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An online, peer-reviewed journal
published in cooperation with the
Texas Water Resources Institute

Texas Water Journal

Volume 12 Number 1 | 2021

Texas Water Journal

Volume 12, Number 1
2021
ISSN 2160-5319

texaswaterjournal.org

THE TEXAS WATER JOURNAL is an online, peer-reviewed journal devoted to the timely consideration of Texas water resources management, research, and policy issues. The journal provides in-depth analysis of Texas water resources management and policies from a multidisciplinary perspective that integrates science, engineering, law, planning, and other disciplines. It also provides updates on key state legislation and policy changes by Texas administrative agencies.

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Texas Water Resources Institute
Texas Water Journal
Volume 12, Number 1, May 11, 2021
Pages 42-57

Economic Analyses of the Seadrift Wind-Aided Wastewater Treatment Plant Operations

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Abstract: Seadrift is a city located on the Texas Gulf Coast with a population of 1,364 people as of the 2010 U.S. Census. In 2012, the city started operating a $610,878 wind turbine, dedicated to its wastewater treatment plant. The city contributed only 3% of the funds for the project, with the balance from state agencies or the state of Texas. The city hoped to save $25,500 yearly using wind energy to displace some of the plant's electrical demand. The plant's average load is 0.05 million gallons per day, requiring 236,000 kilowatt-hours (kWh; 8.05×10^8 British thermal units [BTU]) yearly. From 2012 to 2015, Seadrift saved $15,928 per year, with yearly wind energy production of 155,738 kWh (5.31×10^8 BTU) and net present value of $211,493 at the city level. Yet, the project's applicability to other locations is limited. Indeed, when considering the project's total cost and return, the economic results, driven by a lower than predicted wind speed, are negative. Still, the study serves as a valuable tool to aid government agencies and rural communities in devising alternative and sustainable solutions to water-energy nexus challenges in Texas and beyond.

Keywords: renewable energy, water, water-energy nexus, wastewater, wind energy

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Received 28 June 2019, Accepted 13 January 2021, Published online 11 May 2021.

Citation: Mbarga AHA, Rainwater K, Song L, Theodore C, Williams WR. 2021. Economic Analyses of the Seadrift Wind-Aided Wastewater Treatment Plant Operations. Texas Water Journal. 12(1):42-57. Available from: https://doi.org/10.21423/twj.v12i1.7096.

Terms used in paper

Acronym/Initialism	Descriptive Name
BTU	British thermal units
COE	cost of energy
CRF	capital recovery factor
ECOE	effective cost of energy
EPA	Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
fps	feet per second
ft	feet
HOMER	Hybrid Optimization of Multiple Energy Resources
hp	horsepower
IRR	internal rate of return
kWh	kilowatt-hours
m	meters
MGD	million gallons per day
mps	meters per second
MW	megawatts
NCF	net cash flow
NCSL	National Conference of State Legislatures
NPV	net present value
NREL	National Renewable Energy Lab
O&M	operations and maintenance
PURA	Public Utilities Regulatory Act
PURPA	Public Utility Regulatory Policies Act
QF	qualifying facility
RE	renewable energy
REP	retail electricity provider
ROI	return on investment
RPS	renewable portfolio standards
SCADA	supervisory control and data acquisition
SECO	State Energy Conservation Office
SPP	Southwest Power Pool
TDA	Texas Department of Agriculture
WWTP	wastewater treatment plant

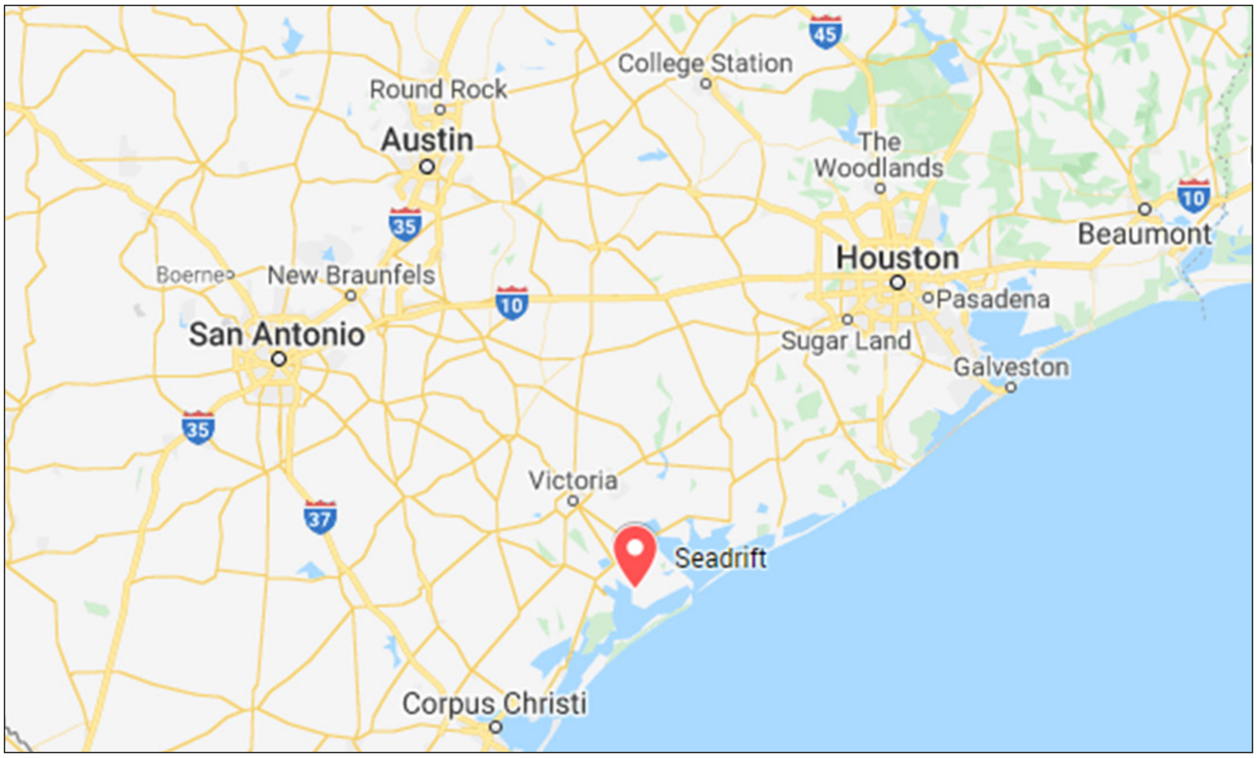

Figure 1. Vicinity Map Seadrift, TX. Map data ©2021 INEGI, Google.

INTRODUCTION

Recent research efforts on the integration of wind energy with water projects have dealt mostly with theoretical systems designed to simulate real applications. In their review, Mbarga et al. (2014) mentioned 25 wind-water systems. Of these, four were conducted in a laboratory (Park et al. 2011, 2012, 2013; Ben Ali et al. 2012), two were pilot projects (López-Ramírez et al. 2013; Rainwater et al. 2013), and all the others were simulated systems. Those contributions are helpful, but full-scale analyses of wind-water systems are needed to give decision-makers reliable data useful for future projects.

The study's primary objective was to perform an economic analysis for the city of Seadrift, Texas, which purchased a grid-connected wind turbine. The turbine would displace some of the grid energy used in its wastewater treatment plant (WWTP) and thereby reduce energy costs (bills) for the municipality. The project was also expected to show how other municipalities could use renewable energy (RE) resources to provide sustainable services to their residents. The project shows how a small community with limited funds can leverage different funding sources to finance RE projects.

The city of Seadrift is located on the Texas Gulf Coast in Calhoun County and has a population of about 1,364 people. The city is about 3 meters (m; 10 feet [ft]) above sea level. Figure 1 is a map of the geographical location of Seadrift. The city's WWTP has a rated capacity of 0.3 MGD with an annual historical average use of 0.05 MGD or 17% capacity. The city estimates that the WWTP consumes 236,000 kilowatt-hour (kWh; 8.05×10^8 British thermal units [BTU]) yearly, serving about 699 sewer utility customers. The WWTP is supplied by three energy sources: the grid, a wind turbine, and a generator in case grid power is interrupted.

