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ABSTRACT

This paper explores the potential to reduce the levelized cost of electricity (LCOE) of offshore wind technology through the use of digitalized financial innovations made possible by Distributed Ledger Technology (DLT). Specifically, this paper proposed a novel application of DLT to crowdsource project finance for clean energy projects. An introduction to DLT technology and some of its potential applications is provided first. Next, the potential to move from a more centralized, top-down energy system to a more decentralized, two-way transactive energy system enabled by DLT is discussed. Within this new energy system framework, the idea of crowd-sourced equity funding of the capital cost of renewable energy is introduced. The impact of crowdfunded equity on the LCOE is then explored via the creation of a theoretical offshore wind installation off the coast of New Jersey. An existing offshore wind capital cost model is modified for use in the U.S., and an existing wind annual energy production model is utilized to provide inputs into a LCOE model. Finally, the potential impacts that DLT based crowdfunded equity may have on cost of debt, debt tenor, and debt-to-equity ratio are also input into the LCOE model in order to examine the range of potential impacts it may have on offshore wind LCOE.

I. INTRODUCTION

The electricity generation sector is undergoing major changes driven by concerns over climate change. This concern has driven many governments to mandate the procurement of renewable energy technologies, predominantly solar photovoltaics (PV) and onshore wind. As deployment of these renewable energy technologies has grown, technology, financial innovation, and learning have allowed costs to fall to the point where, in many locations, their levelized costs are below that of more traditional electricity generation sources such as coal and nuclear power generation. However, there are numerous locations that lack the resource or land availability for wind or solar PV but still desire to reduce the emissions from their electricity generation. Many of these locations are located in coastal areas or islands, making offshore wind an attractive option to meet this need.

One such area meeting this criterion is the northeast U.S., which has a relatively poor solar resource and is densely populated, leaving little land available for the deployment of either solar PV or onshore wind. The population of the U.S. northeast, however, has been a leader in both clean energy policy and renewable energy deployment, with states such as New York setting 100% clean energy goals, while other states, such as New Jersey, served as an earlier leader in the deployment of solar PV technology. The U.S. northeast borders the Atlantic Ocean and a significant offshore wind resource, which has led many of the states in the northeast to mandate procurement of offshore wind, with a total of approximately 22 GW mandated amongst the separate states.[1]

Offshore wind is currently significantly more expensive than onshore wind and generally more expensive than other non-renewable options. The technology is in the early stages of commercialization, with only 16.3 GW having been deployed globally by the end of 2017.[2] This means that there is still ample opportunity for technology development and learning to drive down the capital cost of the technology, though the technology does implement much of the technology innovation already employed in the onshore wind industry. Offshore wind can also already benefit from financial innovation that has been utilized by other renewable energy technologies. While building off existing technology in onshore wind and financial innovations from other renewable energy technologies is positive from the aspect that these items make offshore wind more cost effective than it would otherwise be, it also means that there is less room for improvement in each of these areas. Therefore, new financial innovations apart from those already deployed in the renewable energy space may be necessary to ultimately make offshore wind economically competitive with traditional electricity generation assets.

One potential financial innovation that offshore wind technology may utilize to reduce cost is distributed ledger technology (DLT). DLT has many potential applications in the energy space; however, in this paper, we propose a novel application of DLT to crowd-source project finance and, specifically, explore the impacts in the field of energy production, specifically in reducing the cost of offshore wind energy. The crowd-sourcing of capital has the potential to reduce the cost of debt an offshore wind project might incur, increase the amount of debt that an individual offshore wind project may take on (thereby reducing project equity needs), and/or increase the debt tenor for an offshore wind project in addition to making more capital available for offshore wind deployment generally than would be available if only traditional sources of project finance were utilized. In this study, a representative capital cost model and a representative annual energy production (AEP) model for an offshore wind project located off the coast of New Jersey are constructed, and a parameterized exploration of the impacts that DLT technology could have in reducing the levelized cost of energy (LCOE) of this offshore wind installation is examined.

II. BACKGROUND

A. Sharing economy

As mobile phone performance and ubiquity have been increased over the past decade, the development of platforms that enable a sharing economy (SE) has been increased substantially. Initially, the SE generally focused on the renting of properties, such as homes or cars, from the owner of the properties to another party who wanted to use them (with, in many cases, the owner still serving as the operator of the properties while they were rented). More recently, as consumers have increasingly become more comfortable with SE tools and practices, the SE has broadened from property rental to other forms of sharing, such as the pooling of capital to support the funding of large expenses. The motivation for sharing has also grown from its initial drivers, which were primarily focused on additional sources of income for owners and an avoidance of capital outlays for renters, to include motivations such as environmental sustainability.

Currently, a consensus definition of what activities are considered SE does not exist. For example, Meelen and Frenken defined the SE as "consumers (or firms) granting each other temporary access to their under-utilized physical assets ("idle capacity"), possibly for money."[3] Alternatively, Hamari *et al.* defined SE as "[t]he peer-to-peer-based activity of obtaining, giving, or sharing the access to goods and services, coordinated through community-based online services."[4] Whatever specific definition one selects, SE has four core characteristics: (1) the sharing or trading of goods or services, (2) goods or services that owners underutilize or have excess capacity of, (3) sharing or trading enabled by technology, primarily software and mobile phones, and (4) reciprocation between two separate users (i.e., the buyer and the seller).

