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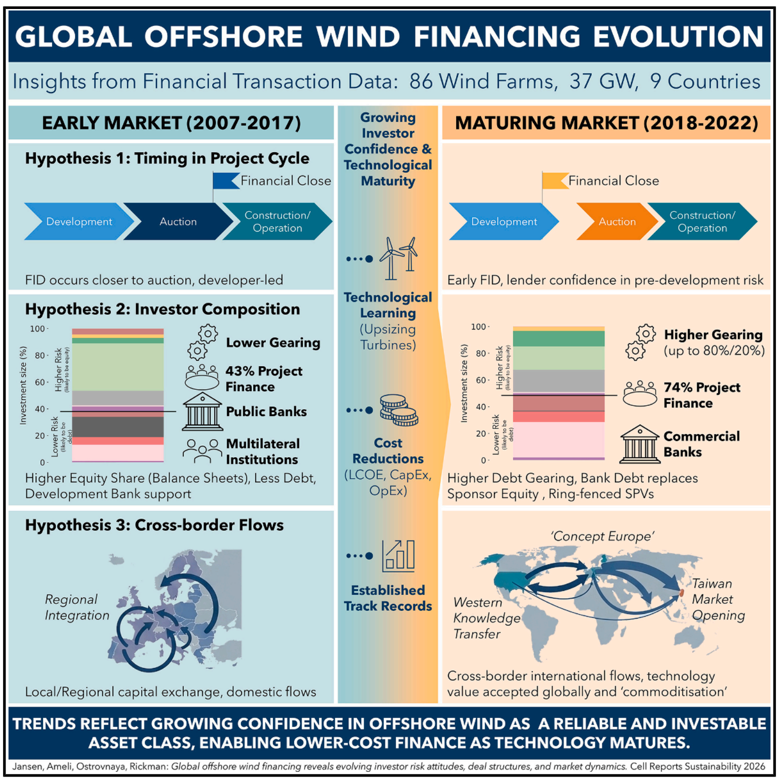
Global offshore wind financing reveals evolving investor risk attitudes, deal structures, and market dynamics

Graphical abstract



Highlights

- Offshore wind projects rely increasingly on lower-cost financing
- Financial close occurs earlier as investor confidence grows
- Debt shares reach up to 80%, indicating low-risk perception
- Cross-border investment signals global standardization

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In brief

Jansen et al. show that offshore wind has evolved into a mature, investable asset class. Analyzing 86 global projects, they find financing occurs earlier, relies more on low-cost financing, and increasingly involves international investors. These trends indicate growing confidence and standardization of offshore wind as infrastructure, lowering financing costs and supporting scale-up. The findings provide insights for policymakers and investors seeking to accelerate clean energy deployment.

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Global offshore wind financing reveals evolving investor risk attitudes, deal structures, and market dynamics

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SCIENCE FOR SOCIETY Offshore wind power has become a cornerstone of global decarbonization strategies, yet its expansion depends not only on technological progress but also on access to affordable finance. This study shows how the financial structure of offshore wind projects has evolved as the technology matured, offering important insights for policymakers, investors, and society. By analyzing 86 offshore wind projects across nine countries, we find that investors increasingly perceive offshore wind as a low-risk, reliable infrastructure asset. This is reflected in three key trends: projects reach financial close earlier in their development cycle, they rely more heavily on debt (i.e., lower-cost capital), and they attract a growing share of international investment. Together, these trends indicate rising investor confidence and a transition toward a more standardized, "commoditized" asset class. These findings have direct societal relevance. Lower perceived risk reduces the cost of capital, which in turn lowers electricity prices and accelerates the deployment of clean energy. This makes offshore wind more accessible and affordable for consumers while supporting climate goals. At the same time, the increased participation of global investors highlights the importance of stable and transparent policy frameworks, such as long-term revenue support schemes, to continue attracting capital at scale. For emerging offshore wind markets, the results provide a blueprint: policy certainty, well-designed auctions, and credible pipelines can unlock private finance and accelerate industry growth. More broadly, the financing model observed here may inform the deployment of other capital-intensive clean technologies, such as hydrogen and energy storage. Understanding how investor structures evolve is therefore critical, not only for scaling offshore wind but also for shaping the wider transition to a low-carbon energy system.

SUMMARY

Offshore wind energy has grown rapidly to 91 GW in 2025, demonstrating maturity and cost competitiveness. Beyond technological improvements, changes in financing conditions have played an important role in shaping project economics. This raises the question of how investor confidence has evolved alongside technological maturity. Independent from the cost of capital, the investor structure signals long-term risk attitudes and investment behavior. Here, we analyze 86 offshore wind financing deals (37 GW) between 2007 and 2022. We show the evolution of financing options, investor decision-making, and composition, which signal the technology's "commoditization." More recent deals reach financial close increasingly early in the project cycle and are financed with higher proportions of debt and greater participation from international investors. Traditionally risk-averse investors, who usually invest later in the project cycle, have taken earlier stakes in more recent wind farms. These trends reflect growing confidence in offshore wind as a reliable and investable infrastructure class.

INTRODUCTION

Offshore wind energy has emerged as a rapidly growing energy source and a crucial technology for decarbonizing the energy system.[1] The global cumulative capacity of offshore wind energy reached a record-breaking 91 GW in 2025.[2] Annual capacity additions grew by 19% on average over the last 5 years.[3] This strong growth is projected to continue (and accelerate) at 32% per year until at least 2027[3] with scenarios suggesting a 4- to 6-fold capacity increase by 2030.[4–9]

The offshore wind costs came down annually by 12% between 2015 and 2020,[10] demonstrating a learning rate of 10% per doubling of capacity.[11,12] This has made more recently commissioned wind farms cost competitive by undercutting fossil fuel's electricity generation prices[10] and led to some wind farms reducing consumer bills during the energy crisis.[10,13] Similar trends can be observed globally, like the subsidy-free Danish Thor wind farm,[14] Germany's negative subsidy bids for 7 GW yielding €12.6 billion in payments to reduce electricity costs,[15] and zero-subsidy bids in Taiwan in 2023.[16] Experts overall anticipate further cost reduction of 38%–58% on a global scale by 2050,[17] albeit in a context of supply-chain constraints and rising interest rates having an inflationary effect on offshore wind costs.[18–20]

The growth of offshore wind has been a remarkable success story, as it transitioned from "zero to hero" in just over a decade. The rapid cost reduction has largely been driven by technological advancements, in particular increasing turbine sizes.[21] Along with technological learning, two crucial factors have contributed further to driving down the levelized cost of electricity (LCoE): the cost for operational expenditures (OpEx) and the cost of capital (CoC). The growing expertise in operations has resulted in a notable 15% reduction in OpEx from 2015 to 2020, even as offshore wind has ventured into more challenging locations and harder-to-access sites.[22]

The CoC, which is particularly significant for capital-intensive technologies, has been reduced significantly over the last decade up until 2022.[23] The historically prevailing macroeconomic environment, characterized by an era of low interest rates in most developed countries, has led to more attractive rates for wind debt. Increasing investors' confidence in wind assets, supported by established investment track records and revenue stabilization, has also lowered the CoC[24,25] and reduced investors' perception of risks associated with offshore wind investment, contributing to a more favorable investment landscape. Since 2022, more recent publications have emphasized the role of CoC on renewable energy investments to derisk investment,[26] the internationalization of investment flows,[27] and, in particular, with regard to investment in developing countries.[28]

The future trajectory of technology growth appears to be more dependent on the availability of finance at attractive terms rather than solely on technological improvements.[29] Hence, the question of investors' confidence in a technology and its impact on required returns on investment is fundamental to understanding market dynamics, investment landscape, and the growth potential of wind energy. The level of confidence exhibited by investors plays a fundamental role in shaping the investment landscape and determining the feasibility of expanding wind energy. While this work focuses on the risk appetite as a proxy for investor risk attitudes and confidence, we recognize that other factors influence investment decisions. These include strategic goals, regulatory compliance, and sustainability mandates.

