dystrybucja przestrzenna brytyjskiego łańcucha dostaw dla morskiej energetyki wiatrowej na podstawie bazy danych firm branży offshore według ORE Catapult (ORE Catapult, 2025), dostęp 01.08.2025.

In contrast to Poland, where clustering is mainly coastal, the UK shows a more diverse geography with several distinct centers. Clusters are visible not only along the shoreline, but also inland, often around major urban and industrial centers. Notable examples include London, Manchester and Cardiff, where the concentration of firms may be linked to the broader industrial base, service sector capacities and the availability of skilled labour. In Scotland, strong clusters appear around Aberdeen, Glasgow and Edinburgh, reflecting both historical links to the oil and gas industry and the more recent growth of offshore wind. Coastal concentrations are still present, for example in Great Yarmouth and Newcastle, but inland clusters are equally prominent. The capital, London, stands out as one of the largest hubs, combining corporate headquarters, project management and financial services, underscoring the multi-layered character of the UK offshore wind sector.

Discussion

The results of this study provide several important observations regarding the geography of offshore wind supply chains and the distribution of economic benefits in Poland and the United Kingdom. By applying an enhanced version of the SEBA method, it was possible to combine the spatial mapping of actors with estimated contract values and thus to analyze not only the distribution of supply chain, but also the relative scale of their participation. This revealed patterns not visible in conventional supply chain analyses without a geographical perspective.

The application of SEBA to the Polish offshore wind sector is novel, as it is the first time the tool has been applied to a pre-operational market in direct comparison with a mature case such as the United Kingdom. Even without operational offshore wind farms, the analysis could indicate where supply chains are most likely to develop and show early signs of clustering. These concentrate along the Baltic coast, in designated O&M ports such as Łeba and Ustka, as well as in large coastal agglomerations traditionally linked to the maritime economy, including shipyards and related industries in Gdynia and Gdańsk in the Gdańsk Bay area and Szczecin on the western coast. Warsaw also emerges as an important center due to its role in project management, corporate headquarters and financial structuring. At the same time, the analysis shows that the supply chain at Tier 1 level remains strongly dependent on foreign suppliers, who secure the most valuable packages of components and services. This is particularly visible in turbine procurement, which in all projects is concentrated in the hands of two companies: the Danish firm Vestas and Siemens Gamesa Renewable Energy, headquartered in Spain. More broadly, most Tier 1 contractors originate from Western European countries, especially those clustered around the North Sea, reflecting the maturity of these industrial bases and their established position in the global offshore wind supply chain.

A similar concentration around the southern North Sea is visible in British offshore wind projects, but with a stronger presence of domestic firms as a key part of the supply chain. At the same time, international suppliers remain important, particularly those based in Belgium, the Netherlands and Denmark - countries with long-standing offshore wind industries. Together, these suppliers form a continuous belt of activity across the southern North Sea, which supports a large share of Europe's offshore wind capacity. Within the UK itself, this external input is complemented by a dense network of national firms. Clusters can be seen both along the coast, for example in Grimsby, Lowestoft, Montrose and Aberdeen or inland, around major industrial centers such as London, Manchester, Birmingham, Glasgow and Edinburgh. These locations illustrate the more advanced stage of the British supply chain, where coastal service ports and several independent inland hubs work together to address the sector's needs.

The observed differences between Poland and the United Kingdom point to the need to consider offshore wind supply chains through both spatial patterns and sectoral policy. In the United Kingdom, local content has been a central objective, reinforced by the Offshore Wind Sector Deal and mandatory reporting of supply chain plans (BVG Associates, 2015, 2021). These measures have contributed to a steady increase in the share of domestic participation with the current goal set to reach a 60% before 2030 (UK Government, 2025). At the same time, the tendency of suppliers to locate in geographical proximity has, over time, produced a dense industrial belt in the southern part of the North Sea. Supply chain concentration is strongest in countries with established offshore wind sectors, especially Belgium, Denmark and the Netherlands, while the UK stands out for the large share of domestic firms, reflecting both the scale of its sector and deliberate policy support. In Poland, government efforts have so far focused primarily on creating the sector itself, with less emphasis on ensuring that local companies capture a significant share of value (*The Act on Promoting Electricity Generation* *by Offshore Wind Farms*, 2020). Local content is mentioned in strategic documents, but targets remain non-binding and reporting is declarative (*Offshore Wind Sector Deal*, 2021). Without stronger instruments and monitoring mechanisms, much of the economic value of offshore wind development may accrue to international contractors. Setting clear targets for local content, as in the UK's benchmark, should therefore be accompanied by a careful balance between strengthening the domestic economy and preserving competitiveness in order to secure further reductions in the LCOE of the offshore wind sector (Bazilian et al., 2020; Kuntze & Moerenhout, 2012).

The analysis demonstrates the usefulness of the SEBA methodology for examining sectors at an early stage of development and for enabling cross-country comparisons. Applying this approach to Poland and the UK provided insights into supply chains and revealed spatial patterns of economic activity. The adapted approach improves understanding, but limitations remain: contract values were estimated using LCOE benchmarks and could be assigned mainly to Tier 1 suppliers. In reality, these values are distributed further across subcontractors at Tier 2 and Tier 3, which were mapped, but not valued. A logical next step in the development of SEBA would be to include contracts from lower tier and allocate their values geographically, thereby offering a full picture of economic benefit flows and the actual scale of local participation. Introducing a transparent and standardized reporting system in Poland as part of sectoral policy could also improve data availability, which remains one of the key constraints of the current analysis.

Offshore wind development in Europe is expected to expand further. While the North Sea will remain the central basin for the industry, the importance of other maritime areas, including the Baltic Sea, is set to increase (EU Baltic Sea Governments, 2022). This evolution is likely to generate demand for new regional supply chains, modelled on the dense network that has emerged in the southern North Sea. Owing to its strategic location and leading role in Baltic offshore wind development, Poland could become a key hub in building such a supply chain for this part of Europe. At present, the European supply chain already shows oligopolistic features at the Tier 1 level, particularly in turbine manufacturing and large installation packages. However, the growing demand for products and services across lower tiers creates opportunities for domestic firms to enter and expand. With an appropriate national policy framework, this could lead to the formation of local supply hubs that reach beyond national markets, contributing to a broader notion of 'European content' - an extension of the local content concept to the European scale (Polish Investment and Trade Agency, 2025).

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Summary

The aim of this paper is to investigate how economic benefits from offshore wind development are distributed in Poland and the United Kingdom, by analyzing the geographical patterns of supply chains. The countries were selected because they illustrate very different stages of maturity: the UK is a global leader with over 25 years of experience and more than 50 operating farms, while Poland is at a pre-operational stage, with ambitious targets of 18 GW by 2040. This contrast makes it possible to explore how supply chains evolve, how benefits are distributed spatially and what role policy frameworks play in shaping local content. Building on the geographical trajectory of supply chain development observed in the UK, this study also examines whether similar patterns are likely to emerge in Poland.

The study applied and refined the Spatial Economic Benefit Analysis (SEBA), originally proposed by Weig and Schultz-Zehden (2019). SEBA links supplier locations to identified project to capture the geography of economic benefits. In this research the method was developed by adding an economic dimension: estimated contract values were assigned to supplier locations, enabling combined financial and spatial analysis.