Accurate and complete estimates of the size of the SE are hard to come by owing to both the rapid growth in the industry and the inconsistency in what is considered sharing by those estimating SE size. According to PwC, the sharing economy in the U.S. was \$15B in 2015 and is expected to grow to \$335B by 2025; however, this estimate only includes sharing for travel, cars, finance, staffing, and music and video streaming.[5] In 2016, McKinsey estimated that approximately 162×10^9 people in the U.S. and European Union were performing work in the SE, either as a primary or supplemental source of income.[6]

Environmental sustainability is becoming an increasing driver of interest in and use of SE. Much of the sustainability benefit SE can provide is through the greater utilization of existing goods, which reduces the need for others to purchase these goods. This results in fewer items being built and less demand for the materials and energy required to build them.[7] However, there are other potential sustainability benefits that SE can provide. One of these is increasing the capital available for the construction of renewable energy facilities using an Equity Crowdfunding option as a next generation financial instrument. While renewable energy costs have fallen below fossil fuel costs in many parts of the world, they typically require greater upfront capital cost when compared to fossil fuel assets, with the fact that renewables require no fuel costs over the life of the asset, ultimately providing their cost advantage. However, there is a finite amount of capital that banks and large corporations have to invest each year. If that pool of capital does not grow, the deployment of renewables will be slower than the deployment of fossil fuel assets has historically been, on an energy generated basis. This limits the pace at which renewables can be deployed to replace fossil fuel assets, meet new energy demand, and mitigate climate change. SE can, however, provide renewable assets access to a new, large pool of capital, thereby speeding up their deployment.

B. Digitalization and democratization of electricity systems

Electricity system technology and financing have evolved significantly over the past forty years to include new sources of energy generation and capital, with increasing access for individuals to participate in both these areas. This new energy system can be categorized via the 5 D's of electricity systems and markets, which are listed below and can be seen in Fig. 1:

- deregulation,
- decentralization,
- decarbonization,
- digitalization, and
- democratization.

In the U.S., the deregulation phase started in the wake of the global oil crisis of 1979 to address increased sustainability and security concerns within the broad energy system. This type of liberalization and restructuring have also occurred in many other locations across the globe, largely dependent upon individual market and power system requirements along with the broader electoral structure (e.g., monarchy vs democracy). Historically, before deregulation, the power systems' technical and ownership structure was the vertically integrated utility model, which tended to focus electricity providers on reliability at the expense of cost due to the cost recovery reimbursement structure typically used to compensate the utilities under this model. However, deregulation enabled the power system and its market design to begin to shift from a centralized control model to one that had increasing amounts of decentralization.

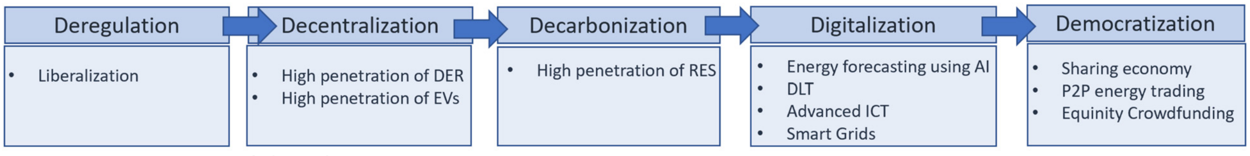

FIG. 1. Five D's of the electricity system.

More recently, the commercialization and deployment of renewable energy technologies such as solar photovoltaics and onshore wind have further increased the decentralization of the power system while simultaneously launching the decarbonization phase. This decarbonization effort has largely overlapped with the increased use and integration of advanced information and communication technologies (ICT) that initiated the digitalization of the power systems and market over the past two decades. Today, advanced artificial intelligence (AI) and optimization algorithms are used for energy production and demand forecasting and dispatch optimization tools, making them an integral part of the day-to-day operation of the modern power system. Increasing adoption of blockchain technology is expected to be the next major step in the digitalization process, bringing with it features that may allow new and next generation power systems and market segments, upending the current paradigm. Blockchain technology enables new market players such as prosumers (producer consumers) or simply everyday power consumers the access to become more active participants in the power market. Peer-to-peer (P2P) energy trading is one of the more prominent examples of allowing active participation of individuals previously incapable of participating in the electricity market and brings about the democratization of the power system. P2P energy trading is only one of the many new options, which blockchain technology enables; another example is the participation of individuals in large-scale (energy) investments through DLT-based equity crowdfunding, which is the primary focus of the analysis contained within this article.

C. Distributed ledger technology

DLT is a digital consensus and record keeping mechanism, which is intended to execute virtual processes by avoiding any type of intervention from a central or third-party authority. DLT accommodates immutable, decentralized, and distributed databases, or digital silos, that enable transactions of a commodity such as food, energy, data, or currency and execution of a service to be stored, shared, and exchanged on a public, private, or hybrid digital medium supported to ensure trust and cyber-security criteria. Building the trust, or validation process, is accomplished by various consensus protocols, which are based on advanced cryptographic algorithms. Proof-of-work (PoW), proof-of-stake (PoS), and proof-of-authority (PoA) are among the most prominent consensus protocols. It should be noted that blockchain technology is used interchangeably for DLT within academia, industry, and media. In fact, blockchain technology is only a subset of DLT.[8,9]

Cryptocurrencies, which are DLT-based digital assets created to act as a currency for exchange, are often cited as a main application of DLT and, along with digital consensus applications, are considered the first generation of DLT. Smart contracts, which are simply computer codes and protocols used as a digital equivalent to a legal contract, are proposed to be the game-changing feature of the second generation of DLT. DLT implementations can be executed in private, public, or hybrid networks dependent upon the required use cases and with or without smart contracting and cryptocurrency features. Public DLT networks require more computational power and higher energy consumption to maintain the core function of the validation processes due to higher cyber-security risks associated with any type of node, which can participate in the system without any permission; this generally causes them to require higher transaction fees relative to the other options. Alternatively, private crypto-networks are designed to run in more cost-effective ways in terms of computation power and other relevant operational costs. Hybrid networks are used where private or public networks alone would not provide a comprehensive solution.