Despite the proven importance of financing conditions on renewable energy deployment,[30–34] research in this field is in its infancy. Previous research, along with consultancy[30] and industry reports,[35] mainly explored behaviors and preferences of different types of investors and their roles in shaping the low-carbon transition[36,37] and tracked key aggregate figures, such as investment volumes. Other studies have underlined heterogeneity in investor-specific attitudes to risk[38] and risks associated with renewable energy investments.[39,40] There is also more specific evidence linking investment decisions with siting conditions.[41]

The wind industry overall is inherently international, with some €2.5 billion of exports and €0.5 billion of imports[42] from the EU across the globe.[43] Components are frequently sourced across borders to minimize project costs, and supply chains are deeply integrated internationally.[44] Major developers often operate across multiple jurisdictions, integrating global procurement of components and service with technical expertise.[4] Considering this global integration of components and project development, an investigation into the financial flows for similar internationalization is warranted. Recent literature on renewable energy finance has shown that renewable energy investment is increasingly internationalized, with cross-border flows shaped by investor type, host-country conditions and climate-policy frameworks.[27,45] Cross-border finance flows would suggest that investors perceive offshore wind as a sufficiently standardized asset class, whose value proposition can travel across regulatory and policy contexts. This would support the notion of offshore wind's growing "commoditization." While technical and operational internationalization has been well documented, financing patterns remain underexplored.[46]

However, there is currently a lack of comprehensive analysis regarding changes in investors' decision-making process within the evolving offshore wind sector, connecting technology dynamics to different types of capital as the sector matures over time. Offshore wind has emerged as a notable success story in the energy transition, experiencing rapid growth and attracting significant investment. Examining how capital has been mobilized on a large scale throughout this process can provide valuable insights for designing future solutions and policies aimed at achieving net-zero targets.

This study thus focuses on how the investment environment (investor composition and decision-making process) has evolved alongside a maturing offshore wind industry globally. Market confidence in a novel technology, specifically who invests in new projects, when they invest, and on what terms, is an under-researched area. We analyze such investor confidence in offshore wind, using the data on type of investors and the timing of their commitment as a proxy for capital market technology confidence. In carrying our analysis, we postulate the following hypotheses: (1) the timing of investments throughout the project life cycle is indicative of market confidence. Debt lenders and low-risk seeking investors taking on early stakes in a project reflects increased confidence in project realization and operational performance.[47,48] (2) Investor

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composition is thus indicative of market confidence, where a higher share of low-risk seeking investors suggests a mature technology.[23,37,49,50] (3) Cross-border finance flows indicate the ‘‘commoditization’’ of offshore wind energy, as its value becomes accepted across jurisdictions and policy or business environment.[27,51]

This interpretation is consistent with wider literature on the internationalization of renewable energy finance, which shows that renewable energy investment increasingly crosses national borders as technologies, revenue models, and project risks become more familiar to international investors, including in offshore wind.[27] It also aligns with work on renewable energy foreign direct investment (FDI), which highlights the role of investor type, host-country conditions and climate-policy frameworks in shaping international renewable energy investment flows.[45] We evaluate these hypotheses using a hypothesis-guided comparative design that combines descriptive transaction-level analysis with targeted non-parametric tests where the data allow formal distributional comparison. Given the structure of the available data, the analysis is designed to assess whether observed empirical patterns are consistent with these hypotheses, while recognizing that data availability and reporting practices vary across countries and financing regimes (see limitations). To explore these aspects, the analysis combines two datasets; an auction dataset reporting the details of offshore wind farms globally,[4] and a projects dataset reporting the financing details of auctioned projects. The auction dataset reports 98 wind auctions from 2007 to 2022 representing 130 GW of the global wind capacity.[4,10] The projects finance database originates from Bloomberg New Energy Finance (BNEF), which is considered the most comprehensive source of renewable asset financing data,[37] outlining whether investors provided equity or debt during different stages of the project life cycle. Combining both datasets allows drawing conclusions on 36.4 GW of offshore wind capacity across 86 wind farms in 9 countries. The analysis focuses on financial actors involved in offshore wind auctions, through which 97% of future offshore wind capacity until 2030 will be realized[4] either through contracts-for-difference (CfDs), Power Purchase Agreements (PPAs), or tendering seabed lease rights to build a wind farm, hence this policy setting is the reference framework to consider for future wind deployment.

Here, we use merged financial investment data, wind farm data, and auction data to identify changes in the investor structure. We find that investor structure follows a predictable pattern through each project life cycle, where the later cohorts of wind farms had more risk-averse investors as the markets mature. Results from this research provide insights on the evolution of offshore wind industry, investors' attitude toward wind investment risks, and financing conditions. Set against a backdrop of rising interest rates globally, such results are essential to support renewable technologies deployment.

Financing offshore wind

One distinctive feature of offshore wind financing is its reliance on project finance.[19] Project finance provides the advantage of creating a separation between the project and the sponsor's finances. A sponsor is a company or a consortium that initiates, plans, and leads project development and ensures the project's success by providing financial and managerial support throughout its life cycle, enabling undertaking projects that would be considered unaffordable using the corporate balance sheet.[52] By establishing a standalone project entity, a special purpose vehicle (SPV), the cash flows and financial risks associated with the project are ring fenced, avoiding recourse to the sponsor's finances, or being influenced by it. This unique feature of project finance not only attracts investors and lenders who might be hesitant to take on sponsor-specific risks but also unlocks opportunities to pursue large-scale, capital-intensive ventures with more debt than would be feasible within a typical corporate structure.[52] Project financing is backed by project's cash flows, which are well matched with long-term policy schemes like PPAs or CfDs, enabling revenue stability over the life of the underlying asset.[53]

In any capital structure, project finance or corporate balance sheet, diverse forms of capital are present, each distinguished by its distinct risk and return characteristics. Equity investors assume higher risk due to potential fluctuations in the value of the investment, influenced by market conditions and the performance of the company or project. However, it also offers the possibility of higher returns. Debt capital carries lower risks and lower returns, which is limited by the coupon rate on a loan or a bond. While there are no contractual payments on equity instruments, non-payment of a coupon on a debt instrument would lead to a default, therefore only a project or a company which generates sufficient revenues can be financed with debt.

Due to the varying risk profiles, equity and debt assets attract different investors based on their risk tolerance and preferences. For example, institutional investors (e.g., pension funds, insurance companies) would traditionally invest in long-term, low-risk fixed income instruments that match closely their own obligations. Conversely, venture capital represents the opposite end of the spectrum, focusing on providing funding to unproven businesses, early-stage companies, and projects with high growth potential, along with the associated risks, in pursuit of substantial returns.

When raising funds, the ratio between debt and equity financing in a project's capital structure, is known as the debt-to-equity ratio. This is often referred to as ‘‘gearing’’ or ‘‘gearing ratio’’ and has a direct impact on the weighted average CoC (WACC), as debt is less costly than equity. Hence, the composition of investors matters as it impacts the capital costs of projects. Some projects in onshore wind in Germany, have a 100% gearing ratio, with projects financed using debt only,[54] with no equity required to make the necessary capital expenditure (CapEx). In the case of offshore wind assets, which require substantial capital investment, it is vital to engage debt lenders to access capital at favorable interest rates and unlock financing at low costs to win competitive auctions. The maximum debt-to-equity ratio (i.e., gearing) observed so far is an 80% share of debt and a 20% of equity in financing.[24,54]

Given the importance of the investor base to the competitiveness and deployment of offshore wind assets, we study how the investment environment has evolved alongside a maturing offshore wind technology. This study combines two datasets: a global auction dataset and a finance dataset. The finance dataset (i.e., BNEF dataset) details the investors involved in each transaction on a project, whether they provided equity or debt and at what point in the project life cycle. Reported transactions are of three types: (1) "new build" transactions, when the finance is committed for the project development, also known as the "final investment decision" or "financial close"; (2) "refinancing," when debt is restructured after development; and (3) "acquisition," when shares in the project company are bought and sold.