The methodology was implemented in three stages. Stage 1 identified 18 offshore wind projects (7 in Poland, 11 in the UK), focusing on projects commissioned since 2023, under development or during construction phase. These were mapped with their designated installation and operations and maintenance (O&M) ports (Figures 1 and 2). Stage 2 examined supply chains of these projects by identifying contractors and estimating contract values based on LCOE benchmarks. The resulting maps (Figures 3 and 5) show the spatial allocation of contracts and its estimated value. Stage 3 extended the analysis to the wider sector. Using industry databases, 280 firms were mapped in Poland and 400 in the UK, highlighting regional clusters and the broader geography of the offshore wind economy (Figures 6 and 7).

The results reveal spatial clustering tendencies. In Poland (Figure 2), projects are concentrated along the Baltic coast, particularly north of Łeba and Ustka. O&M bases are planned in Ustka, Łeba and Władysławowo, while installation activities are linked to Gdańsk and Gdynia. Contract analysis shows that Tier 1 packages are dominated by foreign suppliers, notably Vestas (Denmark) and Siemens Gamesa Renewable Energy (Spain), which together control turbine supply and long-term service contracts. Domestic firms appear mainly as subcontractors, concentrated along the coast and in Warsaw, but their contract values remain relatively modest.

In the UK (Figure 3), similar dominance by Vestas and Siemens Gamesa is observed, but their role is complemented by a wide range of British suppliers. Clusters are developing in the Humber region (Grimsby, Hull), East Anglia (Lowestoft, Great Yarmouth) and Scotland (Aberdeen, Montrose). Inland hubs such as London, Manchester and Birmingham also contribute, reflecting the presence of headquarters, engineering services and finance. Moreover, a wider industrial belt spans the southern North Sea, connecting the UK with Belgium, the Netherlands and Denmark, which together support both local and global offshore wind markets.

The comparative perspective highlights several conclusions. Both countries show strong spatial concentration around O&M ports, which anchor long-term value. Yet in Poland, the largest contracts are captured abroad, while in the UK domestic participation has expanded, supported by deliberate policy. In UK the Offshore Wind Sector Deal and mandatory Supply

Chain Plans help to raise local content to targeted 60%. In Poland, Supply Chain Plans under the CfD scheme lack binding targets or verification, limiting their impact.

In broader perspective, geography explains clustering - proximity to ports and industrial centers drives supply chain concentration, but policy is equally crucial. The UK case shows that targeted policy can strengthen domestic suppliers, while Poland still focuses mainly on sector creation. As offshore wind farms in the Baltic Sea expand, Poland could serve as the foundation for a new regional supply chain hub, comparable to the southern North Sea. Achieving this will depend on predictable policies that support domestic participation without undermining competitiveness or increasing LCOE.

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The Role of Offshore Wind Energy Development in Job Creation: A Real-Time Data Analysis Using LinkedIn in Poland, Germany and United Kingdom

Abstract

This study examines the job creation potential of offshore wind energy development in Poland, Germany, and the United Kingdom using an innovative real-time data analysis approach. By leveraging web scraping techniques to collect job posting data from LinkedIn, the research provides a comparative analysis of labor market trends across these three countries, each representing different stages of offshore wind sector maturity. The methodology combines web scraping, data mining, and statistical analysis to assess the geographical distribution, job types, and relative demand for offshore wind energy positions. Key findings reveal significant differences in job posting patterns among the analyzed countries, with Poland showing the highest ratio of offshore wind job postings per million inhabitants, reflecting its emerging market status. This research contributes to the understanding of how offshore wind energy development impacts local and national job markets, offering valuable insights for policymakers, industry stakeholders, and researchers. The study also highlights the potential of real-time data analytics in labor market assessment, particularly in rapidly evolving sectors like renewable energy.

Keywords: offshore wind, labour market, web scraping, job creation, data mining

Introduction

The expansion of renewable energy in Europe is expected to generate multifaceted benefits, going beyond carbon emission reductions to include substantial economic effects, notably in the area of job creation (Jenniches et al., 2019a; Varela-Vázquez & Sánchez-Carreira, 2017). By the end of 2023, the European Union had installed approximately 19.38 gigawatts of offshore wind capacity (Costanzo & Brindley, 2024). In 2024, this figure increased by an estimated 3.7 GW, bringing the total to around 23.1 GW. Looking ahead, EU member states have set ambitious targets to reach 88 GW of offshore wind capacity by 2030 and over 300 GW by 2050 (European Commission, 2020). These projections highlight the growing importance of offshore wind energy as a key pillar of Europe's renewable energy strategy and its potential to stimulate employment across multiple sectors.

While some countries have been developing their offshore energy sectors for many years, others are still in the early stages of entering the market. It is therefore important to analyze and compare countries at different levels of sectoral maturity and assess how the current stage of offshore wind development influences national and local labor markets.

This study focuses on three such countries: the United Kingdom, Germany, and Poland. Each represents a different stage in the development of the offshore wind sector. The UK leads as the most mature market, with installed offshore wind capacity exceeding 13.9 GW. Germany has been expanding its offshore sector at a steady pace, reaching over 8.5 GW and establishing strong domestic capabilities. Poland, in turn, is at an initial stage, with plans to install 5.9 GW by 2030. Table 1 presents the basic characteristics of energy infrastructure in the analyzed countries.

Table. 1 Offshore wind energy as total energy production in Poland, Germany and United Kingdom

Country	Total Energy Infrastructure installed by the end of 2023 [GW]	Offshore wind energy installed by the end of 2023 [GW]	Total energy produced from the offshore wind sector as a percentage of total energy consumption in the year 2023 [%]	FORECAST: Offshore wind energy installation target by the end of 2030 [GW]
Poland	61,5	0	0 TWh in 2023	5.9
Germany	234,1	8,5	23.41 (TWh) in 2023 (total 436.8 TWh) (5.36%)	30
United Kingdom	74,8	13,9	49 TWh (17%)	50

Source: (Burger, 2023; Crown Estate, 2024)

As Poland plans to establish 5.9 GW of offshore wind capacity by 2030, the first projects entered the construction phase in early 2025. In this initial phase, projects totalling 5.9 GW in the Polish Baltic Sea region were granted support with a guaranteed offtake price of €75/MWh, indexed to inflation. In future rounds, Poland intends to support an additional 12 GW, bringing total capacity to nearly 18 GW by 2040. In this study, Poland is examined as a representative of an emerging offshore wind market with a high probability of advancing rapidly in the coming decade.

In Germany, the majority of the current 8.5 GW offshore wind capacity (as of 2023) is located in the North Sea, while only a few operational projects—ranging from 48 MW to 476 MW—are situated in the Baltic Sea. Ongoing tendering procedures are expected to enable the country to reach 30 GW by 2030 and 50 GW by 2035 (Deutsche Windguard, 2024). Despite being a leader in the EU's offshore wind development, Germany currently covers only around 5% of its electricity demand from offshore sources.

The United Kingdom remains the European frontrunner in offshore wind, with nearly 14 GW of installed capacity by the end of 2023. This allows the UK to meet approximately 17% of its annual electricity demand from offshore wind. The country has set a target of 50 GW by 2030, making it one of the most advanced offshore wind markets globally, second only to China in installed capacity.