According to many scholars and major industrial authorities, DLT has a noteworthy potential to disrupt and transform existing business and industrial conventions as a next generation digitalization technology by eliminating unnecessary third parties and increase the speed and efficiency of the transactions in a secure manner. Supply chain management, health, and energy are the most promising early markets for the DLT based applications.[10]

Conventional power systems and markets accommodate more centralized power systems with one-directional power flow. After the deregulation, decarbonization, and decentralization phases of power markets and systems, the landscape is transformed to a more sophisticated stage where more complex interactions originated from the higher penetration of renewable energy sources (RESs) and electric vehicles (EVs) are handled successfully. The integration of these new components has been accomplished by advanced digitalization technologies such as information communication technologies, artificial intelligence, and optimization algorithms. However, there is now a tremendous opportunity for DLT as a next generation digitalization technology. DLT based next generation power markets and systems are expected to increase the technical and economic efficiency of the power systems by eliminating the third parties, increasing transaction speeds, and enabling near real-time digital track recording of the system.

Various DLT based use cases such as P2P energy tradition, EV payment and settlement platforms, and renewable energy certificate (REC) trading are being tested globally.[11] Figure 2 depicts an overview of the power system value chain and segments blockchain use cases in detail. DLT provides three differing types of transactions: data, financial, and power. Use cases such as P2P energy trading would utilize all three of these types of transactions, while other use cases, such as REC trading, would only use one or two transaction types.[12] This article proposes a novel energy blockchain use case, crowd-sourced project equity funding, as an alternative financial tool that reduces the project cost of capital and, by association, project LCOE.

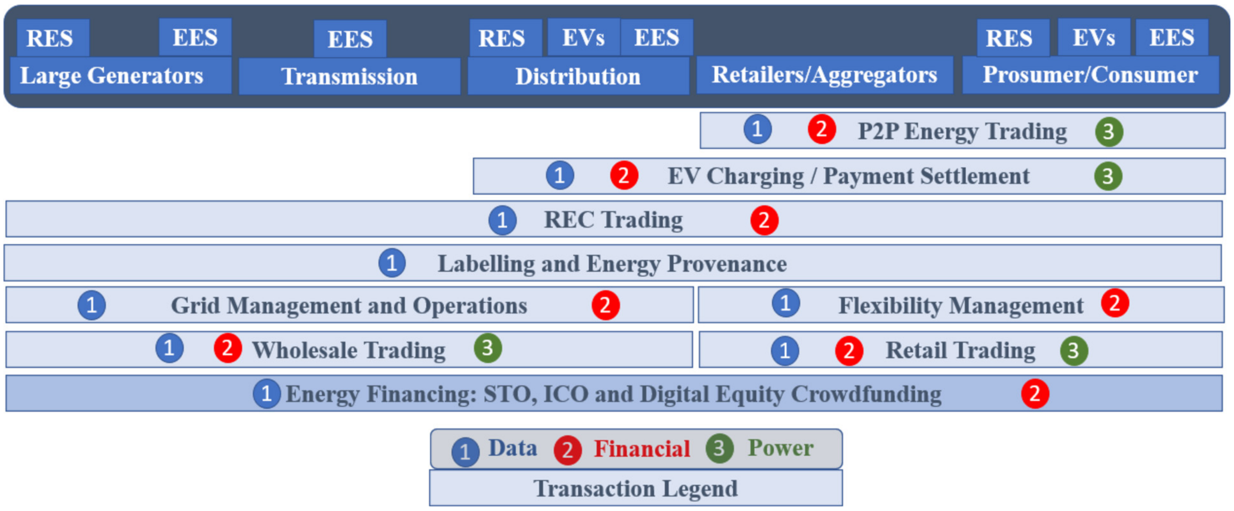

FIG. 2. Segmentation of energy DLT use cases.

Financial assumptions, technical performance and cost, annual energy estimation, project revenue, and incentives, such as offshore wind renewable energy credits (ORECs), are critical inputs in the performance of a viable technoeconomic analysis for large-scale energy projects. Conventional project financing from large financial institutions is the traditional method for financing large-scale energy projects. This study examines the use of innovative financial instruments enabled by DLT and examines the impact it may have on the economic viability of energy investments. Security tokens (STs) are one emerging financial instrument, which could be used to replace traditional project financing. STs offer digital ownership of assets and investments with full profit sharing and can provide voting rights similar to the traditional investments if desired. Initial coin offerings (ICOs) are blockchain supported financial instruments in which investment is initiated by generating a cryptocurrency that is distributed to investors. In this way, ICOs are very similar to a stock initial public offering (IPO) to raise capital for a business or project, with the difference being the ICO using DLT to track and monitor ownership and not requiring third party involvement to perform transactions. By eliminating the additional cost associated with third parties and broadening the potential investor pool, the ST model aims to reduce the financial cost and LCOE of an energy project finance.

D. Offshore wind

Offshore wind deployment has lagged behind that of onshore wind across the globe. This has been due, primarily, to a significant price premium for offshore wind, with prices for offshore wind in Europe, the area of the world with the greatest amount of offshore wind installations, generally exceeding \$150/MWh for projects coming online in 2018.[1] In contrast, onshore wind prices were generally below \$40/MWh in the U.S. during this time.[13] However, recent bids for offshore wind projects to be built in Europe from 2020 to 2023 have seen drastic reductions in pricing, with most falling below \$100/MWh and some coming in as low as \$74/MWh.[1]

This drastic and rapid price reduction has served to drive increased interest in offshore wind technology in Europe and across the globe. In the U.S., this has resulted in numerous states, primarily those located on the coast in New England and the Mid-Atlantic, to create policy mandates for the deployment of offshore wind.[3] These mandates have largely consisted of specific amounts of offshore wind capacity that must be purchased by the state, with the support mechanism generally being some form of renewable energy credit (REC).