The data were augmented by categorizing each investor into 10 types depending on their business and ownership status (public or private) to analyze the composition of investors in each type of transaction and its evolution over time. The value of finance committed by each investor is disclosed in less than 30% of transactions, so project capacity is used as the best available proxy for investment flows between investors (see methods for further details). Any missing data points were added by the researchers, following the original logic of the data structure. The combined dataset offers a comprehensive overview of wind farm data and financial parameters.

RESULTS

Financing deals are "closed" increasingly early in project cycles as offshore wind markets mature and investors' confidence grows

Different project phases (i.e., development, construction, operation) are linked to varying risks that influence investment decisions.[55,56] The development phase of a project is typically associated with high risks pertaining to feasibility assessment, permit acquisition, environmental assessments, and contract negotiations. These risks impact the project's likelihood and profitability before the bulk of capital is spent. The primary investors' concern during the construction phase are cost and time overrun. Wind (and solar) projects are among the top performers measured by on-budget and on-time delivery,[57] but the risks, however small, remain.[24] The operational phase generally carries lower overall risks due to the project's established market presence, revenue generation, reduced construction risks, and increased operational experience.

We break down the project cycle into distinct phases to comprehensively analyze the risks associated with each stage of a project. The timing of investments and how investors participate at various stages of the project reveals their inherent risk preference. In particular, we have identified nine different project phases and events that determine the overall project cycle (see methods section definition of project phases): pre-development, development, auction, financing "date of close" (often referred to as final investment decision), construction, refinancing, commissioning, operation, and decommissioning. Some stages and milestones of projects do not have defined border lines and may overlap with other stages. However, some dates are clearly defined and publicly accessible. In order of their (usual) sequence, dates are typically well defined within the project cycle on any investment. These stages are (1) the final investment decision (FID), (2) the auction date for the CfD or PPA,[53] (3) the start of project construction, and (4) the commencement of operation.

We observe the "date of close," which refers to the finalization of project financing, usually occurs less than 2 years before the auction date, predominantly concentrating around the auction date (Figure 1B). It is important to clarify that in several cases, the observed FID may reflect pre-arranged or conditionally agreed financing, which becomes executable upon successful auction outcome. This is consistent with the industry practice of preparing major procurement and financing terms in anticipation of award. In our dataset, approximately 80% of projects are already financed, or "closed" by the time of auction, indicating that they are fully prepared for project execution. In at least one instance, the project took the FID on the day of winning the auction.[4] This implies that major costs associated with the wind farm, such as turbines, foundations, and other components, have been determined and contracted, ready for deployment at that stage. Additionally, the project's capital costs have already been defined as the project has finalized its financing structure.

Some variation in the timing of financial closure is apparent across countries and policy environments (Figure 2A). All Belgian projects, for example, close financing in the same year as auction. At the same time, China exhibits the highest degree of variability in the timing of financial closure, primarily due to its wind market being governed by strong state-led policies. Changes in the underlying policies in China, alternating between auctions, feed-in-tariffs (and back to auctions),[4] are making the financial investment decisions appear independently of the auction award date. The data are more consistent for the other countries, which exhibit higher policy consistency. The data exhibited some indication that policy schemes may influence the financing decisions, in particular the debt-to-equity ratio, but further research is required.

To assess changes in the timing of financial close over the years, we split the data into two cohorts based on the year of FID, such that the number of projects in each cohort was as balanced as possible and to naturally define two distinct phases of market maturity. The early cohort reached FID between 2007 and 2017, while the late cohort reached FID between 2018 and 2022. Figure 1B illustrates that for the latter period, more projects close financing prior to the auction, with 60% of projects closing the financing deal at least 2 years before the auction. In contrast, earlier deals closed nearer the auction date, with 30% reaching a financing deal earlier than 2 years and 50% in the immediate 2 years before the auction. This may suggest that investors are increasingly willing to undertake pre-development risks by committing funds earlier in the project timeline. The earlier timing of the deals in the late cohort, evidenced by the statistically distinct cumulative distribution curves, could be interpreted as an indication of market confidence in the technology. The fact that debt lenders and other low-risk-seeking investors enter the project at an early stage, shows an increased level of confidence in project realization and its operational performance.

Newer offshore wind farms are more likely to rely on low-cost finance

We analyze how the composition of offshore wind investors and financing structure changed over time as an indicator of increased market confidence. Investors are categorized into 10

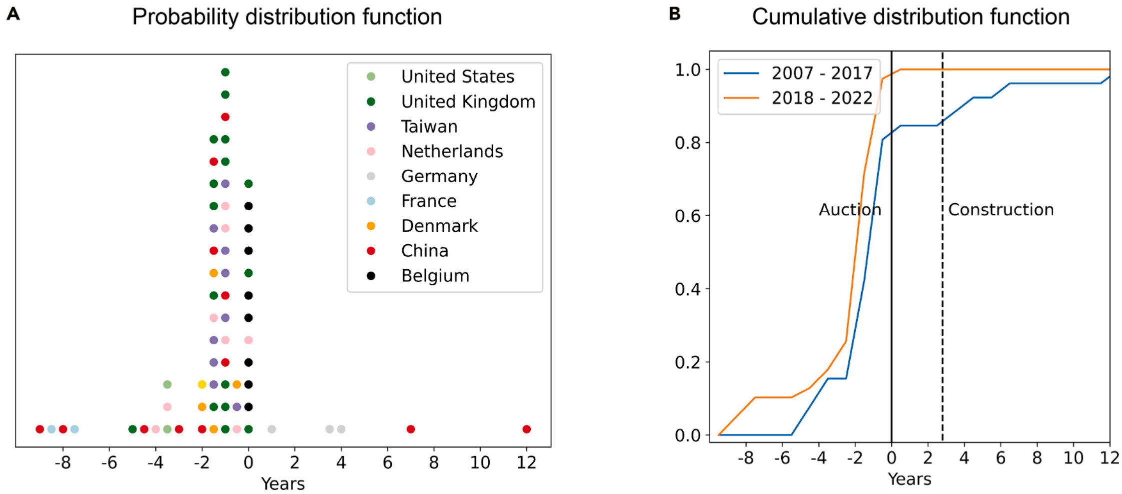

Figure 1. Timing of financing "date of close" with respect to auction (year 0)

The points in (A) each represent a project, color coded by country of auction (i.e., location). The panel shows the time difference between financial close and their respective auction date, which we have found to anchor this decision. Dates of financial close are based on BNEF data and supplemented with data from primary research; auction dates are based on Jansen et al.,[4] updated where necessary. In (B), cumulative distribution curves for projects financed between 2007–2017 (blue line) and between 2018–2022 (orange line). The dashed line represents average time of construction. Exact dates (i.e., not years) for "date of close" are used based on BNEF data and supplemented with data from primary research, while auction time data are based on Jansen et al.[4] and updated where needed. A two-sided Kolmogorov-Smirnov test shows the two cumulative distribution curves are statistically distinct at a significance level of $p < 0.01$.

different types depending on their business and ownership status (public or private). Public actors include public utilities, public banks, state-owned institutions, or multilateral institutions; private actors include private utilities, energy and renewable energy companies, commercial banks, institutional investors, pension/insurance companies, and not-for-profit and other diversified investors (details in methods). Several investor categories represent relatively small shares individually (typically below 5%) but are retained to preserve consistency with established investor classification frameworks used in previous literature.