Four lingering uncertainties attendant to wind-water systems are: (1) the real economic costs and benefits associated with wind projects, (2) accurate prediction of wind potential and intermittence at a location, (3) usefulness of manufacturer-provided power and energy curves, and (4) seamless integration of wind energy into the electrical grid. The literature review that follows provides context to evaluate the contribution of the Seadrift project to the challenges of the water-energy nexus. Then follows the technical and financial background of the genesis of the wind turbine project in Seadrift, including the pertinent economic metrics, the energy flows within the wind turbine-WWTP-grid system, and the results of our economic analyses of the wind-aided WWTP operations.

LITERATURE REVIEW

Wind energy systems have a different cost structure than fossil fuel energy systems. Customers using grid energy share the amortized cost of the generation and distribution infrastructure. Also, on-site diesel generators are typically less complicated and expensive than wind turbines, whose installation requires geotechnical, environmental, and construction considerations. Further, while fossil-fuel driven systems require fuel at a significant operational cost overtime, wind is free. Hence, capital costs are the largest component for wind turbine projects (Gude et al. 2010). Ackermann and Söder (2002) and Gude et al. (2010) found the costs of generation for wind energy to be competitive with grid energy costs in dollars per kWh, depending on the size and location of the project. For instance, costs of electricity varied across the state of Texas, ranging from about \$0.05/kWh to \$0.12/kWh during the 2009–2017 time period. Resale of excess wind energy to the grid typically received \$0.04/kWh. Still, Ackermann and Söder (2002) report that wind energy projects have been buoyed by government or third-party financial incentives such as tax credits in North America and feed-in tariffs in Europe. Energy costs can reach 30% of total cost of produced water in desalination systems (Gude et al. 2010). Thermal-based technologies (7–14 kWh/m^3 or 700–1400 BTU/ft^3) typically require about twice the energy per cubic meter of treated water compared to membrane desalination (2–6 kWh/m^3 or 2–6 BTU/ft^3), making combination with RE more challenging (Subramani et al. 2011).

Conventional energy sources (gas, oil, grid) are still typically cheaper to use than RE sources. One avenue to reduce produced water cost is to use hybridization, the mixing of different energy sources, to supply a load (Subramani et al. 2011; Kalogirou 2005; Karagiannis and Soldatos 2008). Karagiannis and Soldatos (2008) report desalinated water costs for solar-wind systems (Mohamed and Papadakis 2004; Kershman et al. 2005). García-Rodríguez (2003) mentions many hybrid wind-solar powered desalination systems, which used the complementarity of the two energy sources, relying mostly on insolation during the day and on wind energy at night.

Grid energy can also be hybridized with RE. Gude et al. (2010), recognizing the complementarity of RE and fossil fuel energy in capital and maintenance costs, reliability, and environmental impact, advocate combining both sources to reduce the cost and the environmental footprint of desalination projects. Rainwater et al. (2015) reported on a 50-kW (67-horsepower [hp]) wind turbine installed in Seminole, Texas that generated 47% of the energy needs for a brackish water well and an RO system, with the balance from the grid. Finally, cheap and reliable low-grade heat from conventional and nuclear plants can be hybridized with RE (Gude et al. 2010). Still, even in the absence of grid electricity, RE-driven water and wastewater treatment should always be considered in remote locations with robust wind or solar potential such as islands, because it usually is cheaper than the transportation cost of water or grid extension to the location (Gude et al. 2010; Ackermann and Söder 2002).

A clear identification of the costs of wind projects is challenging, and the myriad of RE-water system combinations precludes a meaningful taxonomy and comparison of systems across research efforts (Gude et al. 2010; Karagiannis and Soldatos 2008). Hence, costs must be assessed based on the specific constraints of every project. Further, project designers should consider total cost and total return on a project so that the economic assessment is complete. It has been proposed that life cycle analyses that go beyond economic values can give a more accurate picture of wind power's value than a mere economic analysis. Still, although life cycle-based analyses provide an attractive alternative to pure economic value, the life cycle approach works best when all the expense and revenue items have a common starting point. When the wind energy source is added into an existing system with previous operation constraints, as is the case in the Seadrift project, the life cycle analyses are problematic.

In grid-connected settings, the main economic advantage of wind turbine energy is that it displaces grid energy and thus allows economic savings by using wind as a zero fuel cost energy source (Ackermann and Söder 2002). During the planning phase of a project, investors use average wind speed at a location to estimate the future energy production of the turbine, which in turn indicates potential income generated by displacing grid energy or selling energy to the grid. Over the typical 20–25 year lifespan of a wind turbine, there is little variation in the expected energy generation, as the range of wind speeds at a location tends to remain consistent from one year to the next (Petersen et al. 1998, as cited by Ackermann and Söder 2002). This assumed relative stability in energy production allows project designers to estimate present value of future wind benefits and reduces the uncertainty in energy production for the lifetime of the project. In actual application, however, the variations in wind speed should be considered.

Intermittence is the stochastic nature of wind speed, which leads to fluctuations in the wind power from the wind turbine. Intermittence can also cause mismatches between wind production and energy demand, as illustrated in the inland Seminole project (Rainwater et al. 2015). Yet wind energy seems particularly suitable to islands, coasts, and mountains, which generally enjoy good wind potential (Gude et al. 2010). Subramani et al. (2011) recognized the challenge of matching intermittent wind energy production with constant electrical demand and recommended compressed air storage, battery storage or increased treated water storage to store wind energy.

Wind power is a function of the wind speed cubed until the wind speed reaches its design value, at which point, even as

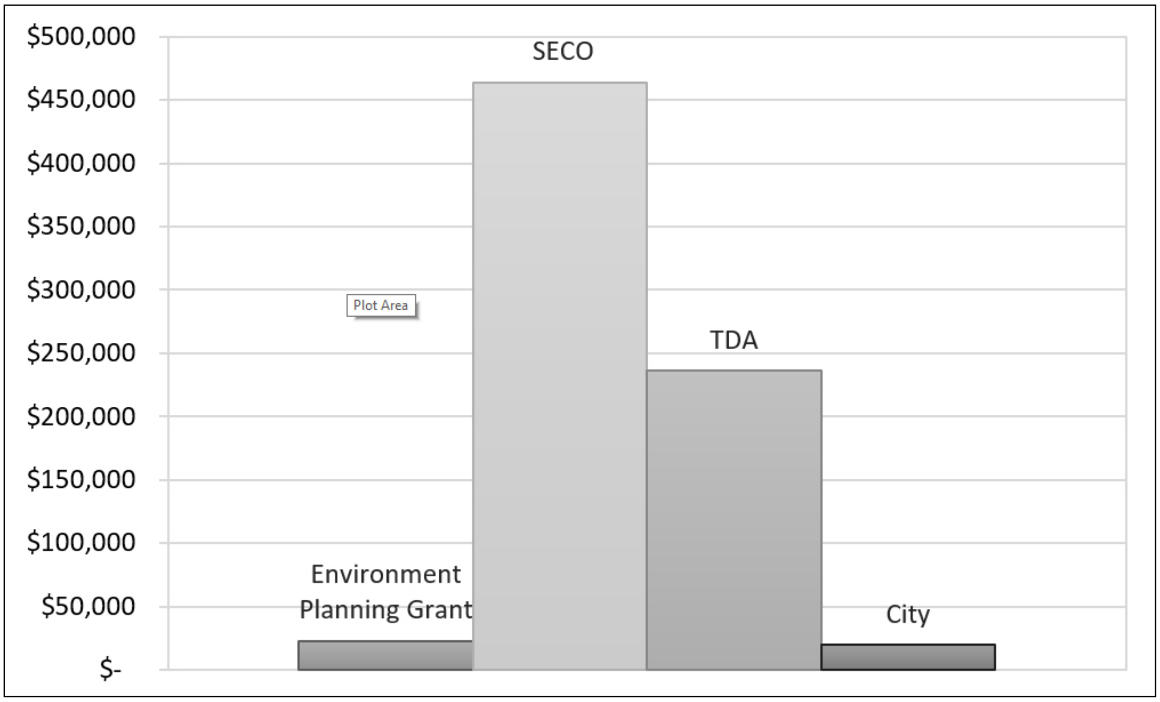

Figure 2. Sources of funds for the Seadrift wastewater treatment plant wind turbine project.