III. METHODOLOGY

This study investigates the impact the equity crowd funding approach may have on offshore wind LCOE in the U.S. relative to traditional project financing. Figure 3 summarizes the scope and structure of this investigation. First, analysis of project costs using traditional financial instruments is used to calculate the key economic metrics used for investment decisions. In this financing scenario, some percentage of Capital Expenditures (CAPEX) is covered by the project owner (i.e., the equity fraction of the project) and the remainder is borrowed (i.e., the debt fraction). In the Equity Crowd Funding scenario, ST funding replaces traditional project finance and, in some cases examined, replaces some or all of the funding from the project owner as well. In addition to increasing the debt fraction, the crowd funding option may also decrease the project cost of capital and/or increase the debt tenor; both of these options are examined. The technical parameters, incentive mechanisms (ORECs), and annual energy production are the same under both financing scenarios.

A. Technical framework

1. Project siting

A number of offshore lease area auctions off the coast of New Jersey have already been held by the U.S. Bureau of Ocean Energy Management (BOEM). For the purposes of this study, a site within the Electricite de France (EDF) renewable lease area was chosen as it would permit the placement of all turbines in a water depth of <40 m,

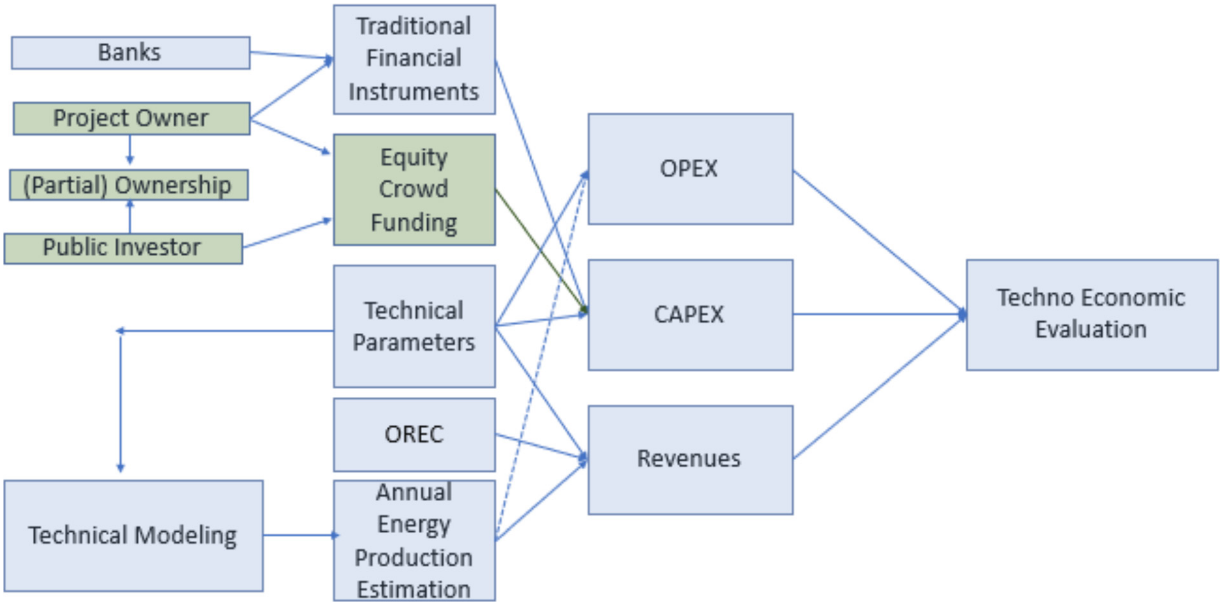

FIG. 3. Flowchart detailing steps to complete the technoeconomic model performed in this study.

allowing for fixed bottom foundation use, and be close to previously proposed onshore transmission connection sites proposed just outside of Atlantic City.[14,15] The turbines were laid out in a square with the Southwest corner at 39 20′N, 74 W, a spacing of eight rotor diameters by eight rotor diameters, in line with most recent offshore wind installations,[16] and facing directly West based upon prevailing wind conditions for a nearby location with wind data taken from January 1, 1947 to June 6, 2019.[17] For the purpose of calculating the distance of the underwater cable needed to connect the project to shore, an onshore connection point near the Atlantic City proposed in Ref. 15 is used. When combined with collection cabling needed for collection of power from each turbine, the total amount of underwater cabling required is estimated to be 100 km and all cabling between turbines and shore is assumed to be of the same size. The location of the proposed offshore wind farm along with the location of the proposed connection to an onshore high voltage transmission line can be seen in Fig. 4.

2. Annual energy production

Accurate prediction of a renewable energy resources' availability is a critical element in both the development of a bid to build a renewable energy plant and the ultimate operation of the plant. Forecasting the wind or solar resource can be separated into differing categories, including the very short-term (minutes), short-term (hours), mid-term (days to weeks), and long-term (months to years). Very short-term, short-term, and day ahead prediction models are utilized for managing and optimizing the daily operations of renewable assets and allow for scheduling of critical assets and power trading operations, while mid-term and long-term prediction models are used for estimating long-term operational considerations such as project planning and other infrastructure development related investment decisions.[18,19]

This effort only examined estimation of annual energy production (AEP) as most project development only considers forecasts of this type when developing estimates of financial performance of the proposed asset. AEP values were estimated using an open source renewable energy resource assessment tool named Virtual Wind Farm (VWF).[20] VWF utilizes weather data from satellite observations along with global reanalysis models such as NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA). Based upon the location and equipment specified by the user, the model generates hourly wind production values over an entire year. For this analysis, the Siemens wind turbine model SWT-4.0–130 is used.[21] While there are newer and larger offshore wind turbine offerings, many of these have not yet been deployed in considerable number, making their actual performance less certain than SWT-4.0–130. For SWT-4.0–130, the cut-in wind speed is 5 m/s and the cut-out wind speed is 25 m/s, while the rated wind speed is 12 m/s. The manufacturer's recommended hub height of 89.5 m and rotor diameter of 130 m were also used in the estimate of AEP. The power losses associated with collecting energy from the turbine array were assumed to be 5%, while it was assumed that power losses due to transmission from the plant to shore in transmitting were 6%.