To attribute a representative share of capacity to each investor in a transaction, we followed the simplified allocation method used in Mazzucato and Semieniuk.[37] Specifically, in cases where the exact financial contribution was not disclosed, we assumed equal shares among investors of the same category (i.e., equity or debt). For example, if two debt investors were reported, we attributed 50% of the debt share to each. Similarly, if three equity investors were involved, the equity share was split equally among them. While this equal-share attribution does not capture all project-specific nuances, it provides a transparent and reproducible way to estimate investor composition across a large sample of projects with limited data availability. The share of investment per investor category is then equal to a percentage of the total capacity of a project attributed to this investor.

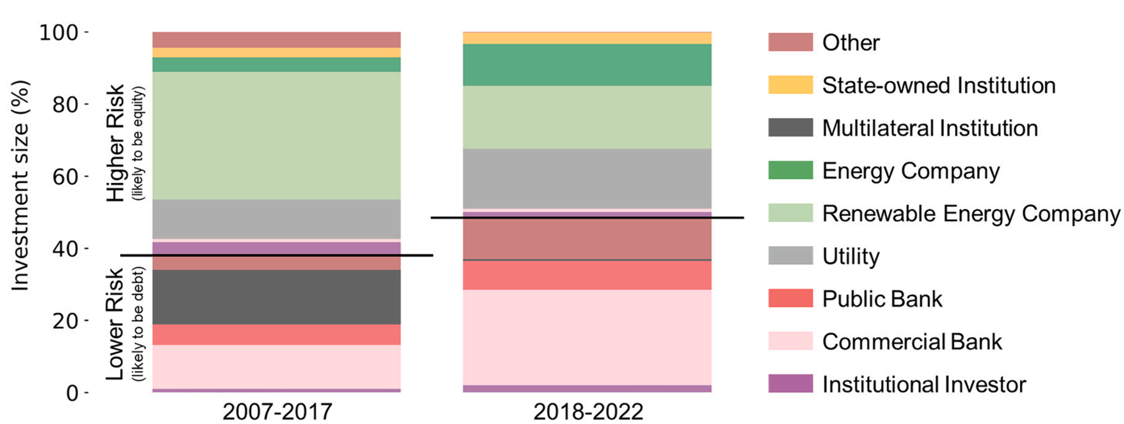

Figure 2. Change in investor composition and financing structure over time

The average investment share per investor category across 65 projects reaching financial close pre- and post-2017. Investor shares are shown separately for equity (above the horizontal axis) and debt (below the horizontal axis). Some investor types, such as institutional investors, appear in both sections because they participate in both equity and debt financing transactions investor types are summarized in Table 1.

The investor composition transformed after 2017, with renewable energy companies reducing equity investment by 18%. This was largely replaced by a 14% point increase in debt financing by commercial banks. Notably, project finance was used in 74% of the deals between 2018 and 2022, compared to 43% between 2007 and 2017 (Figure S1). This shift reflects the trend of project finance, rather than balance sheet finance, as the preferred method of structuring of wind projects in later years.[58] Such increase in project finance might also suggest the growing confidence of commercial banks in the offshore wind assets to service debt reliably. As developers and financiers build up experience and expertise in the sector, the risk profile of new projects improves, allowing project sponsors (typically renewable energy companies) to secure low-cost debt from banks more easily.

In the later years, there is an increase in the share of equity finance provided by utilities, rising from 11% in the early years to 17%. This change can be attributed to a growing number of utility companies active in the sector, which expanded from one (Eneco) to three (Eneco, SSE, Diamond Generating Europe). The greater involvement of utilities in financing offshore wind projects in later years may reflect their preference for larger projects and the prevailing trend of increasing project capacity over time, as the offshore wind technology has improved. It should be noted that several major offshore wind developers (e.g., Ørsted, RWE, Vattenfall) are categorized in this study according to their primary business activity as energy companies rather than utilities. Consequently, the "utility" category in our classification captures only a subset of vertically integrated developers active in offshore wind.

In both time periods, institutional investors play a relatively minor role, contributing 4%–5% of the total investment. This suggests that this type of investor may be hesitant to take on the risk associated with initial investment deals, which often involve uncertain auction outcome. However, it is worth noting that the risk appetite of these investors tends to be higher in refinancing deals, as discussed in the subsequent section.

During the early years, multilateral institutions (e.g., development banks) are active in offshore wind financing, providing 15% of the total debt financing. The involvement of public-private syndicates, formed between development banks and commercial banks, may have been key in facilitating early debt financing in the offshore market. Development banks provided guarantees and contributed with their expertise, generating knowledge and experience in the sector.[59]

These findings indicate that investor composition is a reflection on market confidence. As technology matures, reaching a higher level of stability, reliability, and predictability, it is likely to attract more risk-averse investors, lowering the CoC, and enabling additional projects to become feasible while lowering the LCoE.

Investor composition moves toward a lower-risk profile after project construction

Not all investors are willing to take on the inherent risk of funding a project before the construction has been completed (i.e., construction risk). Instead, many prefer to invest only once a project is fully operational. The risk profile of the project changes dramatically once it reaches operational status, which leads to more conservative investors to step in through full or partial acquisitions (see Figure 3). All 23 wind farms in our database which change ownership do that after auction, on average within 3 years (Figure S2).

Energy companies hold the majority equity (77%) of offshore wind farms at FID. As majority owners, they are responsible for managing the full life cycle of the project, from development, through the auction process, all the way to commissioning and operation. However, once the wind farm is operational, energy companies (among others) tend to divest around 15% of their equity stake.

Most of the divested ownership share in offshore wind farms after FID, approximately 10%, is acquired by institutional investors. Based on the subset of 23 wind farms, institutional investors play a more active role during the refinancing phase, almost doubling their interest from an average of 11% to 21%, reflecting their appetite for investments that offer lower risk and generate consistent revenue streams.

Financing becomes increasingly international

The global spread of offshore wind has changed the energy financing landscape significantly. Capital exchange between regions and countries has increased significantly between earlier years (until 2017) and from 2018 onward (see Figure 4). One notable trend is the increasing flow of international capital. Several structural factors are contributing to this trend: first, climate change mitigation and net-zero targets at national and corporate level have prompted significant attention toward investments in decarbonization technologies, such as offshore wind.[60] Second, lessons learned from some of the offshore wind pioneers are being exported to other jurisdictions. For example, the opening of new markets, such as Taiwan, was accompanied by the transfer of money and knowledge, exemplified by the prominence of western developers being part of the majority of projects.[61] Third, investors from "export" countries may look for geographical diversification of their assets,[62] while investors from jurisdictions less familiar with the technology are attracted by the successes in Europe and China. The last contributing factor is the overall growth in the deployment of offshore wind globally.

The growing scale and frequency of international financial participation may suggest that investors view offshore wind as a deployable, lower-risk asset class across jurisdictions. Increased flows indicate that investors associate a low level of commercial risk with the technology. This overall confidence suggests a certain "commoditization" of offshore wind as a whole, meaning that the technology's value is understood across jurisdictions and can be deployed in a comparable manner, regardless of the energy system in which it is being deployed in.

DISCUSSION

We have investigated the investment in offshore wind to establish capital market technology confidence through three hypotheses. These are based on (1) the timing of investments throughout the project lifecycle, (2) investor composition being a proxy for market maturity, and (3) cross-border finance flows indicating a "commoditization" of offshore wind.

