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The Grand Challenges of Offshore Wind Financing in the U.S.:

A Report from the Offshore Wind Financing Business-Academia Collaboration Workshop, Columbia University, June 23-24, 2022

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Abstract: Interest and development in offshore wind energy in the U.S. is at an all-time high. The Biden Administration committed to increasing offshore wind capacity from a meager 42 megawatts (MW) in 2022 to 30 gigawatts (GW), or 30,000 MW, by 2030—enough to power 10 million homes. Achieving this target would require over $100 billion in new investments and create 80,000 full-time-equivalent jobs from 2023-2030. In addition, states have committed to procuring 64 GW of offshore wind by 2045, and the pipeline of actual offshore wind projects rose to more than 40 GW by May 2022, representing a nearly 1,000-fold increase from current installed capacity. Such a scale-up would transform the sector and make major strides in enabling the nation to rapidly decarbonize, improve energy security, and support universal access to affordable energy in a climate-changing world. Critical to achieving success is financing. While there is no shortage of financial capital, employing it faces major challenges. We explored these challenges during a two-day business-academia collaboration workshop at Columbia University, June 23-24, 2022, and we identified five *grand challenges*, i.e., potential showstoppers—challenges that, if not solved, will prevent the massive and rapid scale-up of offshore wind from taking root. These include (1) navigating the complexities, timing mismatches, and high costs of the early years of developing an offshore wind project; (2) addressing the failure of support policy to provide certainty on future costs and revenues; (3) developing a capable workforce in an immature and inexperienced market; (4) building an offshore wind-friendly transmission network; and (5) financing and scaling up floating offshore wind technologies. If solved, the U.S. will move several steps closer to turning the potential for an offshore wind transformation into reality.

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1 Introduction

The U.S. has recently seen increasing interest and development in offshore wind (OSW) energy, a clean and renewable energy resource widely viewed as critical for decarbonizing energy systems. The Biden Administration committed to increasing OSW capacity from a meager 42 megawatts (MW) in 2022 to 30 gigawatts (GW), or 30,000 MW, by 2030—enough to power 10 million homes [1]. Achieving this target would require over $100 billion in new investments [2] and create 80,000 full-time-equivalent jobs from 2023-2030 [3]. Policies in eight East Coast states—Massachusetts, New York, New Jersey, Rhode Island, Connecticut, Maryland, Virginia, and North Carolina—aim to develop 40 GW of OSW capacity by 2040 [4]. California recently adopted capacity targets of 2-5 GW by 2030 and 25 GW by 2045 [5], and discussions for more OSW targets are underway in Washington and Oregon [6,7], the Gulf Coast [8], and Great Lakes states [9]. The pipeline of actual OSW projects rose to more than 40 GW by May 2022 [4], which represents a nearly 1,000-fold increase from current installed capacity. Such a scale-up, if successful, would transform the sector and make major strides in enabling the nation to rapidly decarbonize, improve energy security, and support universal access to affordable energy in a climate-changing world.

These targets and projects just begin to scratch the surface of OSW's potential in U.S. waters, which is estimated at 2,100 GW of electricity generation capacity, nearly two times the country's electricity capacity from all sources in 2021 [10,11]. This estimate—from the National Renewable Energy Laboratory (NREL)—only includes resources that can feasibly be developed, and excludes resources with technological and economic issues (e.g., too costly due to high water depths or low wind speeds) and industrial and environmental conflicts (e.g., conflicts with shipping lanes or marine protected areas).

Globally, production costs for OSW, like other renewables, have declined precipitously. In mature markets, OSW without subsidy is now competitive with conventional generation [12]. The same can be expected in the U.S. as the market matures.

Despite its slow start, the U.S. is well-positioned to become a leader in OSW energy, helping OSW become a central feature of energy transitions globally. In addition to the reasons laid out above, the U.S. remains the world's largest economy and second-largest energy producer, energy consumer, and carbon emitter [13–15]. The U.S. also has a strong record of fostering transformative innovations, e.g., space travel and the moon landing, computers and the internet, and smartphones [16–18]. If the full pipeline of current projects is successful, the U.S. could increase its global share of the OSW market from zero in 2022 to 11% in the next one to two decades.[1]

An OSW transformation, however, will not come about automatically. With attention on OSW at an all-time high, it is easy to overlook the challenges, which are especially material in the U.S. with a nascent market and many overlapping regulatory and policy jurisdictions. We explored these challenges through the lens of finance—i.e., the sourcing of money, the conditions under which that money is provided, and the challenges and opportunities that surround it—during a two-day business-academia workshop at Columbia University, June 23-24, 2022.

Industry practitioners generally agreed that there is no shortage of financial capital and investors want to invest in OSW. This view is supported by the results of the most recent OSW leasing auctions, where developers bid enormous sums of money (to be paid to the government) for OSW leases that grant them the rights to develop OSW farms in the New

[1] The U.S. pipeline is about 40 GW and the global pipeline (including installed capacity) is about 368 GW [4].

York Bight [4]. The question, therefore, is how to support and accelerate the development of OSW and remove barriers. Specifically, the workshop addressed the following questions:

1. What are the challenges in the next three to five years to financing a massive and rapid scale-up of OSW energy in the U.S.?
2. Which of these challenges are *grand challenges*, i.e., potential showstoppers—challenges that, if not solved, will prevent the massive and rapid scale-up from taking root?