B. Economic framework

1. Capital expenditures (CAPEX)

Capital costs for the offshore wind installation were calculated using the methodology given in Ref. 22. The capital cost of the turbines including transportation costs, C_{WT}, is given by

$$C_{WT} = 1.1 \times \left(2.95 \times 10^3 \times \ln(P_{WT}) - 375.2\right) \times N_T \times E_{eur/usd}(\text{k\$}), \tag{1}$$

where P_{WT} is the capacity of the individual turbines used in MW, N_T is the total number of turbines installed in the offshore wind plant, and $E_{eur/usd}$ is the exchange rate of the euro to U.S. dollar.

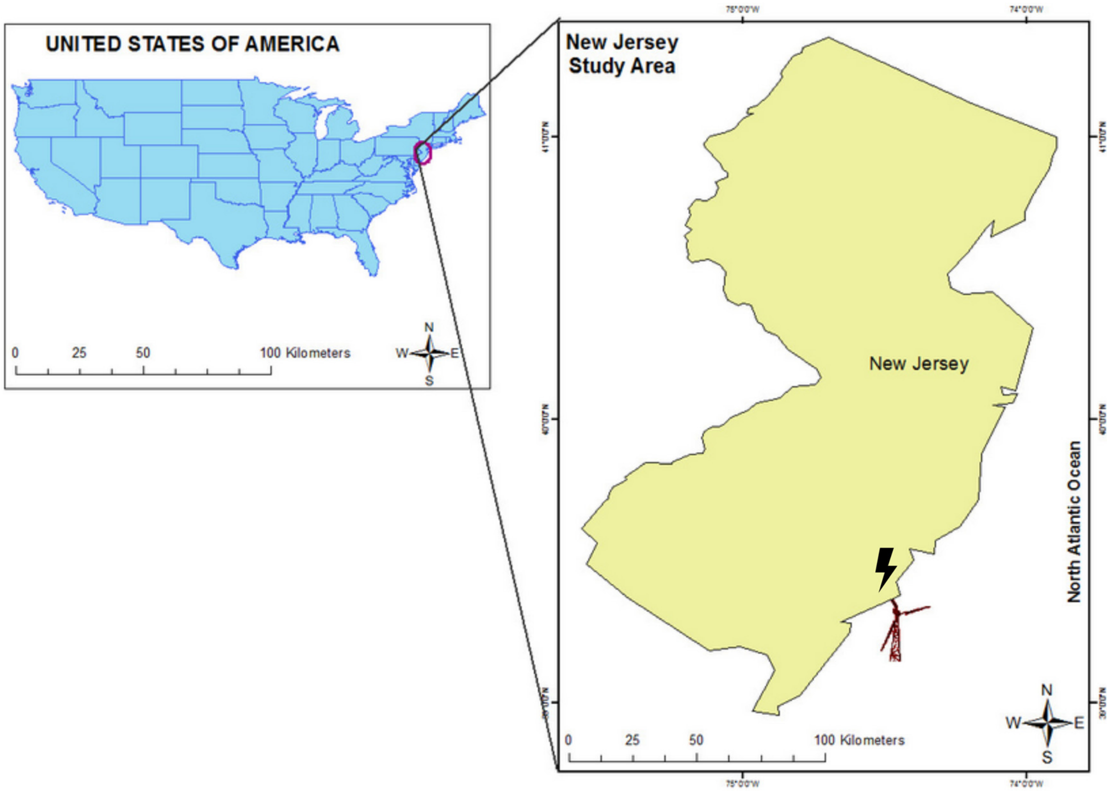

FIG. 4. Location of proposed offshore wind farm and point of transmission interconnection.

The capital cost for the foundation and tower including transportation and installation, $C_{F,T}$, is given by

$$\begin{aligned} C_{F,T} = 1.5 \times (320 \times P_{WT} \times (1 + 0.02 \times (D - 8)) \\ \times \left(1 + 0.8 \times 10^{-6} \times (H \times \frac{R}{2})^2 - 10^5)\right) \\ \times N_T \times E_{eur/usd}(\text{k\$}), \end{aligned} \tag{2}$$

where D is the sea depth in m, H is the hub height in m, and R is the rotor diameter in m.

The capital cost for the underwater electrical cable including transportation and installation, C_C, is given by

$$C_C = \left((0.4818 \times D_C + 99.153) \times L + (365 \times L)\right) \times E_{eur/usd}(\text{k\$}), \tag{3}$$

where D_c is the diameter of the electrical cable in mm and L is the length of the electrical cable in km.

The capital cost for the remaining electrical system equipment, C_{ES}, including the transformers, switchgear, backup generator, and offshore substation, is given by

$$\begin{aligned} C_{ES} = \left((42.688 \times P_T^{0.7513}) + ((40.543 + 0.76 \times V_S) \times N_S)\right. \\ +(21.242 + 2.069 \times N_T \times P_{WT}) \\ \left.+(2534 + 88.7 \times N_T \times P_{WT})\right) \times E_{eur/usd}(\text{k\$}), \end{aligned} \tag{4}$$

where P_T is the rated power output of the transformer in MVA, V_S is the voltage of the switchgear in kV, and N_S is the number of switchgear.