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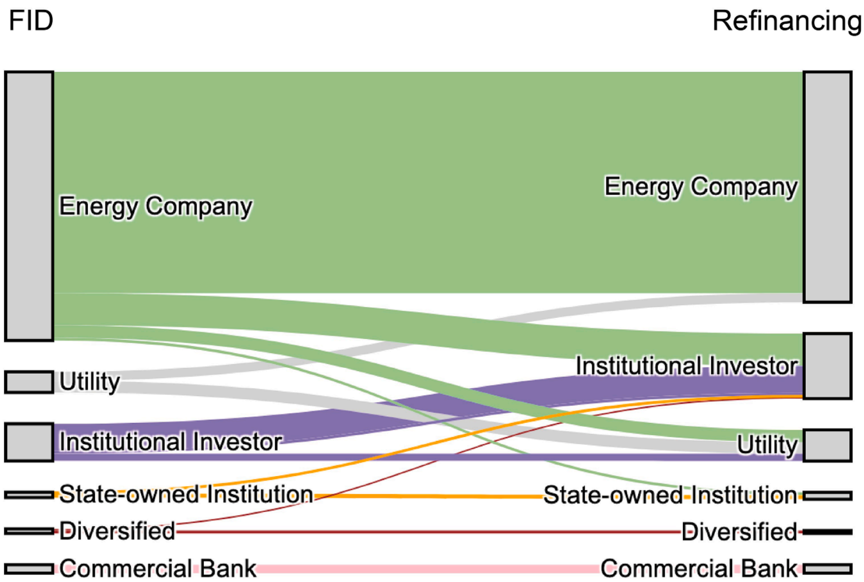

Figure 3. Change in ownership upon acquisition

Sankey diagram shows the average change in ownership from the final investment decision (FID) to acquisition. Data are based on a subset of 23 projects, which had information on FID and refinancing dates.

This allows us to conclude that offshore wind finance markets are likely to have reached a high level of maturity, evidenced by growing investors' confidence in the technology. We have observed a shift in the composition of investors over the last 15 years, toward those seeking lower-risk investment and accepting lower interest rates in return. Notably, the debt-to-equity ratio (i.e., gearing ratio) has increased significantly. The debt-to-equity ratio is an important measure of how well an asset is able to serve its debt and thus an indication of continuity of the income. A high gearing ratio of up to 80% debt and 20% equity indicates that offshore wind projects offer a robust (i.e., mature) investment profile, which is suitable for debt financing, rather than relying heavily on high-risk/high-return equity.

Projects have been attracting a broad range of investors, serving a multitude of investment profiles. Our finding that FID can occur close to or before auction award does not imply that banks commit to full financial close without revenue certainty; rather, it suggests a trend of earlier financial structuring and conditional commitments, reflecting greater market maturity and confidence. This observation is supported by industry sources (e.g., Malleret et al.[63]) and aligns with anecdotal evidence from energy finance professionals, which could be explored further in future research. However, the presence of debt lenders and other risk-averse investor types at early stages of the project cycle, in particular, points toward a low-risk investment profile of offshore wind. The willingness of institutional investors to commit funds at an earlier stage reflects the high likelihood of the projects being realized, with historically high shares of projects progressing following an auction.[4] This trend highlights the maturity and attractiveness of offshore wind projects, as investors with low-risk appetite (e.g., institutional investors) are willing to secure their stakes at an early phase.

The analysis has found a potential increase in international capital flow, demonstrating the changing dynamics and maturity in the offshore wind industry. The trend materializes differently across regions. There is a significant cross-border investment flow between different European countries, indicating a more interconnected financial landscape. On the other hand, in Asia,[64] most of the capital invested in offshore wind projects comes from domestic sources. The cross-border flow of finance suggests a possible growing "commoditization" of offshore wind, where wind farms' risks and returns are similar across different projects and nations, rather than being project specific, likely aided by some policy convergence toward CfDs.[26] Within the global investment market, offshore wind is becoming a critical asset within net-zero and sustainable finance portfolios. This could be seen as evidence that technology, processes, and regulatory frameworks have become more standardized and predictable. As a result, they can be more easily assessed and compared by international financial actors.

This work's contribution on investor structure complements the broader discussion on the CoC. The CoC is primarily driven by technological advancements and maturity (in markets and technology), the debt-to-equity ratio of a project, and is heavily governed by central bank rates along with corresponding risk premiums, which are around 125–175 basis points.[24] The increase in interest rates to curb inflation across western economies in 2022–2023 has raised the CoC for all projects, compounded by supply-chain constraints, leading to higher LCoE for offshore wind. Rising interest rates challenge the sustainable transition overall[65] due to financing costs having a much larger share of the overall total cost of offshore wind (and onshore wind and solar photovoltaics [PV]) than fossil generators.[26,66] The high CapEx requires high levels of borrowing upfront, making a larger part of the overall lifetime cost contingent to interest rate.

Our data do not cover the period of the changing macroeconomic environment since late 2022, but our findings on the investor composition—not the actual level of CoC—are likely to be robust against these short-term interest rate changes. Cost pressures, supply-chain issues, and policy uncertainties throughout 2022, 2023, and 2024 in the UK, United States, and globally have led to the suspension of Norfolk Boreas wind farm[18] and the cancellation of Hornsea 4[55] in the UK and Ocean Wind I in the United States,[19] among others. However, investor confidence in offshore wind appears largely undeterred, as 2023 has been a record year in offshore wind financing with 14 GW of capacity having reached FID.[67] This would validate our finding on investor structure beyond the immediate data