We identified five grand challenges:

1. Navigating The complexities, timing mismatches, and high costs of the development phase (i.e., siting and permitting, setting up contracts for construction and operation, and securing financing).
2. Addressing the failure of support policy to provide certainty on future costs and revenues.
3. Developing a highly skilled and capable workforce in an immature and inexperienced market.
4. Building an OSW-friendly transmission network.
5. Financing and scaling up early-stage floating OSW technologies, which are needed to realize the full potential of OSW in the U.S.

We also include three special mentions, i.e., challenges that were deemed as important at the workshop, but not discussed with the same level of depth as the grand challenges.

Special mentions:

- Political risk and social acceptance.
- Supply chain risks.
- Limitations arising from the National Environmental Policy Act (NEPA).

The report is organized as follows: Section 2 provides context and background information for understanding our workshop and the derivation of the grand challenges. Section 3 describes the grand challenges and special mentions. Section 4 concludes.

2 Background

2.1 The Workshop

The workshop was titled, “Offshore Wind Energy Financing: Grand Challenges and Innovative Solutions.” It brought together practitioners and academics working across policy, finance, and engineering in the U.S. and Europe, within the OSW space. Our purpose was three-fold: (1) identify the “grand challenges” facing OSW financing in the U.S.; (2) develop a larger agenda for research, business, and policy aimed at solving those challenges; and (3) create an ongoing network and collaboration to help realize that agenda.

Before the workshop, the researchers created and sent out a short survey regarding the challenges and drivers facing OSW financing. Participants were asked to spend up to ten minutes on the survey, and the results—summarized in Appendix 1—were used to inform the topics and questions addressed at the workshop.

The workshop lasted two days. The first day included just researchers, who presented their research on OSW financing in the context of the U.S. On the second day, OSW finance practitioners were invited for four hours. Three practitioners gave short presentations on their perspectives on the grand challenges to OSW financing, which was followed by a keynote address that provided an overview of the issues at stake. We then split up into three focus groups, each focused on a different area: (1) risk, (2) siting and permitting, and (3) financing structures. Each group was tasked with determining the key challenges within the given area, and which of those constitute grand challenges. The full group of practitioners and researchers then met to discuss the grand challenges.

The workshop concluded with a de-brief by researchers to identify conclusions and research needs derived from the discussions with the practitioners, and outline next steps for continued collaboration.

2.2 A Brief Introduction to OSW Finance

OSW projects are highly capital intensive. Upfront capital expenditures account for around 95% of an OSW farm's levelized cost of energy (LCOE), i.e., total lifetime costs divided by energy produced [19]. The LCOE represents the lowest price at which energy can be sold for the project to break even. Given the capital-intensive nature of OSW, the single biggest driver of the LCOE is the cost of financing, known as the "cost of capital"—the interest rate that a project owner must pay its security holders. The cost of capital varies inversely with project risk. The higher the risk, the greater the compensation required by security holders, and—therefore—the greater the cost of capital [20].

Developing OSW farms is difficult; they are constructed in extremely harsh conditions—the open sea—and face a variety of physical and logistical challenges. There will *always* be setbacks in the construction process. OSW development also involves multi-contracting and many interfaces between industries and competencies that have not traditionally worked together, and the process of building an OSW farm is path-dependent—each part depends on the success of the previous. No one contractor represents an especially large share of project costs. These challenging conditions might suggest that OSW development is prohibitively expensive, due to cost overruns and a high cost of capital. However, the history of OSW projects in Europe tells a very different story. Experience there shows that projects there have generally been built on time and on budget [21], and that OSW is now competitive with conventional power generation in mature markets [12]. This rapid decrease in costs has fueled OSW development globally.

A large part of OSW's success can be attributed to project finance [21], i.e., a financing structure where the provided funds are backed by the projected cashflows of the project itself, and that incorporates a series of risk-reducing checks and balances. Project finance brought discipline to the inherently risky undertaking of constructing OSW farms. That is, financiers did their due diligence. They brought capabilities such as project management and interface management, set intrusive requirements for making contracts, and carefully analyzed and considered everything that could go wrong. This level of scrutiny has been essential.

Given the inevitable setbacks during OSW construction, financiers focused on worst-case scenarios. They wanted to ensure that they would still make money despite the inevitable setbacks. They financed developers that were competent problem-solvers, and they used contingency budgets, i.e., funds set aside for when something goes wrong (usually about 10% of the project cost). As risks became better understood and managed, the cost of capital to build OSW farms decreased significantly. Evidence shows that, from 2014 to 2020, the LCOE for OSW decreased 28-51%—far faster than experts predicted—and further significant cost reductions are expected [22].

The overarching lesson from early OSW projects across Europe is that project financing works. Given the complexities and risks inherent to OSW development, the rigorous risk analysis and due diligence of project finance are necessary. Project finance will also likely play an important role in developing early-stage floating offshore wind technologies (see Section 3.5).