The cost of equipment to manage the electrical connection of the wind farm to the electrical grid was also captured. These costs are composed of regulation device cost and SCADA system cost. These costs, C_{GI}, are given by

$$C_{GI} = \left(\left(\frac{2}{3} \times (42.688 \times P_T^{0.7513})\right) + (75 \times N_T)\right) \times E_{eur/usd}(\text{k\$}). \tag{5}$$

The final capital cost consideration is the project development cost, C_{PD}. This is given by

$$C_{PD} = 46.8 \times P_{WT} \times N_T \times E_{eur/usd}(\text{k\$}). \tag{6}$$

The total capital cost of the offshore wind farm, C_{WF}, is, therefore,

$$C_{WF} = C_{WT} + C_{F,T} + C_C + C_{ES} + C_{GI} + C_{PD}\ (\text{k\$}). \tag{7}$$

It should be noted that, for this analysis, a value of 1.31 was used for the exchange rate between the euro and U.S. dollar. This is the value of the exchange rate at the time that[22] was written and was used here as it was assumed that capital cost values, in euros, have fluctuated to mitigate any currency exchange rate issues.[23]

2. Operating expenditure (OPEX)

Offshore wind OPEX costs were obtained from Ref. 24. From the reference, the costs for the New York location were used as the ocean and weather conditions for that site should be very similar to those for the New Jersey site utilized for this study. The surface effect ship (SES) methodology was selected as it minimizes OPEX costs while maintaining equipment reliability above 95%.

3. Offshore wind financial incentives in New Jersey and project revenue

The state of New Jersey has passed a mandate to procure 3500 MW of offshore wind by 2030.[25] To start procuring this offshore wind capacity, New Jersey held an initial tender for 1100 MW of offshore wind in 2018. In order to procure this offshore wind, New Jersey is providing offshore wind renewable energy credits (ORECs). The ORECs are to be rewarded through an auction process, with the process requiring that applicants provide New Jersey with bids that are equal to the LCOE of the project calculated using a required revenue model. The lowest bids are, then, selected to receive the ORECs, with the requirement that the project reimburses New Jersey all revenue that the project receives for selling power into the wholesale electricity market.[26] Therefore, the gross revenue, R_{gross}, to the project can be defined as

$$R_{gross} = P \times C_{OREC} + P \times C_{WM}, \tag{8}$$

where P stands for the power the project generates, C_{OREC} stands for the OREC price that New Jersey pays for the power generated by the project, and C_{WM} stands for the price the wholesale market pays for the power generated by the project.

The net revenue, R_{net}, must account for the reimbursement the project must pay to the state of New Jersey for any revenue received on the wholesale market. Therefore, the net revenue to the project is defined by

$$R_{net} = R_{gross} - P \times C_{WM} = P \times C_{OREC}. \tag{9}$$

4. Base case financial assumptions

The financial assumptions for the base case are given in Table I.

It was assumed that the project would not begin construction in time to qualify for the U.S. production tax credit (PTC), so there is no value for the PTC inserted into the LCOE model.

The levelized cost of electricity (LCOE) and net present value (NPV) were the financial metrics examined to determine the impact crowdsourcing may have on the project. The LCOE methodology employed was a required revenue model, which results in a LCOE that ensures that the project achieves the desired rate of return on the project's equity financing (i.e., the cost of equity).[27] The LCOE is given by

$$LCOE = \frac{\sum_{n=0}^{N} \frac{C_A}{(1+r_{D,nom})^n}}{\sum_{n=1}^{N} \frac{Q_A}{(1+r_D)^n}}, \tag{10}$$

where C_A is the annual cost, which includes OPEX and financing costs, for the offshore wind farm; $r_{D,nom}$ is the nominal cost of debt; Q_A is the annual energy production of the plant; and N is the plant lifetime. r_D in the denominator of the LCOE formula is the nominal cost of debt if one calculates the nominal LCOE or is the real cost of debt if one calculates a real LCOE.

TABLE I. Financial assumptions.

Project life	25 years
Debt fraction	55%
Loan period	7 years
Cost of debt	6%
Cost of equity	9%
Inflation	2.5%
Property tax rate	3.85%[27]
Insurance rate	1%
Property tax and insurance rate escalation	1%/year
Federal income tax rate	21%
State income tax rate	9%[28]
City/local tax rate	0%
Depreciation schedule	5-year Modified Accelerated Cost Recovery System (MACRS)

The NPV is calculated by

$$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+r_{D,nom})^n}, \tag{11}$$

where CF_n is the cash flow in year n and N is the economic lifetime of the offshore wind farm, which, for this analysis, is assumed to be the same as the plant lifetime.

5. Potential effects of crowdsourcing on project financing

There are at least three potential ways in which crowdsourcing funding could affect the financing of offshore wind farms. One of these methods is through reducing the cost of debt for an offshore wind project. Many individuals do not expect the same rate of return from an investment as traditional sources of project financing, such as large banks, do. One example of this is simply the lower rate of return individuals will accept from banks for certificates of deposit vs the rate of return that banks require to loan money to individuals for loans of similar tenor.

The second means whereby crowdsourcing may affect offshore wind financing is through an increase in the loan period over which the debt must be repaid. To achieve a lower cost of debt, many traditional project financiers require loans be paid back in under 10 years. This is largely due to the risk associated with a lack of liquidity as these loans are not easily transferred to another party once the initial loan has been made, primarily due to their size. However, crowdfunding equity from a large number of individuals generally means that each individual owns a much smaller share, and there are a greater number of other individuals that have the necessary resources to purchase that share should the original owner needs liquidity. Furthermore, exchanges could be set up to allow for easier trading of these debt holdings, as is already done for crowdsourcing equity for startup companies providing goods and services (e.g., Startengine[29]). Ultimately,

TABLE II. Technical assumptions and results of VWF modeling.