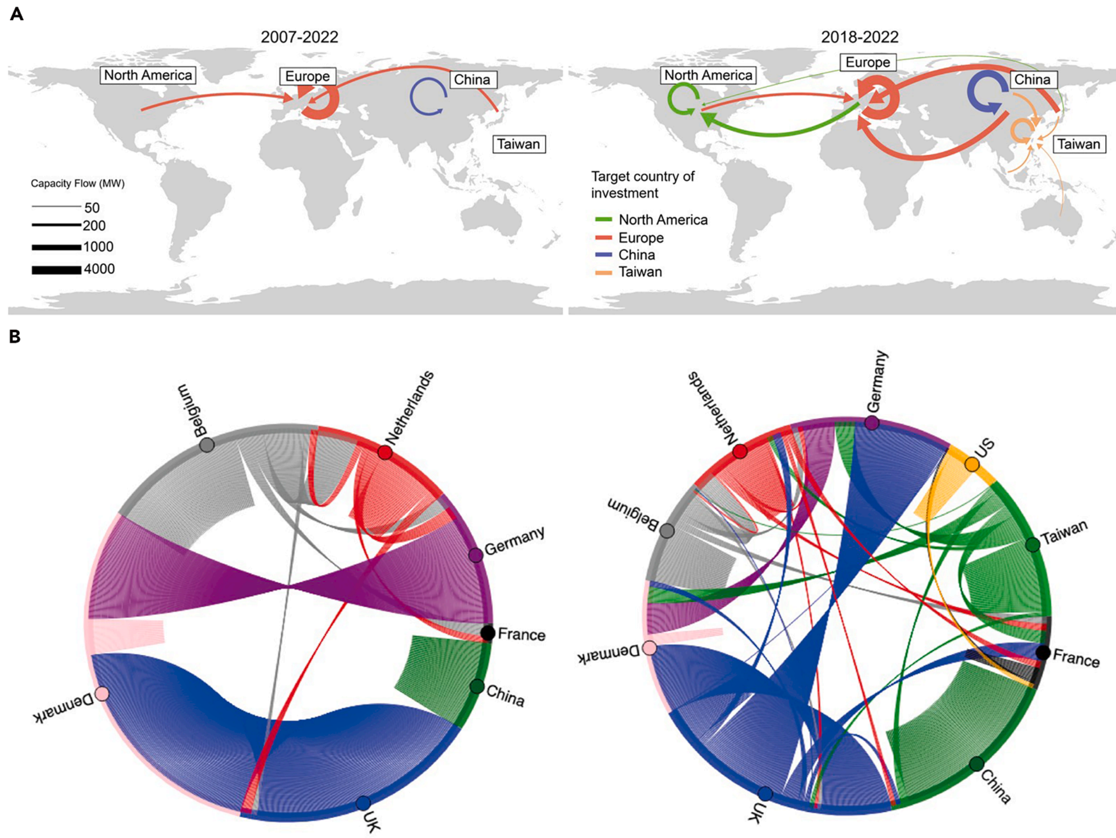

Figure 4. Map of finance flows for earlier and more recent offshore wind farms

International investment increases over time. (A) shows the financial flows on the global map. The width of the arrows represents the size of the investment flow between countries, using project capacity as a proxy for financial transaction value (see methods). The arrows are colored according to the target country of the investment. (B) shows the chord diagrams for the cross-border finance flows between the nine countries analyzed in an early period (2007–2017) and a recent period (2018–2022). The width of the chords represents the size of the investment flows between countries, using project capacity as a proxy for financial transaction value (see methods). The color of the chord represents the source country of investment. The color of the arc represents the target country of investment.

coverage. This is further underpinned by the emergence of merchant offshore wind projects (i.e., not supported by a PPA or a CfD but relying on the wholesale electricity price for offtake) like the Danish Thor wind farm, zero-subsidy wind farms and even negative bids in Germany.

Gaining an understanding of the evolution of offshore wind finance thus provides insights and foresights in two dimensions. First, it offers guidance for nascent offshore wind markets, especially in developing countries. Second, it serves as a blueprint for the financing of new capital-intensive, but lower operation cost, technologies, such as batteries or hydrogen electrolysis. The insights gained from offshore wind finance can facilitate informed decision-making and efficient financing for the deployment of these technologies.

METHODS

BNEF data

The investor data come from a BNEF database, which reports financial transactions on wind assets. The coverage of BNEF's data is highly complete, it is considered the most comprehensive data source for renewable asset financing,[68] and in some cases reports more capacity than other trusted sources such as the International Renewable Energy Agency (IRENA), likely because the BNEF data include information on wind assets that have secured finance but are not yet operational.[34] Such data were included in the analysis as it represents committed finance, which is the focus of our study. Comparing installed (operational) wind capacity reported by BNEF to IRENA in 2021 shows on average 78% of offshore wind projects are covered by BNEF in the countries selected for analysis (Table 2). The full dataset covers onshore, and offshore wind transactions made between 2000 and 2021, globally. Note that some primary data were collected to update the dataset to 2022, in line with the wind farm data.

Each reported transaction on a wind project contains the following relevant information; the investor/s involved in the transaction (labeled as either a debt or equity investor), the type of transaction (''new build,'' ''refinancing,'' or ''acquisition''), the financing type (''balance sheet,'' ''loan,'' or ''bond''), the date of the transaction, the project capacity and location the disclosed transaction value (if available) and a semi-structured text field providing further details of financing structure.

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The three transaction types refer to different stages of a wind project's financing: (1) "new build" transactions give details of the initial project development, and the date of the new build transaction is synonymous with FID. The "financing type" of a new build transaction is "balance sheet" if funds were raised through corporate finance or "loan" if project financing was used. (2) Refinancing transactions give details of debt restructuring, typically after project development. (3) Acquisition transactions give details of changes in the ownership of projects. The semi-structured text data are of the form "company X acquired a 12.5% stake in windfarm Y for an undisclosed amount from company Z."

Data preparation

Extensive data preparation was undertaken to obtain a clean and consistent dataset, including the following steps: (1) the data were cleaned such that all debt transactions include at least one debt investor and at least one equity investor. (2) The data were cleaned such that all equity transactions include at least one equity investor. (3) Where investor information was not reported, investors were assigned a unique identifier and categorized as "unknown."

Empirical research design

The study adopts a hypothesis-guided, primarily descriptive comparative research design. The three hypotheses concern observable changes in offshore wind financing over time: the timing of financial close relative to auction, the composition of investors and financing instruments, and the internationalization of finance flows. These hypotheses are evaluated by comparing early and later project cohorts and by examining whether the observed patterns are consistent with the expected direction of change implied by market maturation and increasing investor confidence.

This design is appropriate for the structure of the available data. The merged dataset combines BNEF transaction records, organization data, project-level information, and auction data, yielding 86 matched offshore wind farms with available financial information. The data span heterogeneous regulatory, geographic, and financial contexts, and several key variables are incompletely observed because deal values and individual investor contributions are often undisclosed. Accordingly, the analysis does not aim to estimate causal effects or to provide full statistical generalization across the global offshore wind market. Instead, it provides a transparent empirical assessment of theoretically motivated patterns in investor behavior using the best available transaction-level evidence.

Where the data structure allows a meaningful formal comparison, we supplement the descriptive analysis with targeted statistical testing. Specifically, we use two-sample Kolmogorov-Smirnov tests to assess whether the distributions of timing to financial close and debt share differ between early and later project cohorts. For investor composition, acquisition patterns and cross-border finance flows, the analysis remains descriptive because the relevant observations are sparse, heterogeneous, and partly based on capacity-weighted attribution rather than fully disclosed transaction values. We therefore interpret these results as evidence of directional changes in financing structures and investor participation rather than as causal estimates or exhaustive tests of all possible determinants of investor behavior.

Debt and equity share of projects and transaction volumes

Data were augmented by categorizing each investor as one of ten types: public utility, private utility, renewable energy company, energy company, commercial bank, public bank, institutional investor, non-profit investor, multilateral institution, and state-owned institution. This categorization follows the work of Mazzucato and Semieniuk[37] and distinguishes the key business types involved in renewable energy financing and their ownership status (public or private). Investors were categorized according to their primary business activity and ownership structure. For example, specialized offshore wind developers such as Ørsted are classified as renewable energy companies, reflecting their core business in developing and operating renewable energy assets rather than functioning as traditional vertically integrated utilities.

The categorization was performed using a semi-automated method; structured data provided by BNEF on business activity and ownership of organizations were used where possible, otherwise an internet search was undertaken. Table 1 provides definitions for each investor category and their representation in the data. The transaction costs are disclosed in less than 30% of cases, and we therefore used project capacity as the best available proxy for the size of the investment. To attribute a representative share of capacity to each investor in a transaction we follow the protocol of Mazzucato and Semieniuk.[37] It is assumed that when only a single equity investor is disclosed, the deal is entirely financed by this sponsor (balance sheet transaction). Second, where equity and debt investor/s are disclosed (typically a project finance transaction) we assume the equity share of the project capacity is divided between equity investors and the debt share of project capacity is divided equally between debt investors. Where not reported, the debt share of the project is assumed to be 78%, which is the average debt share in our dataset and in line with industry standards.[69]

The equal-share attribution implicitly assumes all investors take on the same proportion of project risk and cost. This assumption may overlook differences driven by project-specific factors such as deeper water requiring more expensive foundations, longer export cables, or complex seabed conditions, which could be more prevalent in later projects. In reality, CapEx for an offshore wind farm can vary significantly based on water depth, distance to shore, turbine size, and grid-connection logistics. While these factors are critical for detailed cost engineering, they are not central to our primary objective of identifying structural trends in investor participation, including timing, debt versus equity shares, and international involvement. Moreover, reliable project-level breakdowns of such cost drivers are rarely publicly available, and attempting to incorporate them would introduce additional uncertainty. In fact, difficulties in obtaining project-specific reliable data are discussed in Malleret et al.,[63] and uncertainties around LCoE modeling are well documented, e.g., Martinez and Iglesias[71] or inputs to Bosch et al.[72]