2.3 The State of OSW Development

Table 1 summarizes the state of the global OSW industry as of end-of-year 2021. Total installed capacity amounts to 48.4 GW, with 47.5 GW concentrated in six countries: China (19.7 GW), the UK (12.3 GW), Germany (7.7 GW), the Netherlands (3 GW), Belgium (2.4 GW), and Denmark (2.3 GW). The pipeline of future projects and stated capacity targets amounts to 232.3 GW through 2035. The U.S. ranks third with 25.9 GW. As shown in Table 2 below, U.S. state-level capacity targets have since grown to 64.3 GW through 2045, largely due to California's target of 25 GW by 2045.

As of 2021, 24% of installed OSW capacity globally had been auctioned. By 2030, however, this figure is expected to rise to 97% [23]. There are two main forms of auctions for OSW development: *seabed lease auctions* and *support auctions*. In a *seabed lease auction*, developers bid for the right to develop an OSW farm on a pre-selected area of seabed. The highest credible bid wins. Seabed is generally owned and controlled by governments, so the winning bidder pays the agreed amount to the government. In a *support auction*, developers bid to receive government financial support to develop an OSW farm. The lowest credible bid wins. As support auctions have seen more zero-dollar bids—i.e., where developers do not need government financial support—governments have begun to include more qualitative criteria in their processes for selecting winners.

Support auctions also generally provide long-term price stabilization, and thus revenue stabilization, which lowers project risk and costs of capital. Revenue stabilization can also come outside of support auctions. There are three main revenue regimes that provide revenue stabilization:[2]

1. Contract for difference (CfD): CfD schemes are based on the difference between the strike price, i.e., the pre-agreed electricity price that the generator receives, and the reference price, i.e., some measure of the market electricity price. The strike price is generally determined via support auctions, where generators bid how high of a strike price they need. CfD schemes are 1-sided or 2-sided:
    - 1-sided: If the reference price is below the strike price, the generator receives the difference between the two.
    - 2-sided: In addition to the arrangement in the 1-sided CfD, if the reference price is higher than the strike price, then the generator pays the difference back to the government, up to a government-determined cap.
2. Feed-in-tariff (FiT): The generator receives a fixed price, i.e., tariff, for electricity generated and sold, regardless of the market price. The tariff level is usually set administratively by the government, generally above the expected market price and reflecting the cost of production. FiTs are used less and less for OSW.
3. Competitive bidding for a fixed-price power purchase agreement (PPA) or fixed-price offshore renewable energy certificate (OREC): A PPA is a long-term price contract between generator and buyer. An OREC represents the positive environmental attributes of one megawatt-hour (MWh) of electricity generated. In both cases, bidders—usually utilities—bid how much they are willing to pay for a government-mandated quantity of electricity (or ORECs, which are exchanged for electricity) to be generated in the future. The highest bid wins.

[2] See Tables 1-6 in Beiter et al. [24].

Table 1. Summary of installed and expected future OSW capacity—and how much has been or will be auctioned—across the globe as of end-of-year 2021.

Country/ Region	Installed capacity [in MW]		Capacity under construction [in MW]		Expected additional capacity (Projects announced + policy targets through 2030/35) [in MW]			Future capacity pipeline (under construction + announced + policy targets) [in MW]		Auction share of…	
	Total	…of which auctioned	Total	…of which auctioned	Total	…of which auctioned	Expected to be auctioned	Total	…of which auctioned + expected auctions	2021 installed capacity	Future capacity pipeline
China	19,747	3,000	7,992	2,850	58,391	4,650	53,741	66,383	61,241	15.2%	92.3%
UK	12,281	4,358	2,990	2,288	37,623	11,466	26,157	40,613	39,911	35.5%	98.3%
Germany	7,701	0	0	0	22,299	4,058	18,241	22,299	22,299	0%	100%
Netherlands	3,010	2,232	2,299	2,299	6,191	6,100	91	8,490	8,490	74.1%	100%
Belgium	2,434	0	0	0	3,366	0	0	3,366	0	0%	0%
Denmark	2,343	1,806	0	0	7,350	1,350	6,000	7,350	7,350	77.1%	100%
Taiwan	237	237	2,505	2,505	11,531	2,758	8,773	14,036	14,036	100%	100%
South Korea	104	0	0	0	8,200	0	8,200	8,200	8,200	0%	100%
Japan	85	0	140	0	9,915	1,532	8,383	10,055	9,915	0%	98.6%
U.S.	42	0	0	0	25,850	8,528	17,322	25,850	25,850	0%	100%
Italy	30	30	30	30	900	0	900	930	930	100%	100%
Norway	6	0	88	0	4,500	0	4,500	4,588	4,500	0%	98.1%
France	2	0	976	976	4,224	2,703	1,521	5,200	5,200	0%	100%
India	0	0	0	0	4,000	0	4,000	4,000	4,000	-	100%
Poland	0	0	0	0	10,900	5,400	5,500	10,900	10,900	-	100%
Rest of world	416	0	0	0	n/a	n/a	n/a	n/a	n/a	0%	n/a
Europe	27,807	8,426	6,383	5,593	97,353	31,077	66,060	103,736	102,730	30.3%	99.0%
Asia	20,173	3,237	10,637	5,355	92,037	8,940	83,097	102,674	97,392	16.0%	94.9%
North America	42	0	0	0	25,850	8,528	17,322	25,850	25,850	0%	100%
World	48,438	11,663	17,020	10,948	215,240	48,545	166,479	232,260	225,972	24.1%	97.3%

Source: Adapted from Table 1 of Jansen et al. [23].