wind speed increases, the power is prevented from exceeding capacity by power-limiting mechanisms until the wind speed reaches shut-off speed. Wind turbines need a minimum wind speed (cut-in speed) to start generating energy, and they turn off if the wind speed exceeds the shutdown speed (20–30 meters per second [mps] or 66–98 feet per second [fps]). Turbines generate less than rated capacity at wind speeds below design wind speed, typically 12–16 mps (39–52 fps). Rainwater et al. (2015) reported that the Seminole turbine's cut-in speed was 5.5 mps (18 fps) and shut-down wind speed was 25 mps (82 fps), while its rated 50-kW (67 hp) power was reached at about 11 mps (36 fps). The median wind speed during the 17-month demonstration project was 5.4 mps (18 fps), while maximum wind speeds reached 23 mps (75 fps). Local wind data and the manufacturer's power curve were used to calculate the theoretical energy generation.

The key technical and economic parameter for the design and analysis of wind energy projects is the wind speed at the location, as it determines the productivity of the wind turbine and therefore its economic benefits. There exists a whole field of inquiry that is separate from the water literature and instead focuses on power grid design, with the HOMER software (Lilienthal et al. 2011) as the predominant design tool. An example is Sen and Bhattacharyya (2014) who address the intermittence of renewable energy by modeling a hybrid system as an effective alternative to grid extension in an off-grid location in India.

BACKGROUND

Project funding sources and organizations

The city of Seadrift purchased the wind turbine to help meet the WWTP energy demand by displacing some of the grid energy. Hence, city administrators applied for and received SECO (State Energy Conservation Office) grants totaling $464,000, grants from the Texas Department of Agriculture (TDA) totaling $236,000, and an additional TDA environmental planning grant of $23,000. The city itself paid $19,500 for the project. Total funds were about $742,500. The turbine cost $610,878, with additional costs for an access road, a connection fee, engineering, and general contract administration. The city has no operation and maintenance (O&M) cost, as the maintenance is the vendor's responsibility for 5 years per the contract with the city. A one-time interconnection fee of $10,451 was necessary to allow the turbine to feed excess electricity (i.e., not used by the WWTP) back to the grid. Note that the wind turbine can only operate while the grid is functioning to avoid electrocution of maintenance utility workers because of power going from the wind turbine to the grid. Other costs include an access road cost of $18,150, engineering costs of $51,112, and contract administration costs of $51,200. Total costs incurred were about $741,791. Figure 2 shows clearly that the project was financed mostly through external funds, as the city only provided about 3% of the total funds for the project.

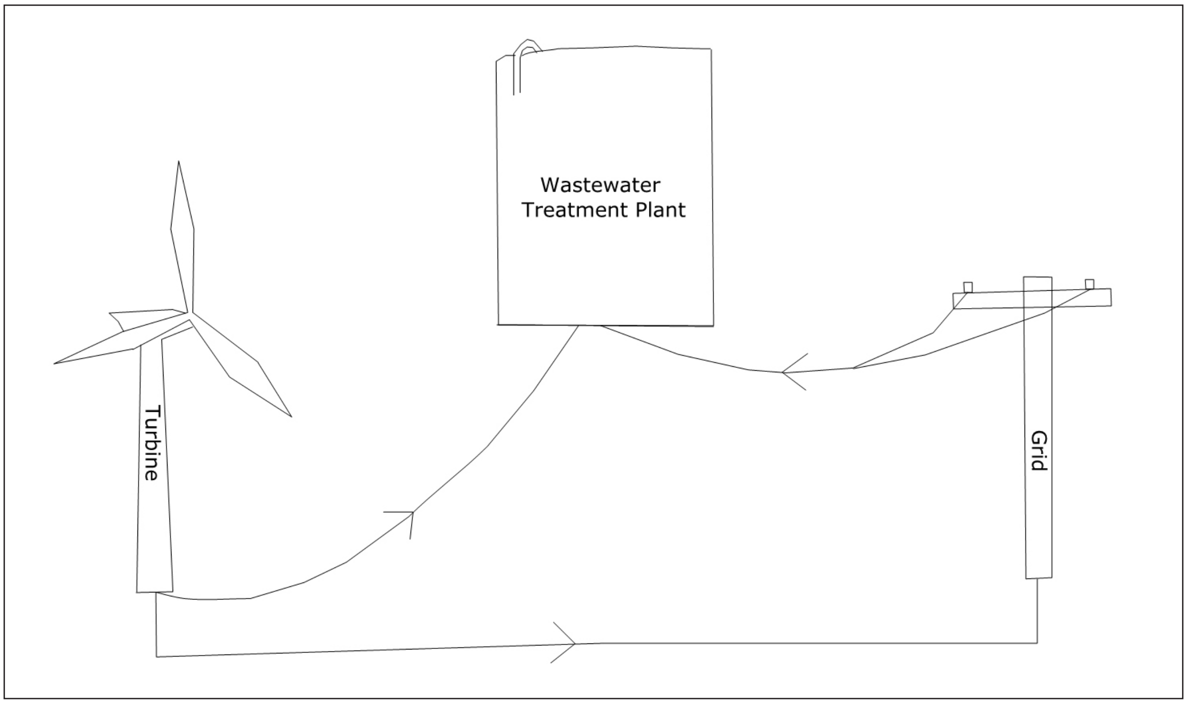

Figure 3. Seadrift wind-water-grid system schematic.

Different organizations contributed to the project. First, GrantWorks (www.grantworks.net) helped with grant applications as well as overall contract administration. GrantWorks then hired Wind Energy Consulting and Contracting, Inc. (http://weccsolutions.com; WECC), for the preliminary wind study at the proposed site. WECC also performed an economic analysis of the potential savings the city could obtain from the turbine. GrantWorks also completed an environmental assessment to ensure that whooping cranes, which pass near Calhoun County on their yearly migration, would not be threatened by the turbine. The study, submitted to the Texas Commission on Environmental Quality (TCEQ), showed that because the turbine was low enough to avoid disrupting bird migration, and because the turbine is a stand-alone, rather than a wind farm, the risk to birds was low.

After the preliminary studies, the city hired a geotechnical firm, Arias & Associates, Inc., to evaluate the subsurface and groundwater characteristics that were relevant to securely installing the turbine. G&W Engineers, Inc. provided the construction plans for the turbine, and Cascade Engineering was responsible for turbine installation, operation, and maintenance. Finally, after installation, G&W Engineers inspected the turbine.

The basic system consists of the turbine, the grid, and the WWTP, as shown in Figure 3. Arrows on the schematic indicate energy flow direction. The turbine supplies some of its energy to the WWTP, and excess energy is sold to the grid. The grid still supplies some energy to the WWTP. The wind turbine does draw some energy from the grid, but very little, even if the turbine is not operating (wind speed is lower than the cut-in wind speed), to maintain operation of the Supervisory Control and Data Acquisition (SCADA) systems and other components of the wind turbine.

Preliminary wind analysis

The cut-in wind speed is 10 fps. The preliminary study showed an average wind velocity of 6.4 mps (21 fps) at 50 m (160 ft), corresponding to a class 3 wind resource at 50 m (160 ft), according to the classification given by the National Renewable Energy Lab (NREL 2016).