To meet their targets of offshore wind energy production, substantial financial investments must be put in place, particularly in expanding energy infrastructure and transmission networks (Gonzalez-Rodriguez, 2017; Sarker & Faiz, 2017). While such investments are expected to generate employment, the extent to which this potential translates into measurable job creation remains insufficiently understood (Kahouli & Martin, 2018). This gap is particularly evident when comparing countries at different stages of offshore wind sector development—a perspective this study aims to address.

To better understand the employment context of offshore wind energy across the analyzed countries, Table 2 presents comparative labor market data, including total employment, jobs in the energy sector, and direct jobs in the offshore wind industry. The table also includes forecasts for 2030, illustrating the expected scale of job creation related to the ongoing development of offshore wind. These figures highlight the diversity of labor market baselines and sectoral scales, which are important when interpreting hiring trends observed in the LinkedIn-based data analysis.

Table 2. Labor Market characteristics in the energy sector within the analyzed countries

Country	Number of persons in the employment as of the end of 2023 [thousand]	Number of jobs in the energy sector as of the end of 2023 [thousand]	Number of direct jobs in the offshore wind industry as of the end of 2023 [thousand]	FORECAST: Number of direct jobs in the offshore wind industry as of the end of 2030 [thousand]
Poland	15 210	113		13.000-21.000
Germany	46 035	243	24.350	32.350
United Kingdom	33 114	130	32 257	17 394

Source:(wind:research, 2019)

This study builds on real-time labor market data collected through an emerging method: web scraping of job postings from LinkedIn. This approach made it possible to construct an up-to-date and structured dataset on employment opportunities in the offshore wind sector. Job postings contain key details that allow for the analysis of parameters such as geographical distribution, job role, and seniority level. While sea-land interactions in offshore wind are often concentrated near coastal clusters, the broader economic influence of the sector may extend inland (Zaucha, 2018). For this reason, spatial analysis of job postings serves as an important lens for assessing whether employment benefits from offshore wind development are concentrated or more widely distributed.

The research also investigates how offshore wind development relates to job creation and how the structure of advertised positions differs depending on a country's stage of market maturity. In doing so, the article serves a dual purpose: first, to assess the usefulness of LinkedIn-based web scraping as a methodological tool for labor market analysis, and second, to apply this method to compare labor demand patterns in three distinct national contexts—Poland, Germany, and the United Kingdom.

The study also examines how offshore wind energy development can contribute to job creation, and how the structure of these jobs varies depending on the sector's maturity in each country. By employing a novel methodological approach and offering a comparative perspective, this research provides insights for policymakers and industry stakeholders seeking to better understand the economic impacts of offshore wind development (Ortega et al., 2015; van der Loos et al., 2022; Varela-Vázquez & Sánchez-Carreira, 2017). In doing so, the article serves a dual purpose: it assesses the utility of LinkedIn-based web scraping as a real-time labor market tool and applies this method to compare job demand structures in three different national contexts—Poland, Germany, and the United Kingdom.

The offshore wind industry has generated notable economic effects in all three countries examined. In the United Kingdom, large-scale investments have been directed toward infrastructure, technological development, and workforce training. Germany has also allocated significant financial resources to the expansion of its offshore wind capacity, supporting both economic growth and employment creation. In Poland, the anticipated entry into the offshore wind sector is expected to attract considerable investment, stimulating job opportunities and industrial development (Sobotka et al., 2019).

Despite these positive developments, there remains a lack of up-to-date data on job creation directly associated with offshore wind projects—particularly in emerging markets such as Poland. Traditional data collection methods often fail to keep pace with the rapidly evolving dynamics of the industry and typically lack the granularity needed to track specific occupations or regional trends. To address this gap, the present study applies an alternative methodological approach: real-time web scraping of LinkedIn job postings related to the offshore wind sector. This method allows for the timely collection of detailed information on employment opportunities, job roles, and their geographic distribution, offering a more nuanced picture of labor market activity influenced by offshore wind development (Aldieri et al., 2020).

This study pursues a dual objective. First, it aims to explore the applicability of LinkedIn-based web scraping as a real-time method for labor market monitoring. Second, it implements this approach to examine how job demand in the offshore wind sector varies across three national contexts—Poland, Germany, and the United Kingdom—each representing a different stage of market development.

By comparing data from these countries, the research provides insight into how sector maturity influences both the volume and structure of employment opportunities. The findings are intended to support policymakers, industry stakeholders, and researchers in assessing the employment impacts of offshore wind development and evaluating the added value of high-frequency data analytics in dynamic, emerging industries.

As job creation becomes an increasingly important factor in local content strategies and investment evaluation, the development of timely and adaptable tools for labor market assessment is essential. While existing research highlights the employment potential of offshore wind energy—particularly through local supply chains and workforce expansion—there remains a gap in methods capable of capturing real-time labor market dynamics.

Traditional data sources are often retrospective and lack the resolution needed to detect early signals of labor demand, especially at the moment when job vacancies first appear. A more granular approach, based on real-world job postings, can offer valuable insights into the specific skills, occupations, and geographic areas where labor demand is emerging.

This study addresses that gap by applying a real-time data scraping method to analyze employment trends in the offshore wind sector. Through a comparative perspective across Poland, Germany, and the United Kingdom, it demonstrates how this approach can enhance understanding of workforce needs in fast-growing industries and support more responsive planning within the broader context of energy transition.

LITERATURE REVIEW

The expansion of offshore wind energy has become a focal point of research, particularly regarding its implications for labor markets and local economies. Understanding employment trends within this sector is critical for assessing its contribution to economic development, workforce transformation, and industrial policy. Existing studies emphasize both the direct and indirect benefits of offshore wind employment, highlighting its role in regional revitalization, workforce adaptation, and supply chain integration. Analyzing labor market trends in the offshore wind sector is essential for understanding the industry's development dynamics and its broader economic impact.

--- The renewable energy sector has witnessed substantial growth in recent years, exhibiting a marked increase in both installed capacity and employment generation. The offshore wind industry, in particular, has emerged as a significant contributor to this trend, creating a wealth of new job opportunities (IRENA, 2024). As of 2023, the global renewable energy industry employed approximately 16.2 million persons with wind power accounting for 1.5 millions of these jobs, whereas Europe was responsible for only 22% of these (IRENA, 2024). Notably, the European Union and the United Kingdom have emerged as global leaders in offshore wind energy, with a combined installed capacity of 34 GW as of 2023 (Costanzo & Brindley, 2024). Studies on job creation have been the objective of several independent reports published by different institutions (IRENA, 2024; Linkedin Economic Graph, 2022; Offshore Wind Industry Council, 2023; Scassola, 2023; UK Department for Business Energy and Industrial Strategy, 2021).

Table 3 presents some basic parameters of the studies published, which provides an overview of the wide range of the number of estimated jobs created, based on the given methodology. Variations in the figures reported across different studies create challenges in obtaining a precise assessment of the offshore wind labor market. Additionally, since these reports are typically published only annually or even less frequently, they do not allow for continuous monitoring of labor market dynamics, making it difficult to track short-term changes and emerging trends.