In the U.S., seabed is allocated through auctions, revenue stabilization is achieved through fixed-price PPAs and ORECs, and government financial support is provided through tax credits (see Sections 2.4.2 and 3.2) [23]. New York employs an Index OREC, which works like the 2-sided CfD [24]. Most European countries employ support auctions under 1- or 2-sided CfD schemes, but not seabed lease auctions. The right to develop an OSW farm in a particular area of seabed is automatically given to the winner of the CfD auction. The UK employs both seabed lease and CfD auctions in a two-step process [23].

Table 2. State-level OSW goals and procurement

State	Offshore Target (MW)	Goal Year	Amount Procured (MW)
California	25,000	2045	0
New York	9,000	2035	4,362
North Carolina	8,000	2040	0
New Jersey	7,500	2035	3,758
Massachusetts	5,600	2035	3,236
Virginia	5,200	2034	2,652
Maryland	2,022	2030	2,022
Connecticut	2,000	2030	1,104
Rhode Island	-	-	430
Ohio	-	-	21
Maine	-	-	12
Total	**64,322**		**17,597**

Sources: Table 12 in Musial et al. [4]; [5].

2.4 The U.S. Political and Economic Context

2.4.1 Five Interrelated Crises

The broader U.S. context for OSW development is being shaped by five interrelated crises. To begin with, the U.S. continues to experience devastating impacts from *(1) the climate crisis*, including record-breaking heat waves [25], wildfires [26], droughts [27], and flooding [28]. The realities of the climate change demand social and political attention and response, even amidst the more immediate crises discussed below. One important effect has been the changing social-license-to-operate of carbon-intensive businesses. Maintaining this social license provides an incentive for businesses to address climate change at the firm and industry levels, even without government policy or regulation.

Russia's invasion of Ukraine created a *(2) humanitarian crisis*, one of the worst in recent memory. Due to the world's dependence on Russia for oil and natural gas, and on both Russia and Ukraine for wheat, the war fueled a global *(3) energy crisis* and *(4) food crisis*, characterized by soaring energy and food prices, which were already high due to supply chain issues from the COVID-19 pandemic. These crises have sparked serious discussions surrounding energy and food security, including calls for a more rapid clean energy transition, but also for increasing oil and gas supply outside Russia. As a result, restrictions on oil and natural gas are politically risky, if not completely untenable.

The energy and food crises are part of a more general *(5) macroeconomic crisis* afflicting much of the globe. The crisis is characterized by high inflation, i.e., prices across all economic sectors—not just energy and food—are generally on the rise. Inflation in the U.S. is at its highest level in four decades [29]. To stem inflation, the Federal Reserve has implemented the highest interest rate hikes since 1994 [30], which has increased the likelihood of a recession.

The macroeconomic crisis has transformed political priorities. Indeed, the historic climate, health, and tax bill just signed into law—discussed more below—is called the "Inflation Reduction Act." The prior version of the bill—the Build Back Better Act—was stalled in part due to inflation worries [31], and President Biden's recent executive action on student debt cancellation has sparked a flurry of inflation-based criticisms [32].

The high inflation levels are rooted in a multitude of factors, largely stemming from the two historic external shocks discussed above—the COVID-19 pandemic and Russia's invasion of Ukraine—and societies' responses to them.[3] However, no matter the exact causes, inflation is associated with and often blamed on those in power, i.e., the Biden Administration [39,40]. As long as inflation remains high, it will continue to define politics and serve as a major obstacle to future bills and executive actions that contain major spending components.

2.4.2 U.S. Climate Targets and the Inflation Reduction Act

The Biden Administration has committed to reducing greenhouse gas emissions by 50-52% by 2030 and to net zero by 2050 (2035 for electricity generation), in line with the goals of the Paris Climate Agreement [41]. To support these targets, the 117th Congress passed the Inflation Reduction Act (IRA), which President Biden signed into law on Aug. 16, 2022 [42]. Three climate policy modeling groups suggest that the IRA, which invests $369 billion in clean energy technologies and initiatives over ten years, can be expected to reduce carbon emissions by about 40% below 2005 levels by 2030.[4] While below the 50-52% emissions reduction target, the IRA represents the largest investment in clean energy in U.S. history.

The IRA impacts OSW in three areas: leasing, transmission development, and tax credits [46,47].

OSW leasing: In September 2020, then-President Trump used executive authority to ban offshore leasing in the Atlantic off the coasts of North Carolina, South Carolina, Georgia, and Florida, and in the Gulf of Mexico off the coast of Florida, from July 1, 2022, to June 30, 2032. The IRA reverses these orders for OSW, i.e., opens these areas for OSW leasing, but leaves the ban intact for offshore oil and gas. The IRA also opens the possibility of leasing seabed for OSW development off the coasts of U.S. territories.

The IRA imposes a potential impediment to OSW leasing by tying it to offshore oil and gas. In order to lease seabed for OSW development, the Bureau of Ocean Energy Management (BOEM) must first offer at least 60 million acres of seabed for offshore oil and gas leasing. The most immediate impact is California's OSW lease auction planned for the fourth quarter of 2022, which could support 4.5 GW of development. To conduct the auction as scheduled, BOEM would have to reinstate oil and gas Lease Sale 257 and award it to the highest bidder. The IRA requires BOEM to do this within 30 days of enactment. However, doing so is not a guarantee, as it would override a District Court ruling in Friends of the Earth v. Haaland, which vacated the lease sale.