Manufacturer's power and energy curves

The city purchased a Northern Power Systems (NPS 100/21) wind turbine with hub height at 37 m (120 ft), rotor diameter of 21 m (69 ft), and power rating of 100 kW (130 hp). The design life of the turbine is 20 years (NPS 2021). From the manufacturer's power curve, we note that the power system rating (100 kW or 130 hp) is realized at a wind velocity of 15 mps (49 fps). According to the manufacturer's energy curve (NPS 2021) if the average wind speed is 6.4 mps (21 fps), the wind turbine will generate about 250,000 kWh ($8.50\text{x}10^8$ BTU), which exceeds the 236,000 kWh ($8.05\text{x}10^8$ BTU) needed for the WWTP. The city based its preliminary analysis on the expected 6.4 mps (21 fps) wind speed and its corresponding 250,000 kWh/year (8.50×10^8 BTU/year) energy production. Hence, with an average cost of energy of $0.10/kWh, the wind turbine would help the city save about $25,500 per year.

METHODS

The economic analyses of the wind turbine-WWTP-grid system started with the cost of energy (COE), a key metric, defined by equation 1:

$$\mathrm{COE} = \frac{\text{Monthly Electric Bill (\$)}}{\text{Grid WWTP Electric Consumption (kWh)}} \quad (1)$$

The second economic metric is the effective cost of energy (ECOE):

$$\mathrm{ECOE} = \frac{\text{Monthly Electric Bill (\$)}}{\text{Total WWTP Electric Consumption (kWh)}} \quad (2)$$

Adding the wind turbine should lower the ECOE, since the electrical bill would decrease while the WWTP's electricity consumption (supplied by both the grid and the turbine) remains the same. To assess the profitability of the wind turbine, three more metrics are useful: (1) net present value (NPV), (2) internal rate of return (IRR), and (3) return on investment (ROI). NPV is defined as:

$$\mathrm{NPV} = \sum_{N=1}^{20} \frac{NCF}{(1+i)^N} - C_0 \quad (3)$$

where C_0 is the initial cost ($19,500 for the city and $742,500 total cost) paid for the project, at time 0. NCF is the net cash flow in a year (positive cash flows minus negative cash flows in the year). The interest rate (%) is i, and N is the project lifetime (20 years)[1].

To perform NPV analyses, we use the capital recovery factor (CRF), the factor by which a present amount is multiplied to find its equivalent present value annuity payments over a period, at a specific interest rate. To raise money in capital markets, municipalities may issue debt obligations called municipal bonds. Where corporate bonds are issued by private companies and sovereign bonds are issued by national governments, municipal bonds are issued by smaller government entities such as states, counties, and cities. Although municipal bonds are generally exempt from federal taxes, they carry a higher risk than federal securities and therefore require a higher return. The MRSB (Municipal Securities Rulemaking Board) is the government agency responsible for the municipal bond market. The MRSB's factbook reported an average daily yield of 2.87%, 2.15%, 2.48%, 2.46%, 2.44%, 2.12%, 2.63%, 2.61%, and 2.11% for municipal bonds of value $500,001-$1,000,000 for years 2011 through 2019, in order. Here, we use an interest rate of is 2.84%, and the CRF is 0.0662:

[1] We will use the 20-year timeframe for the expected lifetime of the turbine. First the turbine's own documentation states that its design life is 20 years. The 20-year period is also an industry standard, because the IEC 61400-1 standard, established by the International Electrotechnical Commission (IEC), states that "the design lifetime for wind turbine classes I to III shall be at least 20 years." The turbine is an IEC IIA turbine. Third, 20 years is also the standard timeframe for research on wind turbines (Ziegler et al. 2018).

The presumption is that by increasing the useful life of the turbine, we also increase the benefits, supposing that operation and maintenance costs, coupled with the normal decrease in energy production efficiency due to age, do not overwhelm yearly benefit of the turbine. Sources of income include tax credits, sale of electricity to the grid, and displacement of grid electricity by cheaper wind-produced energy. Costs include the initial cost and operations and maintenance costs. The longer the turbine operates and produces energy efficiently, the better chance investors have to recover their initial capital.

A study of wind turbines in the United States by the Lawrence Berkeley National Laboratory (Hamilton et al. 2020) found what they called the "year-10 drop," an abrupt decrease in energy production between years 10 and 11 due probably to a reduction in operator maintenance effort, as the 10-year production tax credits (PTC) expire. While this study shows the sensitivity of turbine economic viability to tax credits, operators decrease operation and maintenance efforts but do not stop production after year 10. The authors mention also that the production at year 17 on average declines to 87% of initial production. Ziegler et al. (2018) point to the fact that tax incentives in Europe have a 20-year duration. At the expiration of the tax credits, the economic viability of wind projects is subject to the vagaries of turbine component repair and replacement cost and market prices in the energy market.

The 20-year timeframe is more an economic concern than a technical concern. Indeed, turbines typically do not fail catastrophically; it is components such as gear boxes or braking systems that fail and need to be repaired or replaced to continue operation. Based on manufacturer design expectations, industry standards, and research results, we feel a 20-year timeframe is reasonable for our analysis.

$$\mathrm{CRF}(i,N)=\frac{i(1+i)^N}{(1+i)^N-1} \quad (4)$$

Another tool for financial analysis is the IRR, the discount rate (i) that makes the NPV equal to zero. A discount rate lower than the IRR makes the project profitable; hence, the higher the IRR, the better the investment. IRR is defined so that:

$$\mathrm{NPV}=0=\sum_{N=1}^{20}\frac{\mathrm{NCF}}{(1+\mathrm{IRR})^N}-C_0 \quad (5)$$

Finally, the project's return on investment, over the 20-year holding period (ROI) and annually (annual ROI), can be used. A high ROI is preferred over a low ROI:

$$\mathrm{ROI}=\frac{\sum_{N=1}^{20}\mathrm{NCF}-C_0}{C_0} \quad (6)$$

$$\text{Annual ROI}=(ROI+1)^{\frac{1}{20}} \quad (7)$$

DISCUSSION AND RESULTS

Wind turbine energy production

It is important to compare energy prediction to actual performance of the turbine. Often, wind speeds for preliminary studies are not measured at hub height, requiring raw measurements to be extrapolated to approximate actual performance. Modelers can use the power law equation for that purpose:

$$u_2=u_{measured}\left(\frac{z_2}{z_{measured}}\right)^{\alpha} \quad (8)$$

where $z_{measured}$ is the anemometer elevation (meters), $u_{measured}$ is the wind speed at anemometer (mps), z_2 is the turbine hub height, u_2 is the wind speed at turbine hub (in mps), and α is the wind shear coefficient (power law exponent), dimensionless. The most common value used for α is 1/7. Wind power production is theoretically related to wind speed by the wind power density equation. Here P is wind power (in watts), A is turbine area (in m²), ρ is the density of air in kg/m³ (1.225 kg/m³ or 0.00237 slugs per ft³), and U is wind speed (in mps):

$$P=\frac{1}{2}A\rho U^3 \quad (9)$$

This relationship was used in the Seminole project to show the theoretical energy production at the site, as shown in Figure 4. We can observe the seasonality of the energy generation, with the months of April to about June 2013 and 2014 (late spring) having the highest energy, followed by a sharp drop in the months of July 2013 and July 2014, respectively. A comparison with actual energy produced in Seadrift also reveals a seasonal pattern shown in Figure 5, with the spring months of January through April having the highest energy generated and the summer months of June through August having the lowest energy production. On average, the turbine generates about 13,000 kWh per month. The highest wind energy production of 177,140 kWh (6.044×10^8 BTU) was in 2013. All years fell short of the expected energy production of 250,000 kWh (8.50×10^8 BTU). The average wind energy production (2012 to 2015) was 155,738 kWh (5.31×10^8 BTU).