Description	Value
Mean wind speed (m/s)	7.8
Installed capacity of each wind turbine (MW)	4
Number of wind turbines (–)	100
Gross AEP (MWh/annum)	1 611 729
Assumed array efficiency (%)	95
Assumed grid efficiency (%)	94
Net AEP (MWh/annum)	1 439 274
Net capacity factor (%)	41.1

crowdsourcing of project debt could allow for the debt tenor to be increased to match the expected lifetime of the project, which is currently 25 years for many projects.

A third manner in which crowdsourcing could affect project financing is by allowing for an increase in the portion of the project that is financed via debt. This increase in the debt fraction could be achieved for three reasons, two of which are intimately tied to the other effects crowdsourcing may have on project financing previously discussed. The gating factor in the debt fraction a plant can receive is typically the debt service coverage ratio (DSCR), which is effectively a ratio of the cash flow from an asset to the premium and interest payments on that same asset over a given time period (for project finance, typically one month). As the premium and interest payment are defined by the cost of debt and the loan period for the debt, a reduction in cost of debt or an increase in the loan period will reduce the periodic premium and interest payment for a given amount of debt. As the potential cash flow from the asset is, to a first order, unaffected by its financing terms, this effectively allows more money to be borrowed in order to achieve the same DSCR. Beyond these two effects and for similar reasons discussed in the potential increase in debt tenor that crowdsourcing may allow, an increase in the debt fraction may be possible due to the smaller amount of money that each debt holder will have dedicated to investment in the given project if debt were crowdsourced, increasing risk tolerance, and the increased liquidity crowdsourcing provides relative to the traditional project.

IV. RESULTS

A. Technical results

The average wind speed at the selected site is 7.8 m/s, and using the power curve for the SWT-130–4.0 turbine, it was found that the resulting gross AEP is 1 611 729 MWh. It was assumed that the wind farm array and electrical network (grid) efficiency are 95% and 94%, respectively. While more detailed investigations can provide greater accuracy for these parameters, this article focus is on novel approaches of project financing, and therefore, such detailed investigations were deemed unnecessary. Multiplying the gross AEP by these values results in a net AEP of 1 439 274 MWh, which equates to a 41.1% capacity factor. Table II summarizes the results and assumptions of the technical performance of the wind farm in this study.

B. Economic results

Each of the potential impacts that crowdsourcing could have on offshore wind project financing was first explored independently, with the LCOE utilized as the metric for measuring this impact. A final case was run, which examined what the “best-case” impact might be should the most aggressive assumptions that crowdsourcing could have on cost of debt, debt fraction, and loan period were achieved. Table III provides the full range of scenarios that were examined.

Figure 5 shows the real LCOE, nominal LCOE, and the associated net present value (NPV) calculated for the offshore wind farm at various costs of debt. The cost of debt was reduced from the base rate in 50 basis point increments down to 4.5%, as it was assumed that crowdsourcing could potentially reduce the debt interest rate by up to 150 basis points. This reduction in cost of debt does reduce the LCOE, though the effect is relatively small at 2.0% and 1.3% for real and nominal LCOEs, respectively. The impact on NPV is more significant, however, as it increases by 29.4% over the cost of debt range examined.

TABLE III. Study case matrix.

Case number	Debt fraction	Equity fraction	Cost of debt	Cost of equity	Loan period
1	55%	45%	6.00%	9.00%	7
2	55%	45%	5.50%	9.00%	7
3	55%	45%	5.00%	9.00%	7
4	55%	45%	4.50%	9.00%	7
5	65%	35%	6.00%	9.00%	7
6	75%	25%	6.00%	9.00%	7
7	85%	15%	6.00%	9.00%	7
8	95%	5%	6.00%	9.00%	7
9	100%	0%	6.00%	9.00%	7
10	55%	45%	6.00%	9.00%	10
11	55%	45%	6.00%	9.00%	15
12	55%	45%	6.00%	9.00%	20
13	55%	45%	6.00%	9.00%	25
14	100%	0%	4.50%	9.00%	25

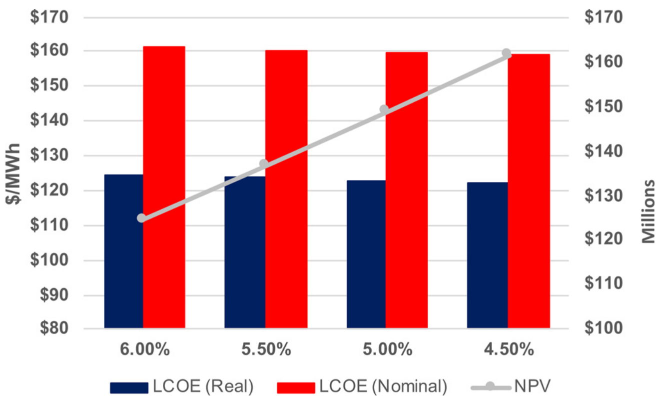

FIG. 5. Real LCOE ($/MWh), nominal LCOE ($/MWh), and NPV ($, right axis) vs cost of debt.

Figure 6 shows the effect that the debt fraction has on real LCOE, nominal LCOE, and NPV. For the purposes of this study, it was assumed that a project could potentially be entirely funded through crowdsourcing, effectively making the debt fraction 100%. This increase in the debt fraction from 55% to 100% reduced real and nominal LCOEs by 14.2% and 12.9%, respectively. Increasing the debt fraction reduces NPV all the way to 0 at a debt fraction of 100%; however, this is not a negative development as NPV is based upon the equity put into the project, and as that amount decreases, the NPV does proportionally as well. It should be noted that this study does not consider additional costs that might be associated with a project that is completely funded through crowdsourcing, such as a fee for a third party to perform the crowdsourcing function or any additional charges that the project developer may pass along to the project were they to lead the crowdsourcing effort. While these costs might exist in any crowdsourcing effort, they would almost certainly be necessary if a project were completely crowdsourced in order to entice an entity to arrange funding for a project that they, by definition, hold no equity in.