The overall impact of tying OSW development to oil and gas is unclear. BOEM could, for example, offer 60 million acres of seabed for leasing that is poorly suited for oil and gas development, in which case it is unlikely that any firm would bid.

Transmission development: The IRA appropriates $100 million for analyzing the potential of interregional transmission development, i.e., increasing interconnection between the three

[3] Exact causes of inflation, and the relative contribution of each, continue to be debated. For an overview of possible causes, see [33–35]. For assessments of the relative contribution of each cause, see [36–38].
[4] Central values across the three models range from 39-42% [43–45].

continental transmission regions, and OSW transmission development. Increasing inter-regional transmission capabilities would help address issues arising from the variability of wind and solar energy, by allowing power from especially windy and sunny areas to be transmitted to other parts of the country.

Tax credits: Finally, the IRA expands the Investment Tax Credit (ITC) for renewable energy and creates a new tax credit for domestic manufacturing of wind energy components and related goods. The ITC is the federal government's main vehicle for financially supporting OSW development. Under the IRA, the ITC—previously scheduled to end in 2026—is tied to emissions targets. The tax credit begins to phase out only after carbon emissions in the electricity sector fall by 25% relative to 2022 levels. The tax credit is worth 30% of investment costs, with the possibility of increasing to 40% if certain domestic content targets are met. The amount of the new manufacturing tax credit varies by component type and capacity rating of the project. For OSW vessels, the credit is 10% of the sales price.

2.4.3 Comments on the Prospects for Future U.S. Climate Policy

The IRA passed in the Senate through a process called budget reconciliation, which requires a simple majority vote, i.e., 50+1. With Vice President Harris' tie-breaking vote, it passed entirely along partisan lines, with all 50 Republicans voting against. Congressional approval of additional climate policies will depend on the results of the 2022 midterm elections. If Democrats lose power in either the Senate or House of Representatives—a likely scenario [48]—Republicans will likely block any climate-friendly legislation.

In the absence of further federal climate legislation, President Biden can use executive action, e.g., directing the Environmental Protection Agency (EPA) to regulate greenhouse gas emissions via the 1970 Clean Air Act. A recent Supreme Court Ruling—West Virginia v. EPA—makes this difficult, but not impossible. The ruling states that the EPA cannot use Section 111D of the Clean Air Act to regulate greenhouse gas emissions beyond the fence line, i.e., the physical boundaries, of individual power plants [49]. As a result, the EPA cannot require power plants to shift to carbon-neutral energy sources, as this would require coal- and gas-fired power plants to shut down. The EPA can still regulate inside the fence line, such as improving energy efficiency and reducing carbon leakages. The EPA also has other options within the Clean Air Act, including Section 115 [50], but any such attempts will be challenged in court, which may further limit the EPA's authority.

Finally, there is also meaningful climate action at the state level, especially for OSW. Table 2 displays all current OSW capacity targets at the state level. Together, they add up to 64 GW in capacity by 2045. About 18 GW have already been procured, i.e., allocated to a developer. It is important to note, however, that state and local governments face tighter budget constraints. They are generally required to submit balanced budgets, meaning they cannot engage in the same level of deficit spending as the Federal government.

3 Grand challenges

Amongst the many challenges faced by OSW development in the U.S., we identified five as *grand challenges*. These challenges, if not adequately addressed in the next three to five years, are likely to prevent the planned rapid scale-up of OSW development in the U.S.

3.1 The Complexities, Timing Mismatches, and High Costs of the Development Phase

The development phase of OSW development can be broken into two parts: early and late. The early development phase consists of obtaining exclusive use of an OSW site, a variety of permits for building and operating an OSW farm, grid access, and a revenue regime. Once the project is permitted (or close to), it enters the late development phase, which involves setting up all of the contracts and financing for the construction and operation phases [21].

According to several practitioners, the development phase is highly complex, unpredictable, time-consuming, costly, and risky. In the case of failure—a very real possibility—millions of dollars and years of work are lost. The daunting nature of the development phase decreases the likelihood of success and disincentivizes firms to enter the OSW space.

3.1.1 Unpredictability and Mismatches in Timing of Regulatory and Other OSW Development Processes

A key challenge is the high level of unpredictability and mismatches in the timing of the many different processes involved in OSW development.

OSW development falls under multiple regulatory jurisdictions—federal, state, and local. Each jurisdiction has its own laws, permitting systems, requirements, and courts. This makes the timing of obtaining permits and meeting specific requirements difficult to navigate. In addition, while federal requirements—administered by the Bureau of Ocean and Energy Management (BOEM)—are the same in all U.S. federal waters, requirements in state waters (i.e., within the 12-mile coastal zone) and even some local jurisdictions may vary substantially. Building OSW in Massachusetts will then be different from doing so in North Carolina, California, etc. While there are efforts to improve communication and standardize requirements between the authorities and jurisdictions involved, this remains a major challenge.

Practitioners also discussed litigation risk, noting that all projects will face lawsuits and that the jurisdictional differences create additional complications. The result is highly uncertain timing in the development phase, which increases project risk, e.g., risk of major delays and cost overruns, and can influence the cost of capital.