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Table 1. Definitions of investor categories and the percentage of the offshore wind investment provided by each category

Category		Description	Share of investors
Private bank	private	main business is commercial banking	41.0%
Public bank	public	state-owned bank including multilateral development banks	11.4%
Energy company	private	component manufacturers, project developers, O&M services in energy and renewable energy	16.0%
Institutional investor	private	non-bank financial companies e.g., private equity firms, pension funds, investment funds, insurance companies	8.2%
State-owned institution	public	government agencies e.g., ministries, municipalities, councils, research institutions, state-owned institutions	5.6%
Public utility	public	main business is the generation and distribution of energy	5.2%
Private utility	private	main business is the generation and distribution of energy	5.7%
Diversified	private	private, non-financial organization whose main business is not in the energy sector e.g., engineering and construction companies	3.6%
Non-profit investor	private	foundations, co-operatives, community organizations	3.1%
Unknown	–	–	–

Wind farm data

The dataset contains all offshore wind farms auctioned until July 2022. The dataset is a continuation of previously developed and published dataset of offshore wind[4,10] and was adapted to align with the BNEF dataset. In total, the dataset contains 169 existing and upcoming wind farm projects with 130 GW of capacity. The database contains all existing wind farms that have been auctioned, and all known future wind farms, or tendered sites up to 2031. The dataset captures technical wind farm details, support schemes, auction results, strike prices, and key project dates, such as construction start, commissioning date, among many others.

Data matching

The BNEF data and wind farm data were matched manually, since projects can be named according to different conventions (e.g., by location or developer), making automated matching inaccurate. To enhance accuracy, we verified auction award dates using the Jansen et al.[4] dataset and official public sources. FID dates reported by BNEF were cross-checked against project press releases, developer disclosures, and public databases. Where inconsistencies were identified, we treated these with caution, verified where possible, and excluded those deemed too ambiguous. From the BNEF data, the project name, transaction name, and named investor/s were used to find matches in the wind farm data with the auction names and/or project names. Once potential matches were identified, they could be verified by comparing the FID data from the wind farm data and the date of the new build transaction in the BNEF data. The matching yielded some wind farms with partial information available, which would not be useful for the analysis going forward. To create the most comprehensive dataset possible, occurring gaps, in particular on the financial transaction data side, were filled with primary data research by the authors. In total, 11 projects required partial manual supplementation of financing information, corresponding to approximately 13% of projects and 4.6 GW (12.5% of total capacity). These cases did not involve reconstruction of complete financing structures; rather, they reflect targeted completion of missing fields, such as investor identity, transaction timing, or financing type, and are taken from publicly available sources (e.g., company disclosures and press releases). Projects for which financing structures could not be established with sufficient confidence were excluded from the final sample.

This means that not all wind farms could be matched. Nonetheless, the process yielded 86 matches of wind farms, totaling 36.4 GW of auctioned capacity. It is worth noting that the underlying available information for the finance structure, on which the BNEF dataset depends on, is not necessarily representative of the global offshore wind market, due to the possible lack of reporting for these data points. Thus, the dataset presents the best possible and most holistic knowledge, albeit with the caveat that some financing structures are not captured representatively.

Splitting cohorts

We split the set of wind farms (that were successfully matched) into an early and a late cohort based on the year of FID (i.e., "date of close"), such that the number of projects in each cohort was as balanced as possible to allow for meaningful comparisons (Table 3). Dividing the data in this way also reflects the fact that new projects drive technological and financial learning processes that advance market maturity and a 50/50 split is a natural choice to define two distinct phases in market development. FID date (rather than e.g., auction award date) was chosen to divide the cohort since it represents the point at which the project was considered viable, and investors committed their finance. It is thus the most natural reference point for analyzing changes in financing conditions.

Definition of project phases

Conceptually, individual project timelines can be categorized into six different phases, some with a distinct date, others being more spread out, depending on the individual project. The phases include (1) the pre-development (early development) phase, which typically includes site surveys, feasibility and environmental studies, among others. (2) The next is pre-auction development, leading up to the auction. This is typically where

Table 2. Merged data statistics

Country	No. of projects covered in this study	Capacity covered in this study (in GW)	Total BNEF 2021 dataset project pipeline (in GW)	IRENA[11] project pipeline (in GW)	Share of coverage based in relation to BNEF data
US	10	6.1	117.6	132.7	5.2%
Germany	6	2.2	46.0	63.9	4.8%
UK	20	10.0	23.2	25.7	43.1%
The Netherlands	8	4.5	5.9	7.8	76.3%
Denmark	4	1.7	4.4	7.0	38.6%
China	12	3.0	242.7	329.0	1.2%
France	6	2.9	15.7	18.7	18.5%
Belgium	8	2.1	4.0	4.8	52.5%
Taiwan	12	3.9	3.7	–	>100%
Sum	**86**	**36.4**	**463.2**	**589.6**	–
Average	**10 ± 5**	**3.8 ± 2.5**	**43.2 ± 75.9**	**65.3 ± 104.7**	**43% ± 34%**

Capacity reported in the merged dataset (and the number of projects) with national project pipeline estimates from BNEF and IRENA in the countries selected for analysis.[70] "Capacity covered in this study" reflects only the subset of projects included in our analysis that have financial information available and are thus either operational or in commissioning phase. BNEF and IRENA figures represent broader national pipelines, including planned, permitted, and under-construction projects, many of which do not contain financial information.

suppliers are chosen, contracts are negotiated, the final turbine layout is defined, and auctions bids are prepared based on the cost basis. (3) Auction date is the final date a bid for in the competitive procurement can be submitted (e.g., CfD/PPA/OREC/FiT; see Beiter et al.[53] for details). The bidding procedure can also happen in several stages. The winning bids are typically announced shortly after the bid submission but can take up to one year. (4) FID (or financial close) determines when all financial transactions are put in place. (5) The construction start date is typically indicated by the start of offshore construction, in most cases, starting with the foundations. Some onshore wind construction may precede offshore construction, such as port works, or onshore grid connection. Offshore construction start is the more significant date, due to the higher cost, weather, and equipment constraints. (6) The commissioning start date indicates the full operational status of the wind farm, which may be preceded by more than a year by the "first power date," when the first turbine delivers power to the grid, while the rest of the wind farm is still under construction. (7) The operation starts after the commissioning date and is expected to last no less than 25 years. This is complemented by the (8) refinancing date and (9) the decommissioning date. The data availability for each project varies broadly, with some dates being regarded as highly privileged information.

Limitations

While the BNEF database is the best available source for data on renewable asset financing, its coverage of deal values and the contributions of individual investors is sparse. Our use of project capacity is not intended as an accurate substitute for investment value but is fit for our purpose of assessing the distribution of investments across investor categories and changes over time. Furthermore, our attribution of investments between investors in a transaction (following the Mazzucato and Semieniuk protocol) is reasonable but potentially over-simplified since it assumes all investors using the same finance instrument (debt or equity) are equivalent. The division of the investment among investors can depend on other factors such as the size of the company and their other roles in the project (i.e., as the lead arranger of a loan syndicate). More sophisticated methods have been developed that rely on statistical inference requiring more data than is available in our dataset.[73]

Discrepancies between "date of close" and "FID" are possible. These inconsistencies stem from a lack of harmonization of language in the industry. Reported dates may therefore mean slightly different project stages. Without inside knowledge on projects on a case-by-case basis, this will be hard or impossible to resolve.

Our analysis on offshore wind energy focuses on the least mature technology in the trio of onshore wind, offshore wind, and solar PV. However, this is a deliberate choice to observe a maturing industry, but it may omit some findings from onshore wind and solar PV.