Intermittence was also seen in both the Seminole and Seadrift studies, as shown in Figure 6 and Figure 7, respectively. For Seminole, an EW50 wind turbine from Entegrity Wind provided a portion of the electricity for a brackish water well and reverse osmosis water treatment system in a demonstration project. The minimum wind speed to generate power was 5.54 mps (18.2 fps), and wind speeds between that value and the cut-in value of 3.98 mps (13.0 fps) actually consumed small amounts of energy. In Seadrift, cut-in wind speed was 10 fps, while predicted wind speed was 21 fps.

When we compare the energy produced to the energy demanded by the WWTP in Seadrift (Figure 8[2]), we notice that the energy supply is lower than the energy demand, except during the months of March, April, and July. Hence, during this period, there can be a matching of the energy supply and the energy demand of the turbine.

The energy produced was used to displace grid energy consumption in the WWTP. On average, the WWTP used about 10,035 kWh (3.42×10^7 BTU) less monthly from the grid in years 2012–2015 than it did before the introduction of wind energy. Hence, 120,420 kWh (4.11×10^8 BTU) were displaced yearly by wind energy in Seadrift.

Energy savings translated to electrical bill savings for the WWTP. The electrical bill, in dollars, for the WWTP steadily decreased since the introduction of wind energy in 2012. The decrease in the WWTP electrical bill corresponded to a decrease in grid energy consumption, which led to monetary savings realized by Seadrift. The savings mentioned here exclude any income received by selling energy to the grid. On average, the city saved $908 per month on its electrical bill, about $10,900 per year.

Figure 9 shows the wind energy sold back to the grid and dedicated to the WWTP. In the years 2012 to 2015, the turbine generated 622,953 kWh (2.13×10^9 BTU) of electricity, 78% of which served the WWTP, while 22% was sold to the grid. It is preferable that wind energy displaces grid energy as grid energy costs an average $0.10 per kWh, while resale value to the grid is $0.04 per kWh.

[2] Effluent flow data extracted from EPA's Echo site (EPA 2020). WWTP energy demand is 0.915 kWh/m³ (Bodík and Kubaská 2013).

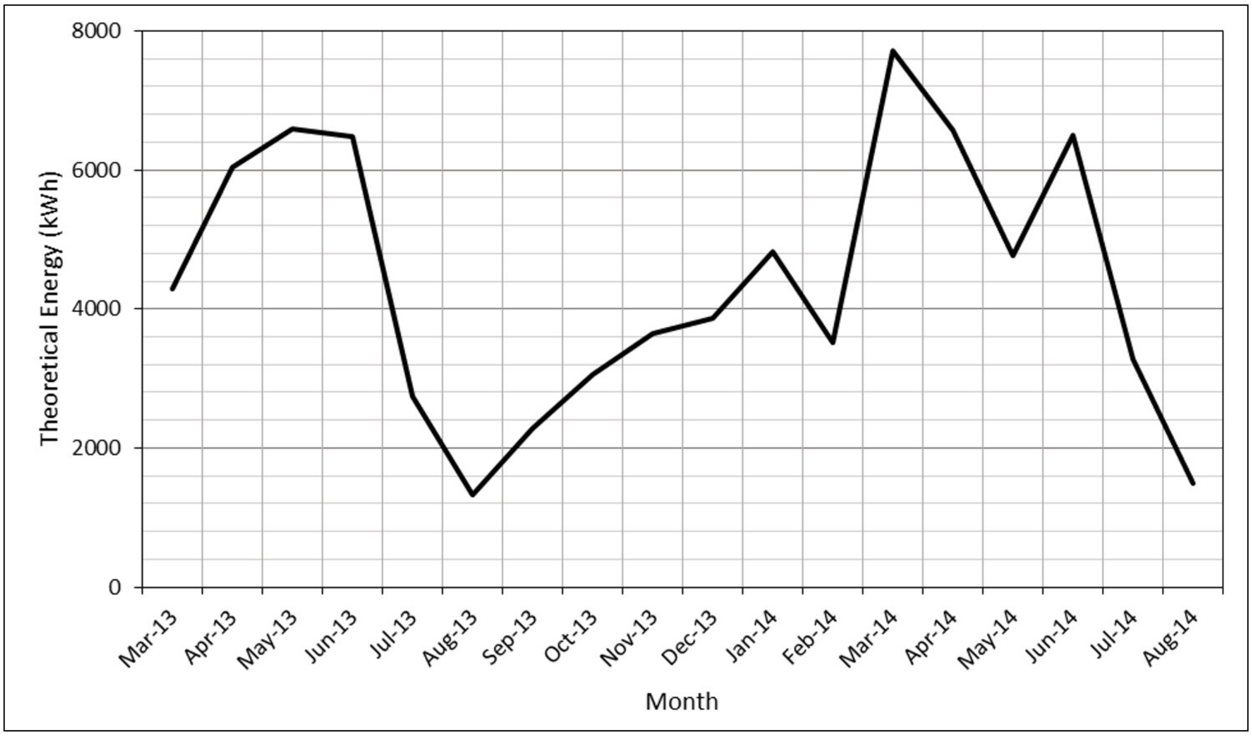

Figure 4. Seminole theoretical energy that could be generated each month.

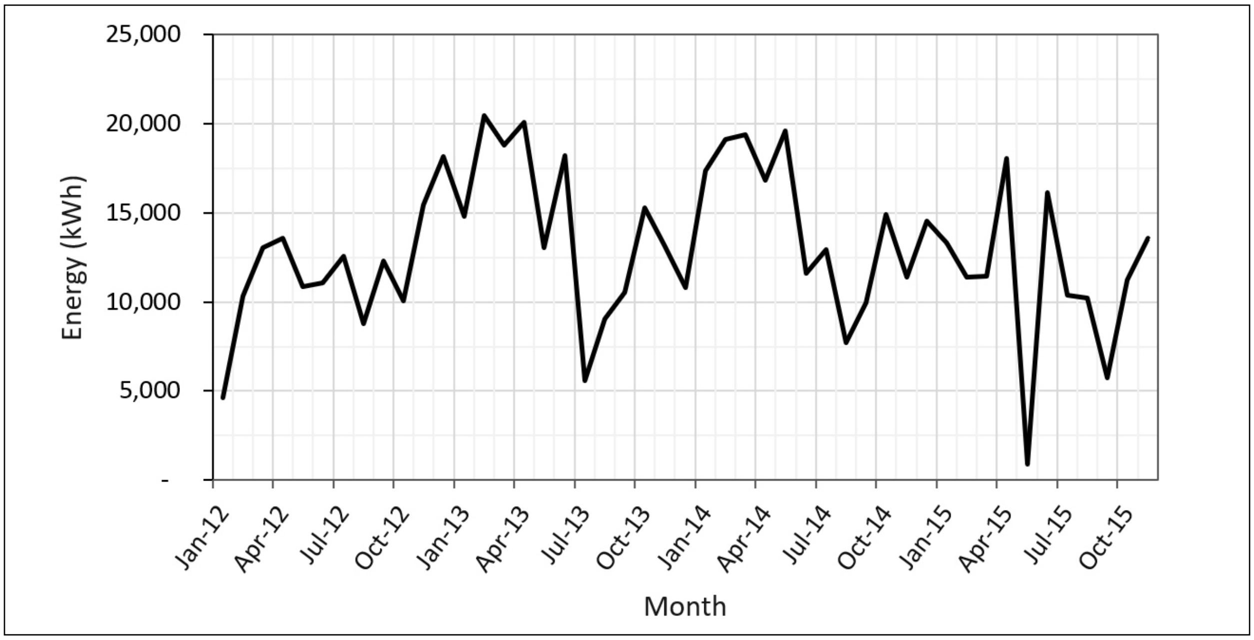

Figure 5. Seadrift actual energy generated in 2012 to 2015.