3.1.2 Seabed Lease Auctions: Costs and Lease Payment Structure

The right to develop offshore energy resources in the U.S. is allocated through seabed lease auctions. OSW developers bid and the winner pays the federal government the amount of the bid. Over time, the lease sale prices, i.e., winning bids, have increased drastically. In 2022, six lease areas in the New York Bight were auctioned for a combined $4.37 billion [4].

Seabed leases, therefore, have become a major cost, and practitioners pointed to the timing and front-heavy lease payment structure as major challenges. OSW developers must invest a staggering amount of capital during the early development phase, prior to having accurate estimates of project costs or future revenues and when risks are highest. In addition, the lease payment structure requires the bulk of lease costs to be paid upfront.

It is important to note that this pay-up-front structure is not standard for BOEM outside the OSW industry. BOEM and the U.S. Federal Government more generally offer a variety of different lease programs and flexible financing structures to a variety of other players in the energy industry. For instance, leases for offshore oil rig operations are traditionally paid over the operation’s lifetime.

3.1.3 Other Development Phase Challenges

Practitioners pointed to three other challenges that represent the high complexity, risks, and costs of the development phase.

1. Prospecting, i.e., the process of finding a suitable location for a wind farm—the first step in the early development phase—is both costly (in the millions of dollars) and time-consuming (can last multiple years).

2. Obtaining the necessary personnel, spanning many competencies, is extremely difficult and costly in an immature market like the U.S. (see Section 3.3.1).
3. Very few people (a few dozen) across the globe, working at even fewer financial institutions (10-15), have the experience and expertise necessary to structure smart project finance deals for OSW. As noted in Section 2.2, project finance has been key to offshore wind's success in Europe.

3.2 Support Policy Fails to Provide Certainty on Future Costs and Revenues

Support policy plays two key roles: (1) subsidizing offshore wind development, which effectively lowers production costs; and (2) stabilizing future revenues, which lowers project risk, and thus cost of capital. When done well, support policy can make OSW development competitive with conventional generation, and thus an attractive investment opportunity. In the U.S., production subsidies come through the Investment Tax Credit (ITC) (see Section 2.4.2), and revenue stabilization comes through government-mandated fixed-price PPAs and ORECs (see Section 2.3). Practitioners, however, generally agreed that the current structure of the ITC and PPAs/ORECs are inadequate. The overarching problem, according to practitioners, is uncertainty on future costs and revenues, which significantly increases project risk, and thus cost of capital. CfD or FiT policies (see Section 2.3), which can provide both subsidies and revenue stabilization, would be better. Such policies, however, while common outside the U.S., face legal problems in the U.S. [24,51]. The following sub-sections discuss some of the key problems with the ITC and PPAs/ORECs, as well as how the IRA makes headway in addressing them

3.2.1 The Investment Tax Credit (ITC)

As discussed in Section 2.4.2, the ITC provides a tax credit to project owners amounting to 30% of the project cost. Under the Inflation Reduction Act (IRA), this is increased to 40% if local content requirements are met. The full amount of the tax credit can be deducted from the owner's tax liability in the year that the OSW farm becomes commercially operational. The tax credit, however, is non-refundable (i.e., if the tax credit is $10 million and the tax liability is $2 million, the owner only receives $2 million). Project owners generally are not profitable enough to have a high enough tax liability to take full advantage of the tax credit. There are two ways to deal with this problem, but neither is ideal.

First, the ITC can be used over multiple years until the developer's tax bill is high enough. However, as explained by Mormann [52], "in the case of a standalone wind project, for example, this lack of current tax liabilities would cost her up to two-thirds of the net present value of her project's tax benefits" (p. 367). This is due to the time value of money. A dollar earned today is worth more than a dollar earned in a few years, because the dollar earned today can be invested.

The second solution is selling the tax credits to highly profitable entities that can use them. We will first describe this process and associated problems prior to the passage of the IRA, and then discuss how the IRA addresses them to a large extent.

Prior to the IRA, the tax credits could only be transferred to entities with an equity stake in the OSW project. This led to the tax equity market. In this market, the unused portion of the tax credit is sold to a large and highly profitable entity that can use it—the tax equity investor—in exchange for an equity stake in the project. However, as noted by Mormann [52], "Historically, fewer than two dozen highly profitable and sophisticated entities—mostly large banks, insurance companies, and other financial firms—have been willing and able to support renewable energy projects through their tax equity investments" (p. 367). This leads to two key problems.

1. The total supply of tax equity available in any given year, i.e., the amount of tax credits that tax equity investors are willing to purchase, is uncertain and often lower than the total value of unused tax credits. The tax equity market is also cyclical, meaning that the supply of tax equity is lower in economic downturns, when project developers need it most [52]. Some practitioners noted that project developers tend to overestimate the level of tax equity they will receive, causing financial problems later on (e.g., needing to cut costs or raise additional capital).
2. There is little competition in the tax equity market, which enables tax equity investors to demand higher rates of return. The result is that a large portion of the tax credit—around 15-25% (up to 10% of total capital expenditures) [53]—is permanently transferred away from renewable energy project developers.