Table. 3. Renewable energy sources sector as the job creation activity, according to different sectoral Reports

Source	Data Provided	Year
European Parliament (EPRS)	Estimated **210,000 jobs** in the offshore wind sector in the EU, a significant share of the total wind industry workforce.	2022
EWEA (European Wind Energy Association)	Reported **75,000 full-time equivalents (FTEs)** in offshore wind in Europe, focusing on sector-specific employment.	2022
WindEurope	According to WindEurope's forecast, the wind power sector in Europe could create between 437,000 and 716,000 jobs by 2030, depending on the development scenario, with the central scenario predicting **569,000 jobs by 2030**.	2022
OECD	Global offshore wind jobs are projected to reach **435,000 by 2030**, with Europe contributing a significant portion.	2030
EWEA Fact Sheet	Renewable energy (including offshore wind) could create **2.8 million jobs** across Europe by 2020, subject to targets met.	2020

Source: Own elaboration based on public domain.

Offshore wind energy has emerged as a crucial component of this expansion, making significant contributions to job creation and economic development. In Europe, the offshore wind industry has experienced record installations, with 3.8 GW of new capacity added in 2023, representing a 40% increase compared to the previous year (Costanzo & Brindley, 2024).

The offshore wind energy sector is poised for substantial investment in the coming years as European countries introduce new support programs and grant location permits for offshore wind developments. These investments are expected to stimulate the local economy by generating demand for supporting services and products, while also fostering employment growth in a sustainable, modern economic landscape (Tafon et al., 2023).

Offshore wind employment is highly diverse, encompassing a wide range of job types that differ in required qualifications, geographic distribution, and industry linkages. As the sector continues to expand, identifying patterns in employment creation becomes increasingly important for workforce planning, regional development, and economic policy formulation.

Jenniches et al. highlight that the expansion of offshore wind energy can generate significant economic benefits, including job creation not only in coastal areas but also further inland (Jenniches et al., 2019a). The geographic distribution of potential socio-economic aspects has been analysed by Barbara Weig and Angela Shultz-Zehden who developed a dedicated Spatial Economic Benefit Analysis (SEBA) tool (Weig & Schultz-zehden, 2019). Their research emphasizes the need for a thorough geographical analysis of employment distribution to better understand the full potential of the sector in supporting regional economic growth. Offshore wind projects require a complex supply chain that spans multiple industries, from engineering and manufacturing to logistics and maintenance, which in turn contributes to employment creation beyond the immediate project sites.

The concept of local content in offshore wind refers to the extent to which national and regional economies benefit from industry development, particularly through domestic workforce participation and supply chain involvement. Allan et al. establish a strong correlation between higher local content levels and increased economic benefits for national economies, emphasizing the importance of policy frameworks that incentivize local employment (Allan et al., 2020). Studies have shown that effective local content policies can enhance job creation, retain economic benefits within host countries, depending on the supply chains structure (Kahouli & Martin, 2018).

Empirical research also suggests that local workforce integration is a key determinant of offshore wind projects' long-term success. Sector reports highlight that countries with well-developed local supply chains and workforce training programs benefit from higher employment retention rates and stronger economic spillovers. The ability to develop a skilled labor force domestically is increasingly seen as a competitive advantage for countries seeking to establish themselves as leaders in offshore wind energy (Hensley & Wanner, 2020).

The employment potential of offshore wind projects is also a key factor influencing public perception and community support for renewable energy investments. The prospect of creating high-quality, long-term jobs in local communities significantly increases public approval of offshore wind farms (Dwyer & Bidwell, 2019). The perception of economic benefits, particularly in regions with limited employment opportunities, can enhance acceptance of new developments and contribute to a more stable investment environment for the industry.

The geographic distribution of employment in the offshore wind industry plays a crucial role in regional development and social acceptance of wind energy projects. The concentration of jobs in coastal areas can contribute to the economic revitalization of regions affected by the decline of traditional industries, such as shipbuilding and commercial fishing (Varela-Vázquez & Sánchez-Carreira, 2017). As offshore wind infrastructure and operations expand, these regions can benefit from new employment opportunities, facilitating economic diversification and workforce transformation (Psuty et al., 2021).

Understanding the geographic distribution of employment benefits in the offshore wind sector is crucial for strategic planning and policy design (Morf et al., 2019). Firestone et al. emphasize that a detailed analysis of labor market trends enables better alignment of training programs, infrastructure planning, and policy measures to maximize the positive economic impact of offshore wind energy. By anticipating employment needs and ensuring the availability of a skilled workforce, policymakers can strengthen local labor markets, support industrial development, and enhance the long-term sustainability of the offshore wind sector (Firestone et al., 2020).

The study of employment trends in offshore wind has evolved alongside advancements in labor market analysis methodologies. Traditional approaches often rely on econometric modeling and input-output analysis to estimate employment impacts (Jenniches et al., 2019b). However, the application of big data analytics and web scraping techniques for tracking real-time labor market trends has been a subject of growing interest (Fabo & Kurekova, 2022; Kureková & Kureková, 2014). While web scraping has been used in various industries to analyze job postings and assess labor demand, its application in the offshore wind sector remains largely unexplored. The use of social media data for monitoring employment trends in certain industries highlights the potential of digital tools in labor market research. These emerging methodologies provide a more dynamic and timely approach to analyzing employment patterns, particularly in fast-growing sectors such as offshore wind energy.

Although research on employment in the offshore wind sector is steadily increasing, significant knowledge gaps remain regarding regional labor market disparities. Large-scale analyses often overlook these regional differences, making it difficult to tailor workforce policies to specific economic contexts. The US National Renewable Energy Laboratory (NREL) conducted a nationwide assessment of workforce needs in the offshore wind sector, highlighting the necessity for more detailed regional studies that account for changes in marine spatial planning and local labor market structures. The report underscores the importance of multi-stakeholder collaboration and regional coordination to address workforce demands and close skill gaps effectively (Shields et al., 2021).

Additionally, the impact of policy interventions on job creation in offshore wind remains an area for further exploration. Researchers stress the need for a deeper understanding of the multiplier effects and indirect economic benefits associated with offshore wind development(Ortega et al., 2015). Future studies should focus on long-term labor market assessments, considering workforce adaptation over multiple years and across different stages of offshore wind sector expansion.

Research method

Data sources for labor market analysis and job postings in existing literature are primarily based on official government statistics, such as those provided by Statistics Poland (GUS) for Poland or Eurostat for broader European labor market trends (Batóg & Wawrzyniak, 2018; Gałecka-Burdziak & Pater, 2015). Additionally, many studies rely on survey data and sector-specific reports to assess employment dynamics. However, with advancements in statistical tools, new possibilities for real-time labor market monitoring have emerged. The era of Big Data has enabled the development of new methods for data collection, including web scraping, which allows for the extraction of publicly available information from online sources (Maślankowski, 2019; Nowak, 2012).

Ongoing research explores the effectiveness and quality of data obtained through web scraping, particularly in labor market studies. Previous studies have applied this methodology to job portals such as pracuj.pl, which primarily caters to the Polish labor market. However, a review of the literature revealed a lack of studies analyzing offshore wind sector job postings using web scraping techniques on LinkedIn. Given LinkedIn's widespread use for professional recruitment in Europe and its relevance to global labor market trends, this research seeks to fill that gap by employing web scraping as a tool for tracking job demand in the offshore wind industry.