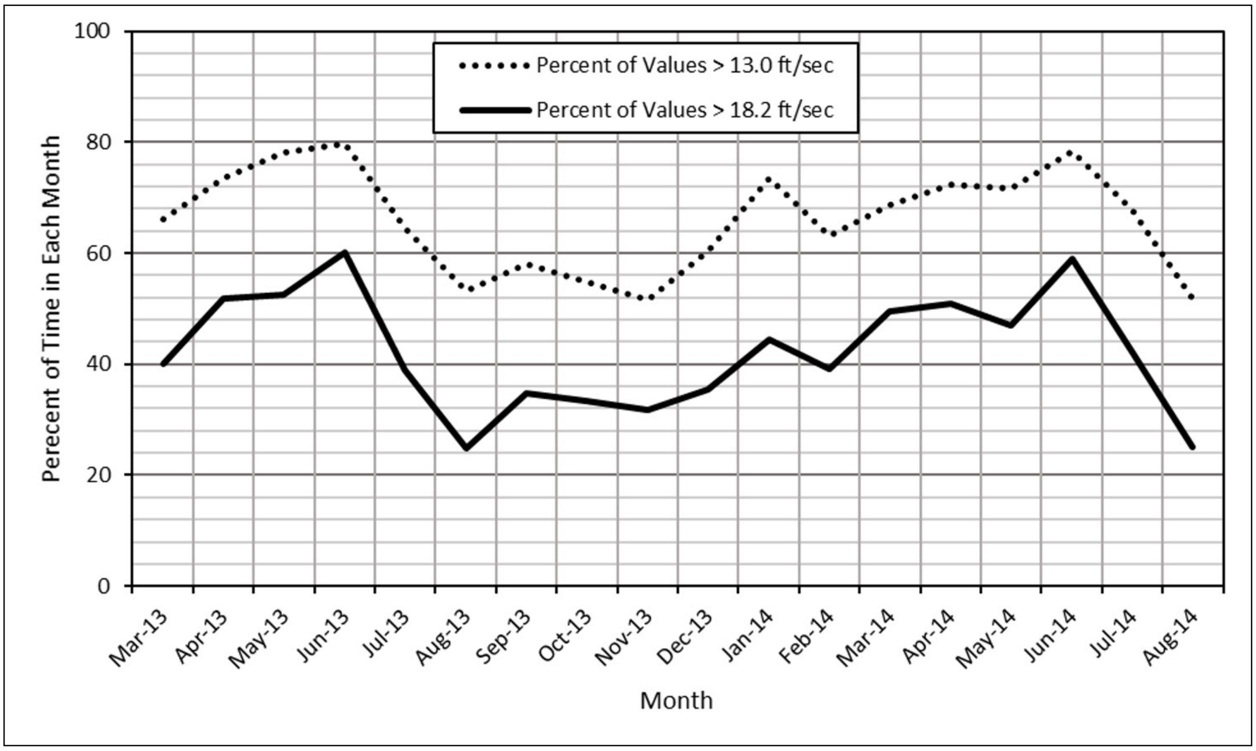

Figure 6. Percent of time each month that wind speeds exceeded 13.0 and 18.2 feet per second in Seminole.

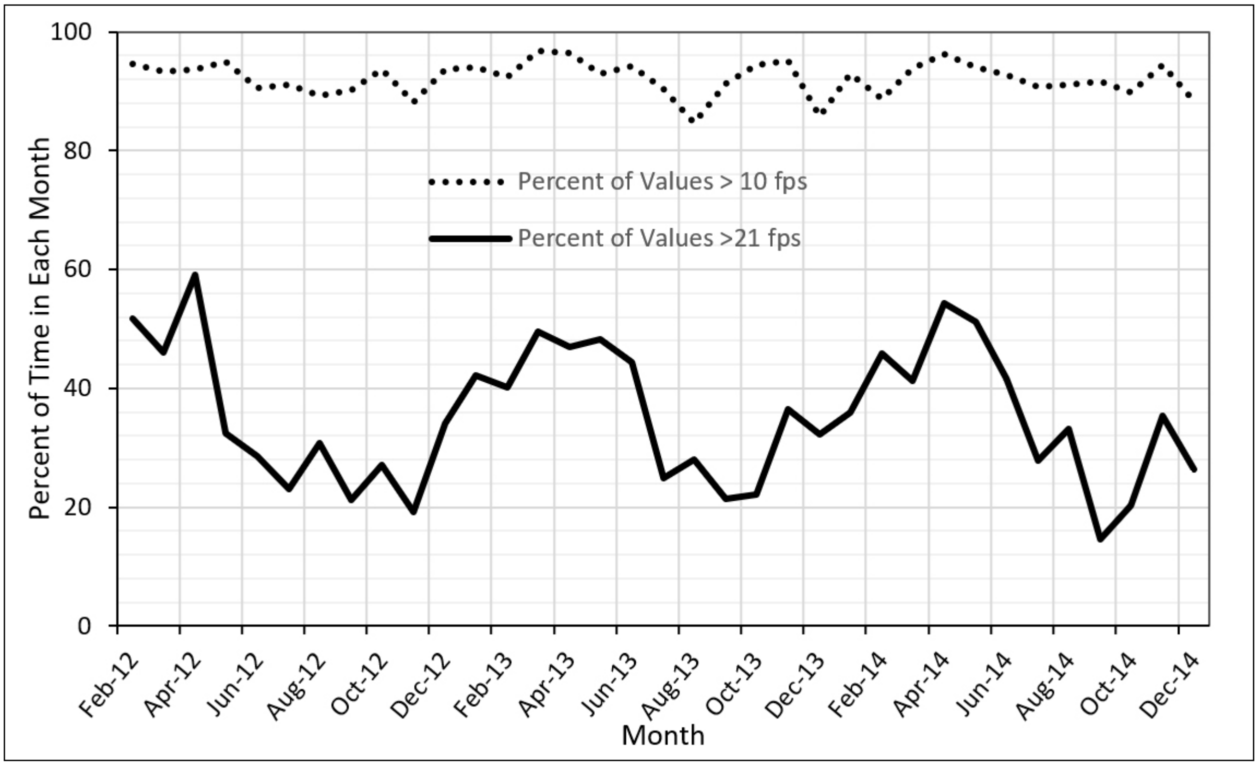

Figure 7. Percent of time each month that wind speeds exceeded 10 and 21 feet per second in Seadrift.

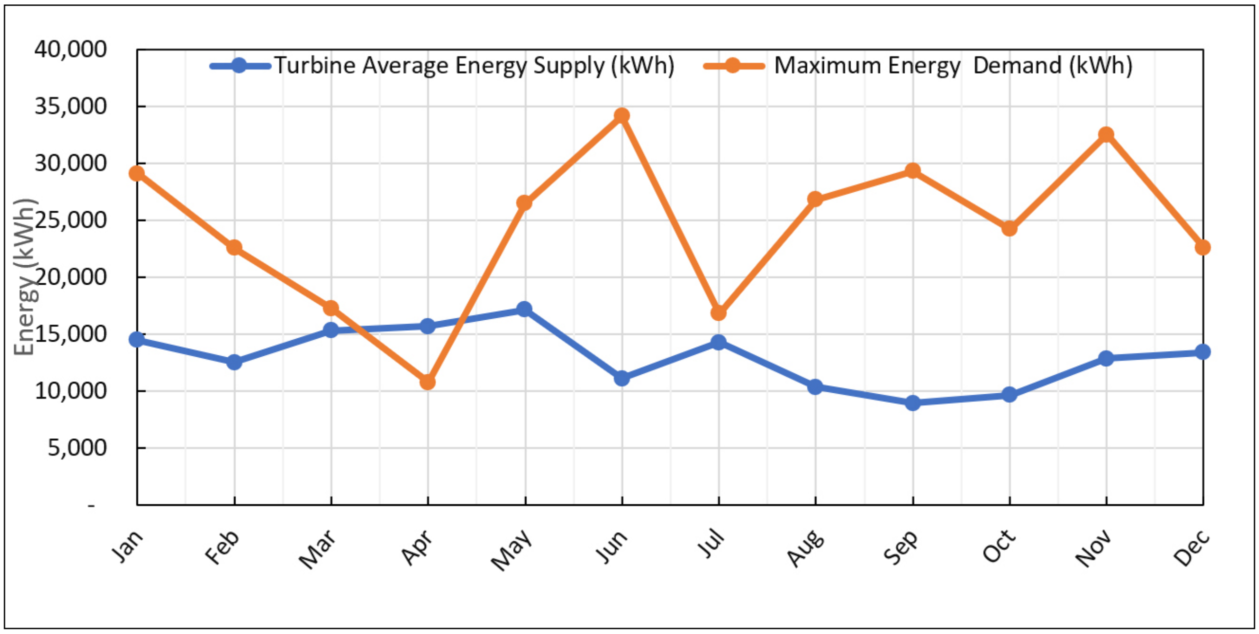

Figure 8. Average turbine energy supplied vs. wastewater treatment plant energy demand.