The IRA addresses these problems to a large extent by making the tax credits transferrable to any entity with corporate income tax liability. That is, banks and corporations no longer have to become equity investors in a renewable energy project to purchase unused tax credits. This greatly increases the pool of entities that can purchase the unused tax credits, and simplifies the process of such transactions. This change will likely solve the tax equity supply problem, and make a lot of headway on the lack of competition problem. Nonetheless, a small portion of tax credits are still likely to be transferred away from OSW projects.

3.2.2 Power Purchase Agreements (PPAs) and Offshore Renewable Energy Certificates (ORECs)

PPAs and ORECs provide revenue stabilization for offshore wind generators. Some practitioners noted, however, that future costs could not be accurately projected prior to signing the PPA and OREC contracts. This is in large part an issue of timing. PPAs and ORECs are generally issued early in the development process, before all permits have been secured, and thus before most costs—e.g., turbines, balance of plant, steel, and interest rates—are known. Prior to the IRA, these uncertainties were exacerbated by the uncertainty in the tax equity market. As explained in the prior section, the IRA solves the tax equity supply problem, but not the more general timing issue.

Given the importance of certainty on future costs and revenues for securing affordable financing, it will be important to continue monitoring (1) the ability of developers to accurately predict costs prior to signing PPA and OREC contracts, and (2) whether PPAs and ORECs provide sufficient prices.

Practitioners and researchers also noted jurisdictional issues. Seabed leases fall under federal jurisdiction, while PPAs and ORECs fall under state jurisdiction. The result is that developers must pay the federal government for the seabed leases, while looking to states to recoup those costs. As discussed in Section 3.1.2, federal lease costs have increased significantly in recent years. For the New York Bight auction, lease costs amounted to 22% of average capital expenditures for offshore wind projects [4]. This could lead to increased electricity prices for offshore wind power.

3.3 Developing a Highly Skilled and Capable Workforce in an Immature and Inexperienced Market

As noted in Section 2.2, developing, constructing, and operating OSW farms is inherently challenging due to the harsh conditions offshore and the many interfaces between industries and competencies that have not historically worked together. Building an OSW farm *always* entails problems and setbacks. These realities require a highly skilled and experienced workforce, from construction workers to engineers to project managers to risk analysts, etc.

The immaturity of the OSW market in the U.S., the lack of comparable industries from which to draw, and the limited skilled-labor market make obtaining the necessary human resources a major challenge.[5]

This issue has increased in relevance with the passage of the National Defense Authorization Act (H.R. 7900) in the House of Representatives on July 14, 2022. The bill—now in the Senate—includes nationality requirements for crew members working on offshore energy projects. Crew members must be U.S. citizens or permanent residents, or their nationality must match the country in which their vessel is flagged [55]. Supporters of the provision, including the U.S. Offshore Marine Service Association, say that the provision will help to protect U.S. workers from being outcompeted by international vessels employing low-wage workers. OSW developers, however, oppose the provision, arguing that it would further strain an already scarce resource: U.S. mariners trained to work on OSW projects [55].

If the bill passes the Senate with the nationality requirements, OSW development in the U.S. will likely become more expensive and potentially face major delays.

3.4 Developing an OSW-friendly Transmission Network

With the first utility-scale OSW farm scheduled to come online in 2023, the U.S. lacks the necessary transmission infrastructure to support the scale of OSW development planned. According to practitioners, this is a major showstopper.

One key issue is that in the U.S., the project developer is currently responsible for transmission infrastructure and connection to the grid. In Germany and the Netherlands, this is socialized (i.e., the grid costs are levied onto all consumer/generator grid charges). Transmission infrastructure and connection in these countries are guaranteed for OSW farms and are the responsibility of transmission system operators (TSOs) [23]. This was also the case for Denmark until 2021, when financial responsibility was transferred to the developer for the Thor OSW farm. Energinet—the Danish TSO—still carries out the work, and the costs the developer must pay to Energinet to conduct this work are capped [56]. In the UK, the developer pays for and constructs the transmission infrastructure up to the onshore connection point [23]. Both Denmark and the UK, however, are mature markets, and the transmission costs are incorporated into the CfD auctions.

As OSW in the U.S. gets bigger, pressure to increase coordination and planning (and reduce public opposition to transmission lines) has grown with the industry. While in the early days transmission for OSW in the U.S. remains the responsibility of the developer, meeting the ambitious policy goals might require additional planning and coordination. This may not be a major problem for initial projects, but transmission system coordination and planning could help to support OSW policy goals in important ways, e.g., reducing project risk for developers and ensuring that offshore transmission infrastructure is built with the bigger picture, i.e., the massive and rapid scale-up of OSW to support decarbonization, in mind.[6]

In a longer term perspective, as the share of wind power in the power system increases, demand response and storage will be important to integrate wind power and ensure stable electricity prices. This can be achieved for short-term flexibility via electric mobility (e.g., electric cars and electric public transit), but may require further sector coupling, such as connecting the power sector with the heating sector and Power-to-X, i.e., using power to generate green hydrogen and other green fuels, for longer term flexibility.

[5] See, e.g., [54].
[6] See also [57] for a useful discussion.

Without significantly improving and coordinating the planning of offshore transmission infrastructure, OSW development may be limited and provide less value to the grid and energy markets, and thus to investors. For the near term, practitioners stated that availability and quality of transmission infrastructure is the most important factor in determining where to build OSW farms.