To achieve the research objectives, a comprehensive methodology was developed, integrating web scraping and data mining techniques. These methods have been increasingly recognized for their ability to provide real-time, granular insights into labor market dynamics, particularly in specialized and rapidly evolving sectors like offshore wind energy. The combination of these techniques enables a robust analysis of job market trends, offering valuable insights into the geographical and hierarchical structure of employment within the industry (Karakatsanis et al., 2016).

In this study web scraping was utilized to collect data from online job posting platforms, with LinkedIn selected as the primary source due to its extensive global reach and relevance as a professional networking and job advertisement platform. The scraping process involved sending HTTP requests based on specific search terms, including "wind" and "offshore wind," to retrieve relevant job postings. The HTML content of the retrieved pages was then processed using the Python library BeautifulSoup, a widely used tool for parsing HTML structures. This approach allowed for the efficient extraction of key data points:

- job locations;
- position levels;
- job titles;
- company names.

The automated nature of this process ensured that data collection was both comprehensive and consistent, with algorithms designed to navigate multiple pages of job listings seamlessly, thereby capturing all relevant data.

The data were further processed and analyzed using data mining techniques. Text analysis played a crucial role in this phase, involving the identification of word frequency distributions, recognition of patterns, and systematic tagging and categorization of job postings. Natural Language Processing (NLP) methods were employed to standardize job titles and descriptions, addressing variations in terminology across different companies and regions. This standardization was critical for ensuring consistency in the dataset and facilitating accurate analysis. Additionally, advanced analytics, including link analysis and trend forecasting, were applied to uncover relationships within the data and predict future trends in the offshore wind energy labor market.

The decision to use LinkedIn as the primary data source was based on its accessibility and the richness of information it offers for selected occupational groups. Public job postings on LinkedIn provide a timely view of labor demand, particularly in sectors such as offshore wind energy, where online recruitment plays a visible role. However, it is acknowledged that LinkedIn does not cover the full spectrum of hiring activity. Recruitment may also take place through internal channels, industry-specific platforms, or informal networks—especially in the case of manual or offshore-based jobs. Therefore, the insights obtained from LinkedIn should be seen as complementary to, rather than representative of, the entire labor market in this sector.

The combined use of web scraping and data mining enables efficient processing of large volumes of unstructured data into analyzable formats. While the advantages of real-time access and occupational detail have been discussed earlier, the focus here lies in the integration of these techniques as a replicable research framework. Scraping provides automation and scalability, while data mining techniques—particularly natural language processing—support the cleaning, standardization, and categorization of job-related information. Together, they form a methodological foundation that can be adapted to monitor employment patterns in fast-evolving sectors and to inform research and policy beyond traditional statistical reporting.

Despite its advantages, this methodology is not without challenges. Additionally, publicly available data may sometimes be incomplete or inconsistent, necessitating rigorous cleaning and validation processes. Furthermore, the implementation of web scraping and NLP techniques requires a level of technical expertise that may not be universally accessible. However, these challenges can be mitigated through careful planning and the use of established tools and frameworks.

By integrating web scraping and data mining techniques, this study provides a robust framework for analyzing the job market in the offshore wind energy sector. The methodology's ability to deliver real-time, detailed insights ensures its relevance and utility for policymakers, industry stakeholders, and researchers seeking to understand and optimize employment dynamics in this critical industry.

To analyze job postings published on the LinkedIn platform, web scraping and data mining methods were employed. This approach allowed for the retrieval of current job offers in the offshore sector from LinkedIn, specifically for three countries: Poland, the United Kingdom, and Germany. The data were collected using an algorithm that automatically retrieved the latest offshore job postings for each country on a daily basis from March to May 2024.

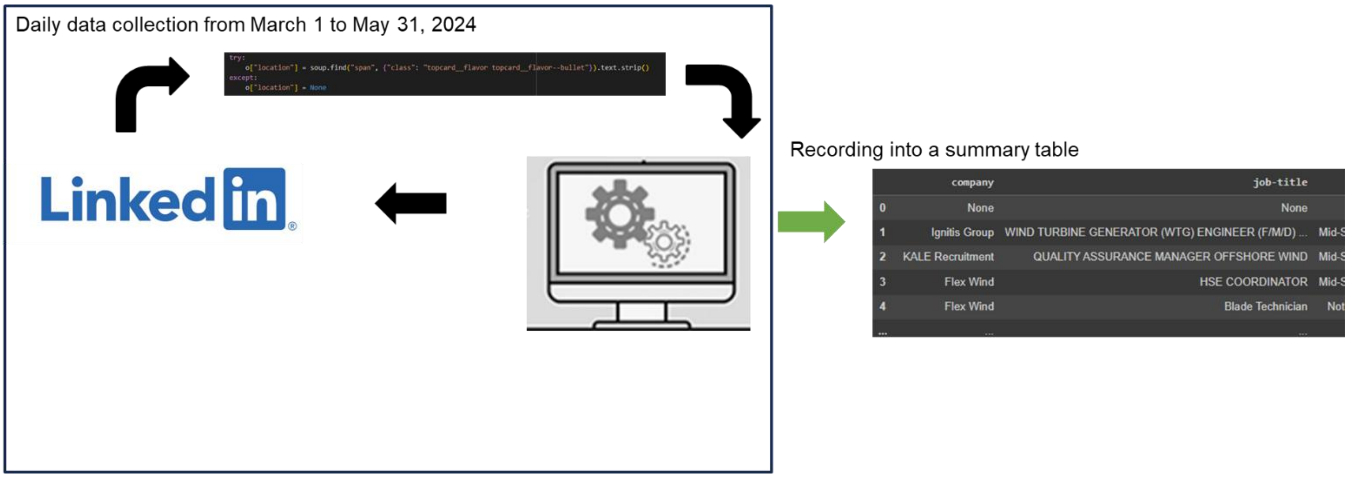

Figure 1Data collection algorithm

The data preparation process included the following steps (Figure 1):

1. Development of an algorithm using python programming language for searching job listings on LinekdIn containing the keyword:wind.
    1. Searching HTML structures
    2. Finding classes or IDs describing:
        1. Location
        2. Position in the company (level)
        3. Company
        4. Job title
2. Verification of data completeness for each job posting.
3. Removal of duplicates, i.e., job postings that appeared multiple times. Duplicates resulted from the algorithm running daily and the possibility of the same job listing being available for several days or even throughout the entire duration of data collection.
4. Data cleaning, which involved removing unnecessary words, typos, or other extraneous characters that occurred during the web scraping process.
5. Analysis of results: basic statistics including the count of job listings at the country and regional levels.

6. Assigning geographic data (coordinates) for visualization on a map.

Results

As a result of the analysis, the following findings were obtained. As shown in Table4, the highest number of offshore job postings during the analyzed period was recorded in Poland (108 job offers), followed by the United Kingdom (82 job offers), and Germany (68 job offers).

Tab 4. Number of Linkedin job offers in offshore wind sector extracted in each of analyzed countries

Country	Number of offers extracted from Linkedin and analyzed during the research period
Poland	108
United Kingdom	82
Germany	68

Source: Own study

Analyzing the geographical distribution of published offshore job postings in Poland reveals a significant concentration of offers in Warsaw and Szczecin (Figure 2). The heatmap (Figure 3) present data on positions across various location in the each country. The concentration of job postings in Warsaw primarily results from the nature of the positions being advertised, as they were mostly specialist roles. In Szczecin, job postings exhibited greater diversity in terms of the types of positions available.