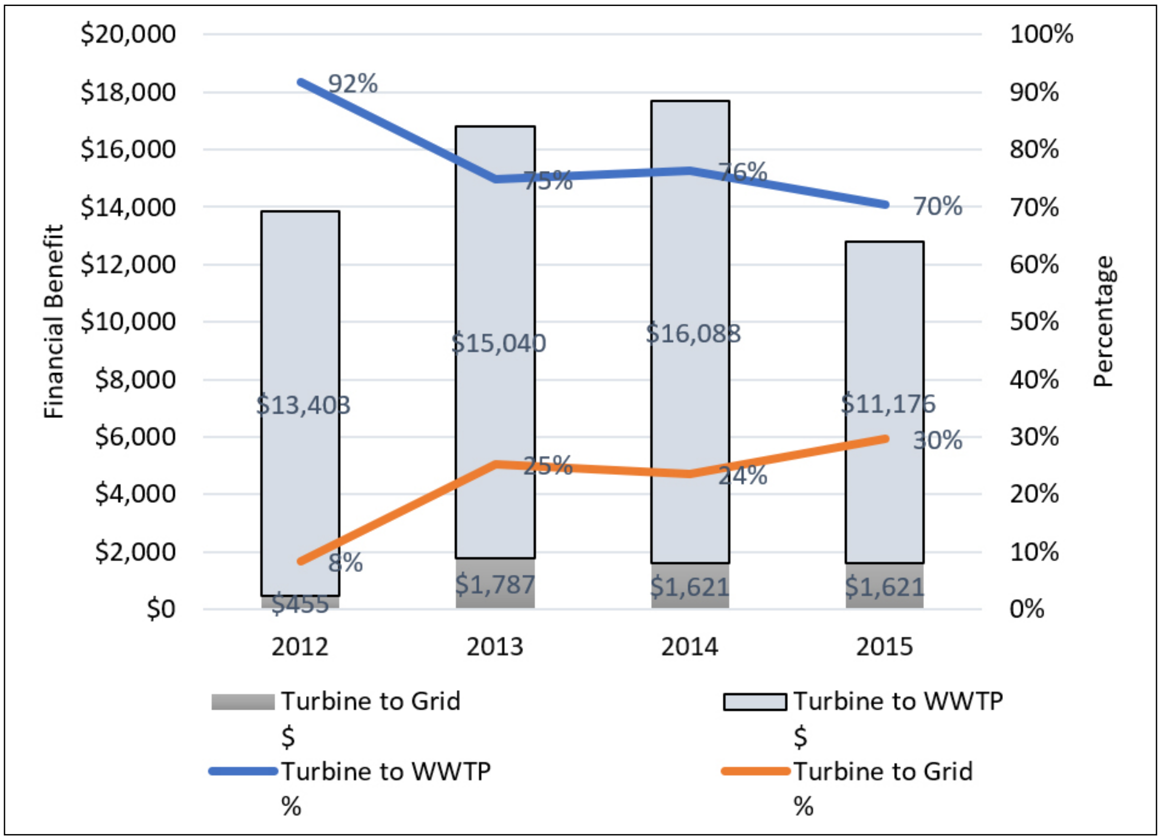

Figure 9. Distribution of turbine energy and savings to the wastewater treatment plant and grid.

Renewable Electricity Purchases in the State of Texas[3]

Within Texas, two rules impact the purchase of renewable energy: (1) the federally mandated purchase from qualifying facilities, which are confirmed by Texas' Public Utilities Regulatory Act of 2011, as amended in 2019 (PURA 2019), and (2) the renewable portfolio standard (RPS) of Texas. The Public Utility Regulatory Policies Act (PURPA 1978) is a federal law that mandates that retail electricity providers (REPs)—Direct Energy in the case of Seadrift—must purchase electrical energy and electrical capacity from qualifying facilities (QFs). QFs, according to the Federal Energy Regulatory Commission (FERC), fall in two categories: (1) facilities that generate at most 80 megawatts (MW) of non-fossil fuel energy such as hydro, wind or solar, biomass, waste, or geothermal energy or (2) cogeneration facilities, which produce both electricity and useful thermal energy "in a way that is more efficient than the separate production of both forms of energy" (FERC 2021a). In this work, the city of Seadrift is the qualifying utility, and it is paid $0.04/kWh by the REP (Direct Energy)[4].

The Texas RPS defines goals for the integration of renewable energy into the electrical grid. This requirement is usually an incentive for REPs to purchase energy from renewable energy producers. As stipulated in PUC § 25.173 (a)(1), Texas set and achieved a goal of integrating 5,880 MW of renewable energy into its grid by 2015 (PUC § 25.173 2009). Further, as of 2016, the state had already achieved its goal of integrating 10,000 MW of renewable energy into the grid by 2025 (NCSL 2016).

[3] Texas REPs and transmission and distribution utilities trade electricity in one of two markets: the Electric Reliability Council of Texas (ERCOT) market or the Southwest Power Pool (SPP) market. The ERCOT market covers most of the state, while the Southwest Power Pool covers portions of the Texas Panhandle (FERC 2021b). ERCOT transmission lines are strictly confined to the state of Texas and hence are subject only to federal rules and state rules as prescribed by the Texas Public Utilities Commission (PUC); they are not subject to interstate transmission rules as administered by the FERC.

[4] Texas mandatory purchase rules are detailed in PUC § 25.242 (f) (PUC § 25.242 2009). The policy mandates that REPs must purchase energy and capacity from QFs with design capacities of 100 kW or more. The QF notifies the REP of the availability of electricity. The law recommends that the QF make the electricity available within 90 days of the notice but does not prohibit longer time periods between notice and power delivery. The REP is then required to purchase the available electricity, unless it needs more time to set up the proper interconnection facilities. PUC § 25.242 (g) (PUC § 25.242 2009) dictates that the REP must purchase the available electricity at a price equal to or lower—but no greater than— than the avoided cost. Avoided cost is the energy production cost that would be incurred by the REP if the energy had not been bought from the QF. In this work, $0.04/kWh is the avoided cost for Direct Energy.

Economic analyses

For present value analyses, first NCF must be determined. From 2012 to 2015, the city realized an average benefit of $15,298 yearly; this is the NCF for NPV analyses. This NCF is different from the yearly $10,900 savings found in the previous section because it includes both the savings realized and the income received by selling back to the grid. Note that we assume that there is no loss of energy in the transition between the wind turbine and the WWTP, while the $10,900 figure is based on actual bills.

Seadrift's perspective

The resulting $15,928 economic benefit is lower than the $25,500 per annum the city expected to save. From the city's perspective, and because the original goal of the project was to help the city reduce its electrical bill, we could say that this is still a good performance, because the city only invested $19,500 in the project.

A project's success largely depends on investor expectations. The system performance was less than anticipated because the average speed over the period was 5.48 mps (18 fps) when it was expected to be 6.40 mps (21fps). Hence, while the city expected the turbine to generate 250,000 kWh per year, the actual total energy output was only 155,738 kWh during the period. Consequently, the economic yearly economic benefit was $15,298 instead of the anticipated $25,500 value. Yet, the turbine produced a significant amount of energy, and the economic metrics for the projects are all positive when analyzed at the city level, as shown in the analysis of ECOE, NPV, IRR, and ROI.