The dataset captures a wide range of offshore wind financing deals, it includes projects from diverse regulatory, geographic, and financial contexts. This heterogeneity limits the extent to which the analysis can support causal inference or statistical generalization to all offshore wind projects globally. We therefore adopt a hypothesis-guided, primarily descriptive comparative research design. The three hypotheses are evaluated through observable transaction-level indicators: timing of financial close, debt and equity participation, investor categories, ownership changes, and cross-border finance flows. Where the data structure allows a meaningful formal comparison, we supplement the descriptive analysis with statistical testing, specifically two-sample Kolmogorov-Smirnov tests for the timing of financial close and debt-share distributions across early and later project cohorts. For other dimensions, including investor composition, acquisition patterns, and international finance flows, the analysis remains descriptive because the relevant observations are sparse, heterogeneous, and partly based on capacity-weighted attribution rather than fully disclosed transaction values. We therefore interpret these findings as structured evidence of directional changes in offshore wind financing, rather than as

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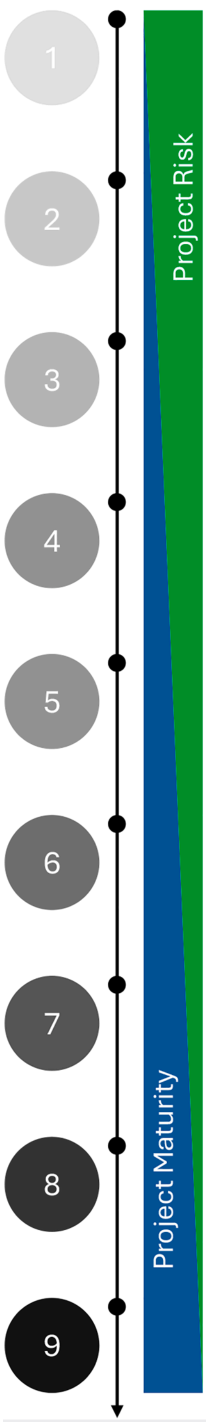
Table 3. Typical phases of an offshore wind project and corresponding data coverage in this study



Phase	Nature of the event	Data coverage of data set	Default values if not known	Further explanation
Pre-development	phase	100%	5+ years before auction, up until 2 years	5+ years before auction, up until 2 years
Development	phase	100%	2 years before auction, after pre-development until FID	–
Auction	date	100%	after auction and before start of construction	–
Final investment decision	date	100%	first investment decision, typically after auction, but not necessarily; also often referred to as financial close	also often referred to as financial close; time when most contracts are closed and backing out would be costly
Construction	date	20%	if unknown, assume construction 2 years before commissioning date	construction start is usual sign posted by offshore activity, but also other considerable efforts count as such (e.g. 10% of CapEx spent)
Commissioning	date	87%	–	–
Operation	phase	N/A	commissioning + 5 years	commissioning dates are typically announced as “first power” and “fully commissioned”; these dates typically lie 1–2 years apart, but it depends on the project
Re-financing date	time span	9%	–	date at which ownership is altered compared to FID date
Decommissioning	phase	N/A	25+ years after operation start	–

The table outlines key milestones in the project life cycle, including their approximate timing and relevance for investor commitment. “Date” refers to the typical point in time (relative to commissioning) when a phase occurs, while “phase” indicates the expected duration of that phase. These phases serve as a framework for analyzing when different investor types participate, rather than strict chronological benchmarks, due to variation across projects. The visuals on the left indicate progression of project risks and maturity. Note: actual timing and definitions may vary across projects, particularly for commissioning and refinancing events.

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causal estimates or exhaustive statistical tests of all possible determinants of investor behavior. We also recognize that policy changes, supply-chain conditions, macroeconomic factors, and investor-specific strategic goals affect investment decisions but are not fully captured in our analysis.

It is to note that the representativeness of the data depends on the underlying availability of publicly available financial investment data. Three main sources of potential bias should be noted. First, there is a geographical reporting bias, originating from different business practices. Second, there is a disclosure bias, as projects financed through internal balance sheets or privately negotiated structures are less likely to appear in transaction-level datasets. Third, there is a visibility bias favoring larger transactions, which are more frequently captured in commercial databases. We are confident that the data are sufficiently large to identify the trends observed. In total, merging both datasets yielded 86 wind farms, totaling 36.4 GW of capacity, which serves as the basis for our analysis. Summary statistics for the merged dataset are available in Table 2. We do note varying degrees in coverage of deals, with a particularly lower percentage coverage for China's pipeline and its global deployment scale. This is not solely due to data availability but also reflects structural differences in the organization of investment. Offshore wind deployment in China is largely driven by state-owned enterprises (SOEs), which combine policy objectives with market-based incentives and frequently finance projects through internal capital allocation or state-directed credit rather than through externally syndicated project finance transactions.[74,75] As a result, investor-level participation, financing structure, and transaction-level detail are less consistently disclosed and less amenable to classification in transaction-based datasets. Consequently, key analytical dimensions used in this study, such as investor composition, deal structuring, and timing of financial close, are less directly observable for China than for western markets. The analysis should therefore be interpreted as most representative of offshore wind markets where financing is organized through transparent, multi-actor project finance structures, and does not necessarily represent state-led economies. The dataset provides strongest coverage of European and OECD markets, where offshore wind has matured earliest and financing structures are most transparent. The results should therefore be interpreted as reflecting structural trends in these markets, rather than globally representative averages.

This descriptive approach was chosen for several reasons: First, the transaction data itself, while sourced from BNEF, relies on public announcements and press releases. These data points come in heterogeneous formats and contain different aspects of the deals. In many cases, public information must be assumed incomplete, which strongly affects any analytical statistical approach. It is likely that statistical significance cannot be established with the dataset at hand, with 86 wind farms available at most, and some subsets less than that. Second, the purpose of the study is to explore the rich dataset available and to identify behavior changes in investors. The descriptive analysis points toward significant changes. Ultimately, it opens up a new research avenue in energy finance, focused on investor composition, instead of cost of debt and equity. For the stated purpose, the descriptive method is deemed appropriate. Third, an analysis of causes for these developments is complex. We have explored the data in a more analytical approach in the initial exploration phase for a number of different aspects. For example, with regard to policy scheme design. Correlation was identified between the revenue stabilizing aspect of a policy[4] and the gearing ratio, but statistical significance could not be established. Many of the underlying causes are not naturally numerically coded and analytical approaches fail to capture the nuance. For these reasons, the descriptive comparative design was selected as the most appropriate way to evaluate the hypotheses transparently without overstating the inferential power of the available data.

RESOURCE AVAILABILITY

Lead contact

Requests for further information and resources should be directed to and will be fulfilled by the lead contact, Malte Jansen (m.jansen@sussex.ac.uk).

Materials availability

This study did not generate new unique materials.

Data and code availability

The analysis results and publicly sourced data are available alongside this paper and the supplemental materials. The BNEF dataset is proprietary and cannot be made publicly available. Details on how to access the BNEF dataset are provided in the supplemental methods section. On obtaining access to the data, the protocols detailed in the methods and supplemental methods can be used to reproduce the results of this study. Any data created in this study are, including raw data for all results presented and the matching to individual BNEF transactions, are available upon request from the lead contact and corresponding author.

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AUTHOR CONTRIBUTIONS

M.J., J.R., A.O., and N.A. conceived the study. J.R. and N.A. carried out data gathering. M.J. developed the analysis. J.R. processed data, carried out analysis, and visualized the results. All authors wrote and edited the paper.

DECLARATION OF INTERESTS

The authors declare no competing financial interests.

SUPPLEMENTAL INFORMATION

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