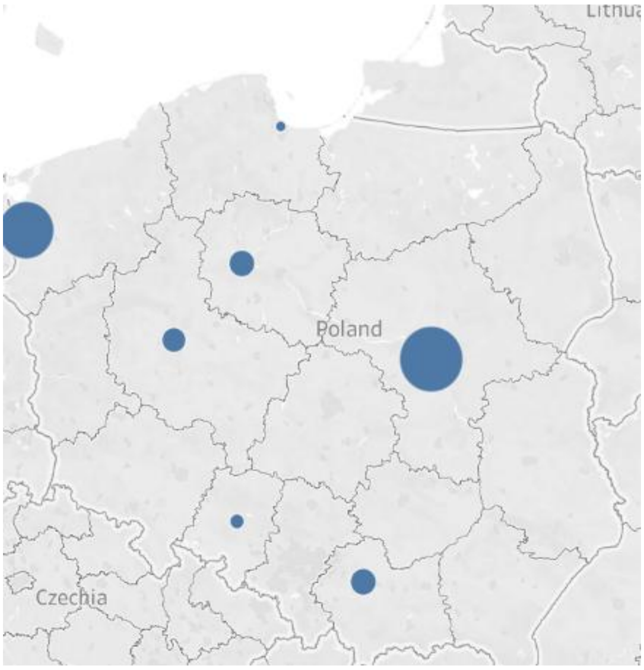

Figure 2 Geographical distribution of analyzed jobs posting in Poland

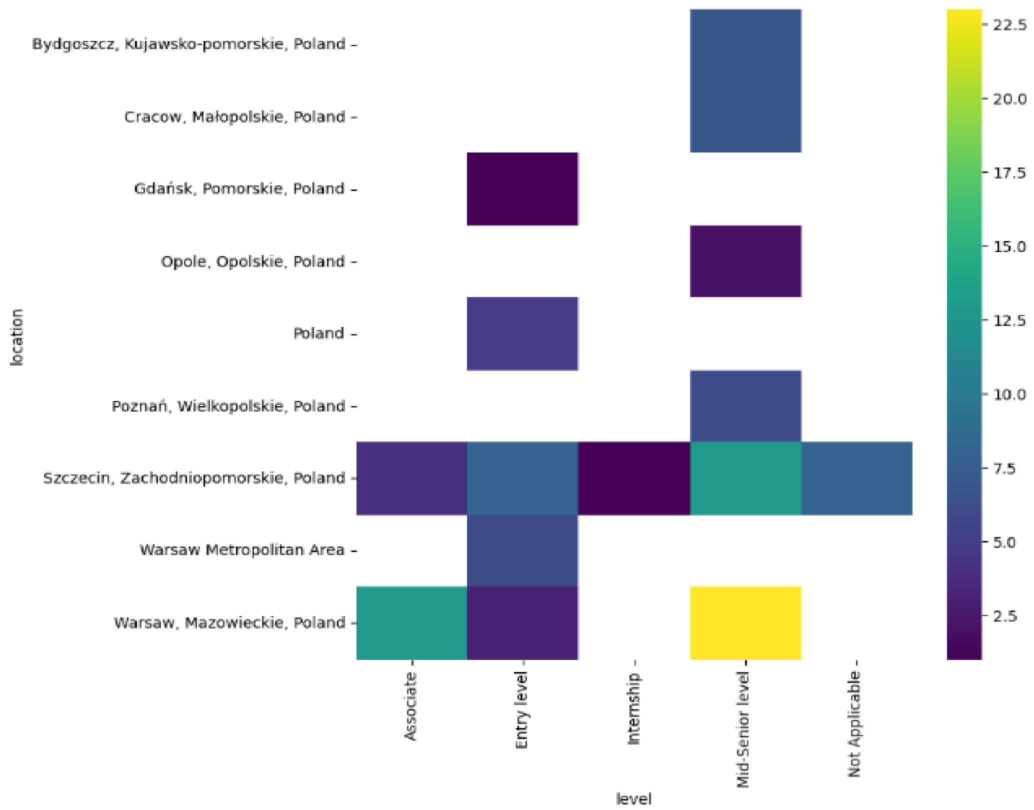

Figure 3 Heatmap for Poland showing the distribution of job offers by level and location

In the United Kingdom, offshore job postings tend to be more geographically dispersed (Figure 4). However, similar to Poland, the highest concentration of job offers is found in the capital, London. Compared to Poland, the United Kingdom had job listings for managerial positions as director roles (Figure 5). This could be due to the developed infrastructure and the entire offshore sector in the United Kingdom compared to Poland, as well as the short data collection period (3 months), since managerial are less frequent in the job market.

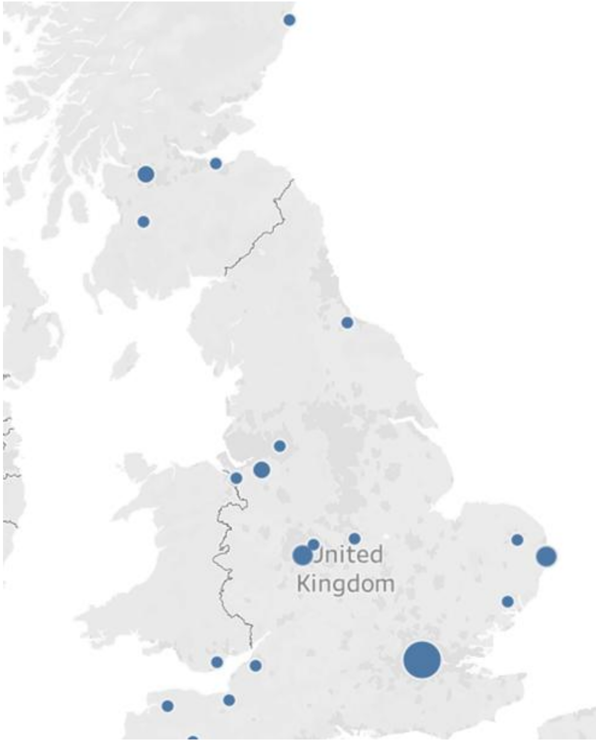

Figure 4 Geographical distribution of analyzed jobs posting in the United Kingdom