3.5 Financing and Scaling Up Floating OSW

All utility-scale OSW farms in operation globally use bottom-fixed turbines, which are turbines are installed on foundations set on the seabed. Much of the seabed in the U.S., however—especially off the West Coast—is too deep for bottom-fixed projects. As a result, floating OSW technologies, where turbines are installed on floating structures, are necessary for realizing the full potential of OSW in the U.S. These technologies will enable developers to build in much deeper waters than is currently possible and without the environmentally destructive dredging procedures needed to construct and install modern fixed-bottom wind turbines. Yet, getting this set of technologies to its first utility-scale project and then to a rapid scale-up will not be an easy task.

The first step is pilot projects—some of which are underway—that demonstrate the risks involved. Until the risks associated with floating OSW are better understood, insurance companies are unlikely to insure floating projects, which will result in a high cost of capital until enough projects are built to make financiers more comfortable with the risk. Some practitioners also noted that investors in early floating OSW projects will likely require that the developers work in concert with turbine manufacturers to design a platform that is compatible with existing turbine technologies and that does not void turbine warranties.

The challenges faced by floating OSW development today are similar to those faced by the early bottom-fixed projects in the 2000s. As explained in Section 2.2, project financing was instrumental to the success of those early bottom-fixed projects. Some practitioners argued that project financing will play a similarly critical role for financing floating OSW projects.

Due to the early-stage nature of floating OSW technologies, some practitioners noted that they did not see floating OSW projects as feasible in the U.S. before 2030.

3.6 Special Mentions

This section briefly outlines three additional challenges that were deemed important by researchers and practitioners at the workshop, but were not discussed with the same level of depth and detail as the grand challenges.

3.6.1 Social and Political Challenges

Practitioners and researchers frequently pointed to social and political challenges. Decarbonization does not have bipartisan support. Democrats tend to be in favor, and Republicans in opposition. Practitioners noted that federal permitting, for example, was far more difficult under the Trump administration than under the Biden administration. A major goal of developers, thus, is to obtain all permits necessary for the foreseeable future while Biden is still in office. Similarly, policies like the ITC are not guaranteed to last if the Republicans come back to power. They could reduce it or turn it off completely.

A massive and rapid scale-up of OSW also requires social acceptance from various stakeholders, e.g., coastal communities, fisheries, political groups, and environmental NGOs. The example of Cape Wind, which failed after ten years largely due to a lack of social acceptance from key stakeholders, is a case in point. Practitioners pointed to two issues concerning social acceptance. First, misinformation about wind energy has circulated for many years, likely lowering social acceptance. Second, coastal communities tend to be wealthier, and thus have the resources to resist if they so choose.

3.6.2 Supply Chain Issues

Access to adequate supply chains is another potential challenge. Some practitioners considered these challenges to be manageable, at least in the short term. Longer-term, however, some researchers expressed more concern. If the whole world is trying to rapidly scale-up wind and solar energy, research suggests that supply chains, e.g., for certain minerals and rare earth metals, will become major bottlenecks without targeted efforts to develop them in the near term [58,59].

3.6.3 The National Environmental Policy Act (NEPA)

NEPA "requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions" [60]. The goal is to minimize the impacts of construction. Practically, however, some researchers noted that NEPA slows down the construction of new energy infrastructure significantly and results in market incentives to continue operating conventional fossil fuel power plants over building new cleaner ones.

4 Conclusion

Conditions in the U.S. are ripe for a massive and rapid expansion of OSW energy. The targets are in place, the financial capital exists, and investors want to invest in OSW. Successfully employing this capital, however, requires overcoming at least five grand challenges: (1) navigating the complexities, timing mismatches, and high costs of the development phase; (2) addressing the failures of support policy to provide certainty on future costs and revenues; (3) developing the required workforce; (4) building an OSW-friendly transmission network; and (5) rapidly developing floating OSW technologies.

Solving the grand challenges will require targeted partnerships and collaborations that cut across sectors, actors, and disciplines. It will require new research, financial engineering, policies and regulations, planning and coordination, and experimentation. If solved, then the U.S. will move several steps closer to turning the potential for an OSW transformation into reality.

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Appendix 1: Survey Questions and Results

Survey question: What are the main challenges and drivers for financing for OSW projects in the development phase (before final investment decision (FID))?

Top 3:

- Regulatory processes
- Revenue/value uncertainty
- Deal complexity

Survey question: What are the main challenges and drivers for financing for OSW projects in the construction phase (after FID)?

Top 3:

- Cost/inflation risks
- Supply chain risks
- Tax equity

Survey question: Which of the following factors will most affect OSW financing in the future?

Top 5 (in order):

1. Decreased risks
2. Siting and permitting
3. Regulatory issues
4. Availability of capital
5. Knowledge transfer between regions

Survey question: What is most important in the future development of OSW?

Top 3 (in order):

1. Cost of equity
2. Entry of actors
3. Loan conditions

Other topics mentioned as relevant:

- Policy stability
- Impact of federal climate policy (what about the next administration?)
- Regulatory differences between state / federal approaches
- Ability to establish a project pipeline
- Establishment of experienced and credit-worthy suppliers and service providers
- Efficient interconnection process
- Size and duration of equity capital required in the development phase
- Financing of floating wind
- Innovative technological solutions (e.g., co-locating wind with storage)