Figure 7 shows the effect that the loan period can have on real and nominal LCOEs. It was assumed that the economic life of the offshore wind farm was 25 years; therefore, it was assumed that crowdsourcing might allow the debt tenor to extend from the base case assumption of 7 years to match the economic lifetime of the plant. The extension of the loan period from 7 to 25 years has the effect of reducing both the real and nominal LCOEs by 3.8%. The NPV is not shown as, by definition, the NPV of the project will not change for a project using a required revenue LCOE while varying the loan period with all else held equal.

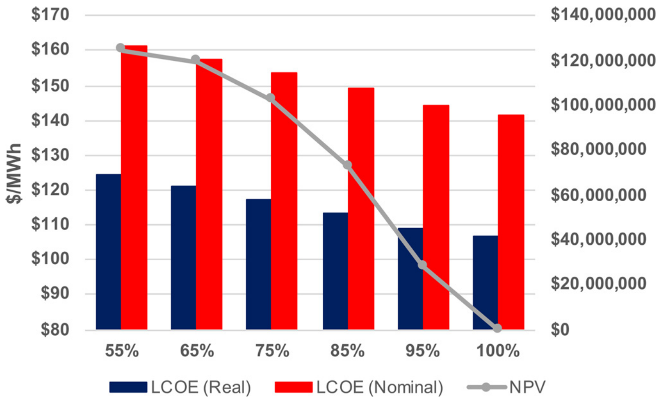

FIG. 6. Real LCOE ($/MWh), nominal LCOE ($/MWh), and NPV ($, right axis) vs debt fraction.

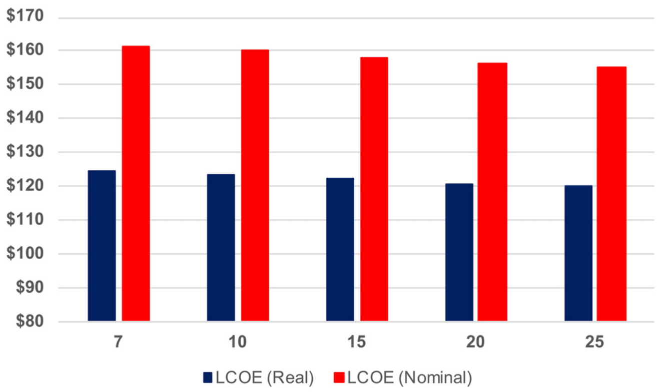

FIG. 7. Real and nominal LCOE ($/MWh) vs loan period.

Finally, to examine the full potential cost reduction that crowdsourcing financing could provide offshore wind installations, a case was run where the most aggressive assumptions for crowdsourcing's impact cost of debt, loan period, and debt fraction were combined together. Figure 8 shows the results of this case against the base case. Real and nominal LCOEs in the aggressive case are reduced by 18.8% and 15.7%, respectively, vs the base case. NPV is not shown due to the fact that the aggressive case assumes 100% debt financing; the same caveats discussed above for the debt financing results apply to this case as well.

V. CONCLUSION AND POLICY IMPLICATIONS

This paper has explored the potential benefits that the crowdsourcing of project finance, made possible by DLT, might provide

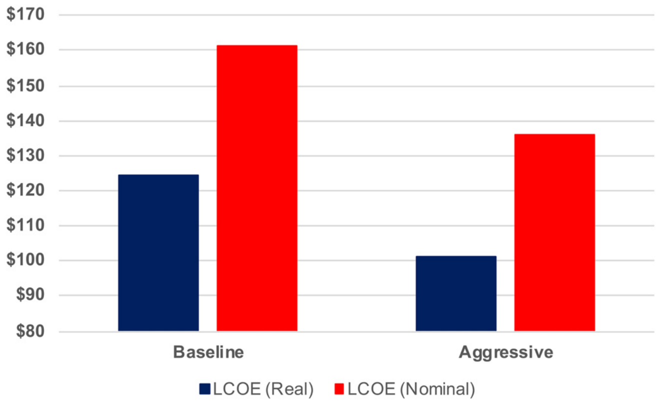

FIG. 8. Real and nominal LCOE ($/MWh) for baseline and aggressive financing assumptions.

offshore wind farms. These benefits include the reduced cost of debt, increased debt tenor, and the ability to increase the debt fraction of the project financing. In order to examine the impact of each of these benefits, a sample wind farm was created off the shore of New Jersey in one of the existing BOEM lease areas and an estimate of the energy generated by this wind farm was created. A parameterization of the effect that each of the potential benefits might have was performed as the ultimate magnitude of the benefit to each of these parameters is not yet empirically established. It was assumed that crowdsourcing project finance could reduce the cost of debt by up to 150 basis points, increase debt tenor by up to 13 years, and increase the percentage of the project financed via debt up to 100% of the financing needed. These items would result in a real LCOE reduction of 2.0%, 2.9%, and 14.2%, respectively, highlighting that increasing the debt fraction of a project is the most impactful benefit crowdsourcing can provide. If all three benefits were realized together, a real LCOE reduction of 18.8% is possible. It is interesting to note that this impact is greater than those found for cost declines of 50% in any single piece of offshore wind equipment.[30]

The results of this case study should serve as motivation for further research into the impact DLT enabled equity financing might have for other potential offshore wind locations, other renewable energy technologies, and specific mechanisms enabling the real-world application of DLT to service these opportunities given various countries specific regulations around public investment in infrastructure projects and project debt in general.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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