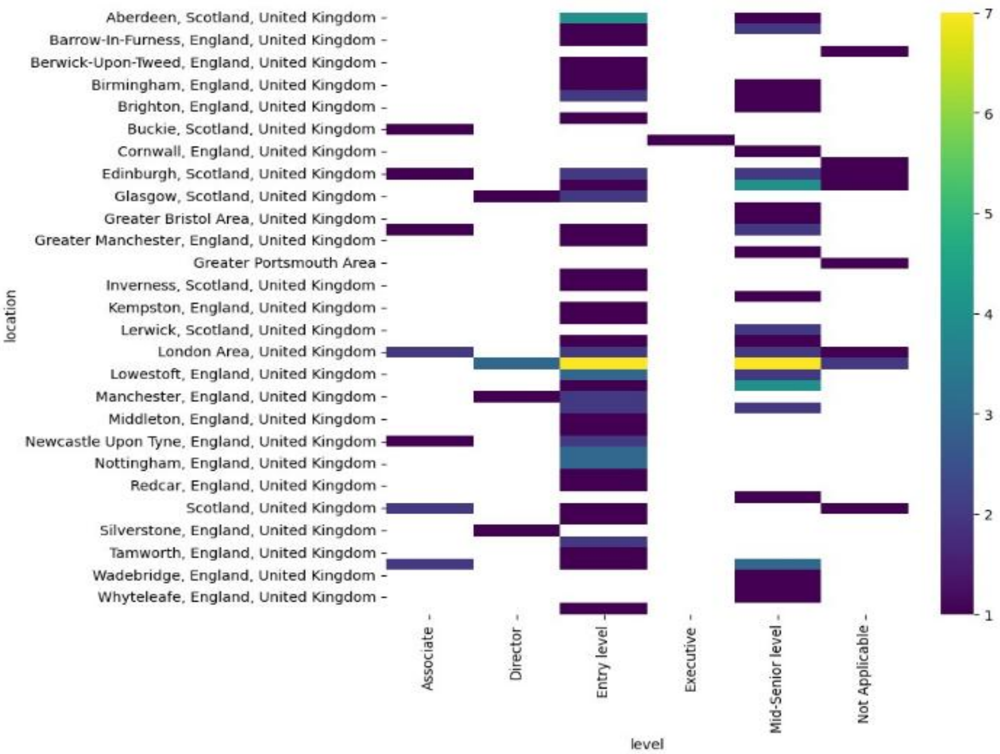

Figure 5 Heatmap for the United Kingdom showing the distribution of job offers by level and location

Germany exhibits an even greater dispersion of job postings than the United Kingdom (Figure 6). The largest clusters of job offers are located in Hamburg and Munich, with Berlin, the capital, ranking third in terms of job concentration. In Germany, there are also job listings for various positions, including managerial, mind and senior levels (Figure 7). However, the majority of job listings were for entry-level and mid-senior level positions.

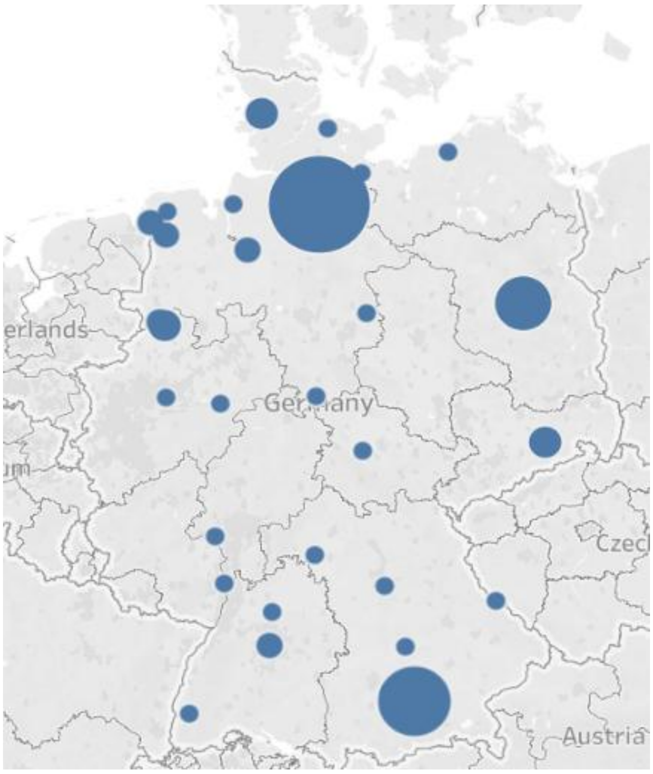

Figure 6 Geographical distribution of analyzed jobs posting in Germany

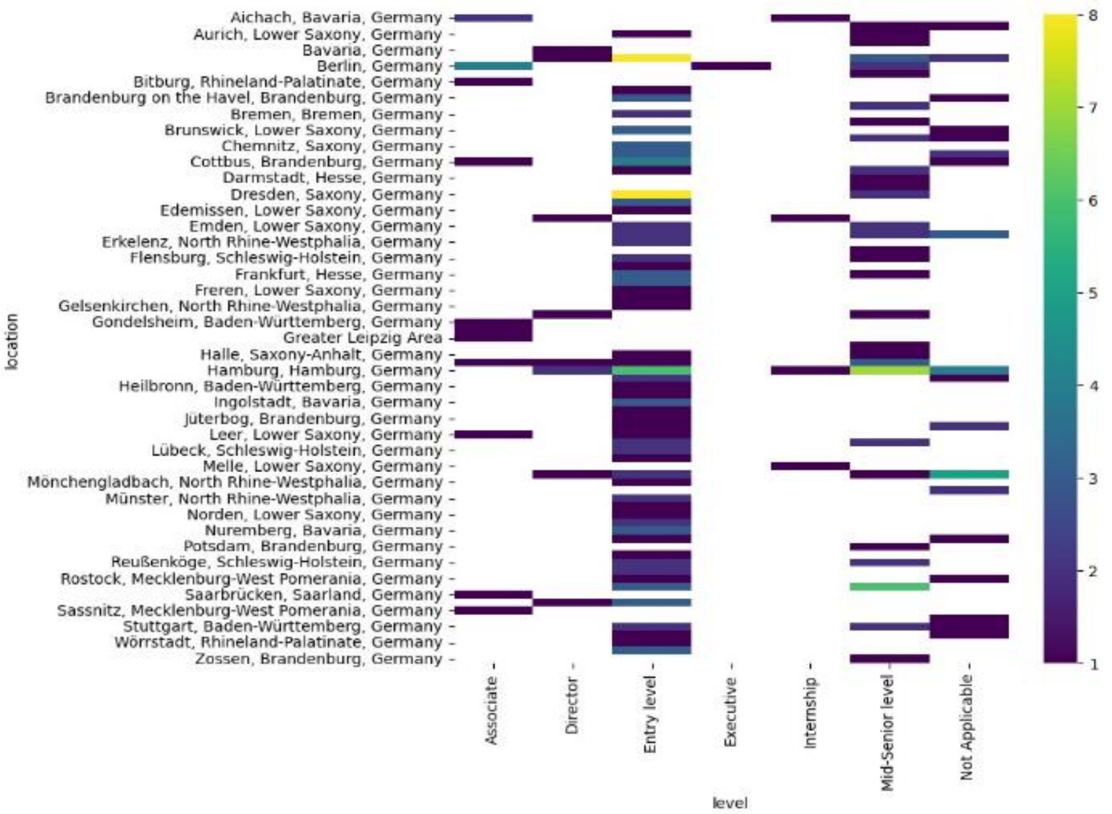

Figure 7 Heatmap for Germany showing the distribution of job offers by level and location

Table 5. Statistics and indicators in analyzed countries

Numbers of offers available on Linkedin to scrap	108	82	68
Population (as of year 2020)	37 958 138	67 025 542	83 166 711
WSK 1 (Offers indicator in the offshore wind industry per 1 million habitants)	**2,82**	**1,22**	**0,82**
Number of jobs in the offshore wind industry (direct 2023)	-[1]	17 394	24 350
WSK 2 (Job vacancy rate in the offshore sector per 1,000 job positions)	**-**	**6,21**	**2,80**

Source: Own study

In Poland, WSK 1 was the highest, reaching 2.82 offshore job postings per 1 million inhabitants, compared to 1.22 in the United Kingdom and 0.82 in Germany.

However, when looking at WSK 2, which represents the number of offshore job postings per 1,000 jobs in the offshore sector during the analyzed period, the United Kingdom had the highest value at 6.21 job postings, while Germany had 2.8 job postings. For the Polish labor market, no data on

[1]Lack of data

the total number of jobs in the offshore sector were found. This may indicate that Poland is at a different stage of offshore sector development, with the highest demand for specialists (108 job postings and the highest WSK 1 indicator).

Conclusions

By examining employment trends in Poland, Germany and the United Kingdom, this study provides a more nuanced understanding of how labor demand evolves in response to sectoral maturity and market development. The application of LinkedIn data scraping has proven especially valuable for capturing real-time labor market dynamics in the offshore wind industry.

Unlike traditional sources such as national labor statistics or sectoral employment reports, which are typically published with significant time lags and at a high level of aggregation, this method allows for timely identification of hiring needs, precise categorization of job roles by seniority and specialization, and a detailed spatial breakdown of employment opportunities. It enables researchers and policymakers to detect emerging labor market trends as they occur—when job offers are first published—rather than retrospectively, after workforce changes have already taken place.

This approach is particularly suited to fast-developing sectors such as offshore wind energy, where project cycles are short, workforce requirements are evolving rapidly, and spatial differentiation is significant. Moreover, it offers a flexible, low-cost and scalable tool for monitoring employment dynamics that can complement existing macroeconomic data systems. As such, the methodology demonstrated here may serve not only academic inquiry, but also support more responsive and geographically informed labor market policies—especially in regions undergoing green industrial transitions.

The combination of statistical analysis with access to extensive datasets from professional networking platforms like LinkedIn offers a powerful tool for continuous labor market monitoring. This approach facilitates real-time tracking of employment fluctuations, providing valuable insights into the demand for specific skills, regional labor shortages, and emerging job opportunities. Such real-time labor market assessments could have widespread applications, supporting workforce development strategies and informing policymaking on employment trends. While the offshore wind sector serves as a compelling case study due to its dynamic expansion and critical role in the energy transition, similar analytical approaches could be applied to other industries undergoing rapid transformation, such as electric mobility, digital services, or others. Exploring labor market trends in new areas could provide valuable insights, reinforcing the relevance of real-time data analytics for understanding and anticipating shifts in employment patterns on a much broader scale.

The results highlight clear differences between the analyzed countries in terms of the number and distribution of job postings. Poland, as an emerging offshore wind market, exhibits the highest ratio of offshore job postings per million inhabitants, which indicates a significant demand for specialists as the country prepares for large-scale offshore wind projects. The United Kingdom, with a well-established offshore sector, demonstrates a more dispersed job market, reflecting a mature industry with a broader range of employment opportunities. Germany, similarly advanced, shows an even greater geographic dispersion of job postings, with employment clusters appearing in key industrial hubs such as Hamburg and Munich. These differences are not random but rather correspond to the varying degrees of market maturity and industry specialization in each country.

Observed differences in job postings have been noted, supporting the conclusion that market maturity influences labor demand structures. The expansion of offshore wind capacity across Europe is expected to drive further job creation, particularly in specialized roles related to engineering, operations, and supply chain management. As the industry evolves, employment patterns will likely shift, with an increasing emphasis on high-skilled positions in advanced markets and a growing demand for technical and operational roles in emerging markets like Poland. The concentration of job postings in capital cities also suggests that strategic and high-level roles are often centralized in urban hubs, while coastal regions accommodate more diverse job opportunities related to infrastructure development and maintenance.

A key limitation of this study is the reliance on LinkedIn as the sole source of job postings. While LinkedIn is a widely used platform in Europe, its role in job recruitment varies across different markets(Johnson et al., 2020). In some countries, it is the primary tool for hiring professionals, particularly in white-collar industries, while in others, alternative job boards or sector-specific recruitment channels play a more significant role. This means that the dataset analyzed may not fully reflect the entire employment landscape of the offshore wind sector, especially for roles that are predominantly advertised through other means.

Another constraint stems from the timeframe of data collection, as the study focused exclusively on job postings from March to May 2024. Given that the dataset covers only three months, it remains unclear whether hiring patterns in the offshore wind sector fluctuate seasonally or follow cyclical trends influenced by project timelines or policy developments. A broader observation period would be required to determine whether the trends identified in this study persist over time or are specific to the selected timeframe.

It is important to emphasize that the analysis conducted in this study is limited to job postings that were publicly available on the LinkedIn platform. Consequently, the results reflect only a subset of labor demand—primarily in roles that are advertised openly, typically in medium- to high-skilled positions. Jobs filled through internal recruitment channels, informal networks, or closed platforms were not captured, meaning that the dataset does not represent the full employment landscape of the offshore wind sector.

As a result, although the number of analyzed postings was sufficient to identify meaningful trends and spatial patterns, the study does not claim to offer a comprehensive picture of the sector's workforce dynamics. To enhance the validity and depth of future research, it would be beneficial to broaden the data sources to include multiple job platforms and extend the observation period, allowing for a more representative and longitudinal assessment of hiring practices and labor demand in offshore wind energy. Future research should aim to expand the scope of analysis by incorporating a broader set of countries job markets to provide a more comprehensive understanding of how offshore wind sector development interacts with labor market trends under different regulatory, economic, and industrial conditions. A wider geographical focus would offer valuable insights into the role of local policies, economic structures, and workforce availability in shaping employment patterns in the offshore wind industry. Furthermore, extending the study over a longer time frame would allow for the identification of shifts in job demand across various phases of offshore wind farm development, from project initiation and infrastructure construction to long-term operations and maintenance. A longitudinal approach would also enable a more detailed examination of potential cyclical trends in employment and evolving skill requirements as the industry matures.

A more detailed investigation of country-specific and region-specific labor market characteristics would also be beneficial. Different markets may exhibit varying degrees of employment concentration in capital cities, industrial hubs, or coastal regions, and understanding these dynamics could provide a clearer picture of how offshore wind development influences local job creation. Such an approach would help identify patterns in workforce distribution and highlight key drivers of labor demand within different segments of the offshore wind supply chain. Additionally, establishing long-term data collection frameworks would improve the accuracy of labor market forecasts, allowing for better anticipation of workforce needs, emerging job categories, and potential skill shortages that could affect the sector's growth trajectory.

The findings of this study highlight the role of offshore wind energy as an emerging source of employment in the renewable energy sector. By integrating real-time labor market data into industry-focused research, policymakers, business leaders, and researchers can gain a more precise understanding of short-term hiring trends and workforce development needs within this specific industry.

As offshore wind energy continues to expand, ensuring a well-trained and adequately supplied labor force will be essential for sustaining its long-term growth (Offshore Wind Industry Council, 2023). Strengthening labor market monitoring frameworks and refining analytical methodologies—particularly in fast-developing and skills-intensive sectors like offshore wind—will be key to optimizing workforce planning, supporting regional employment strategies, and enabling more responsive education and training systems.

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Data availability statement

The authors are willing to share the data supporting the findings of this study for replication purposes upon reasonable request to the corresponding author.

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