Figure 10 shows the COE by year, based on electrical bills per year provided to us by the city. Figure 10 shows a decrease in ECOE since the introduction of the wind turbine. Indeed, in the years 2009–2011, the COE and ECOE values were the same as the grid was the only source of electricity. Then, in the years 2012–2015, the ECOE is on average $0.04/kWh lower than the COE.

From the city's perspective, the return on investment is 14.7, meaning that the project will generate 14.7 times ($286,650) the city's investment ($19,500) over a 20-year period. This result also means that the investment has a growth rate of 15% in value per year. The project's NPV (20 years) is $211,493. The project's IRR is 78.45%, meaning that with a 2.84% municipal discount rate, this project is very profitable at the city's level.

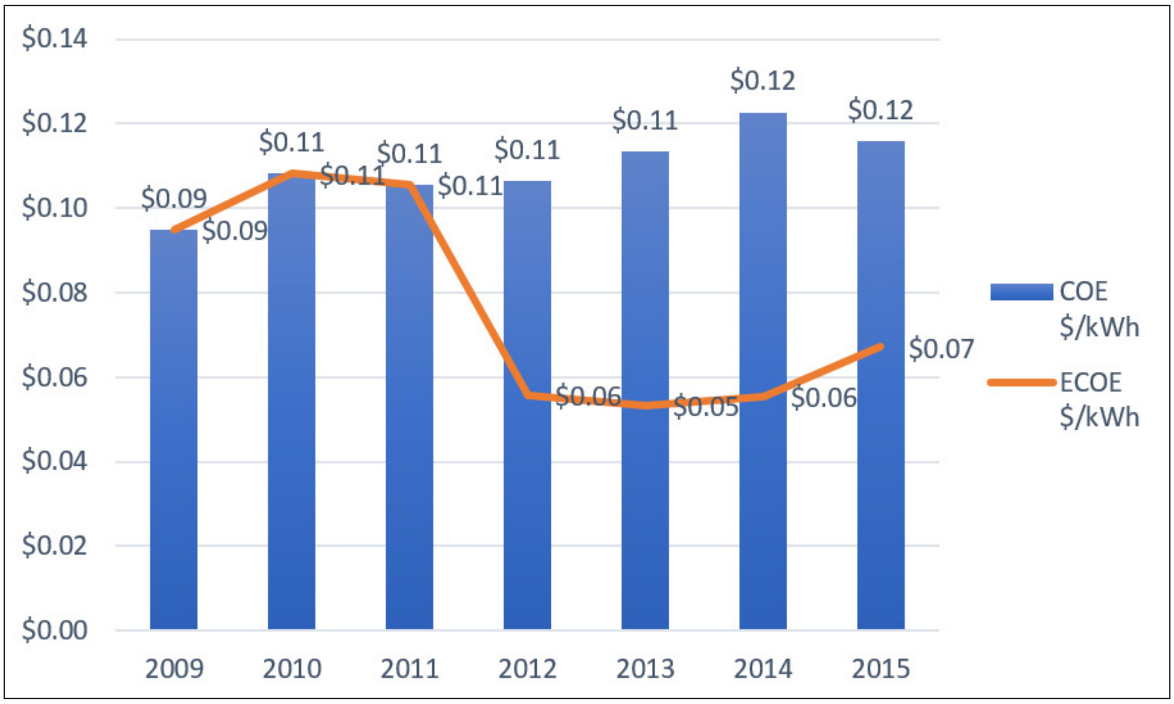

Figure 10. Cost of energy vs effective cost of energy.

Total cost perspective

The cost of a wind project is too high for a small city to shoulder, and the state has to contribute most of the money to make the project successful. However, at the state level, the economic performance is negative. The main difference here is that the state of Texas contributed a total of $742,500 (not $19,500) to the wind turbine. This is a more complete assessment of the economic performance of the project as it accounts for the project's total cost. Here the IRR is –7.27%; the state would have to be paid to borrow money to make the project profitable. Further, the project NPV is negative (–$500,000), and the annual ROI is negative (–4%). For the project to realize a positive NPV at the state level, the turbine would have to generate an economic benefit of about $49,000, or 556,818 kWh ($1.9 \times 10^9$ BTU) per year, with 80% to displace grid energy and 20% sold to the grid. Hence, even the $25,500 savings originally expected would not be sufficient to account for all costs. It would require three times the current economic benefit ($15,928), or 3.5 times the current wind energy production (155,738 kWh or 5.31×10^8 BTU), for the project to be truly profitable.

Summary of economic analyses

The project reveals some of the structural parameters that can undermine the sustainability of wind projects. First, the initial cost of the project is so high that it is difficult to generate returns that repay that initial cost, especially given the 20–25-year lifespan of wind turbines. A small city alone cannot undertake such a project, but investors (even government investors) may not be willing to fund the projects given the limited returns. Second, wind potential at a location is a limiting parameter as it drives energy production and therefore offers economic benefits. It may be possible to increase the returns on wind projects by having multiple beneficiaries (not only one city, but many cities for example) use the turbine's energy output. Yet because of wind potential limitations, the turbine does not produce any excess energy. Third, even though the energy market permits resale of electricity to the grid, the resale price is still lower (i.e., $0.04/kWh) than the purchase price ($0.10/kWh), making it incrementally difficult to cover the original turbine cost, even though there is excess energy from the wind turbine.

To improve the profitability of these systems, project designers should consider the total cost, not only at the city's level but on a total cost basis. Indeed, the turbine performed less than expected, but even if it had produced the expected 250,000 kWh, it would still not have produced enough energy to cover all costs. A design based on total cost would inform the size and choice of adequate wind turbines that can produce enough energy to justify their cost. Further, the turbines can be chosen so they produce sufficient energy despite the wind potential constraints at the location.

ACKNOWLEDGEMENTS

The authors would like to acknowledge city staff for their help in this project, particularly Robert Bryant, Alice Romero, and Seadrift Mayor Elmer DeForest, as well as Engineer JoAnna Weaver with G&W Engineers. Travis Brown with the TDA provided some valuable documents to help understand the genesis and funding of the project. The authors also thank the Water Resources Center at Texas Tech University for funding this effort.

CONCLUSIONS

Wind projects such as Seadrift's offer an alternative to fossil fuel-based approaches for energy generation. Yet project designers must carefully study wind energy intermittency and seasonality at a location to anticipate the matching of wind energy supply with water and wastewater energy demands. Though the preliminary studies in Seadrift did not include such analysis, project designers can compare effluent water and wastewater energy requirements to better match the supply of energy with the demand as we showed in this study.

Further, to be sustainable, projects must be economically viable. State officials and decision-makers who are accountable for the allocation of scarce financial resources should consider whether the project is profitable for the state. In the case of Seadrift, the city only contributed 3% of the initial cost of the project, with all other funding coming from state agencies or the state itself. Cities may consider adding a surcharge to the water or wastewater bill to increase revenues on such projects. Yet this approach is challenging, as an increase in water rates may paradoxically reduce revenues for the city as consumers may decrease their water demand. City leaders may also face staunch resistance from customers who consider water and wastewater services as a basic right and therefore often reject rate increases. The design should also consider total costs and total return to inform sizing of turbines given wind potential and energy resale conditions at a location.

The yearly energy generation of 155,738 kWh or 5.31×10^8 BTU matched expected energy from manufacturer design. However, a cautious approach is warranted, especially in predicting average wind speed at a location. Indeed, a more accurate preliminary study would have revealed the lower average wind speed than predicted (18 fps, not 21fps) and alerted designers to lower energy production (5.31×10^8 BTU, not 8.50×10^8 BTU), and consequently lower yearly economic benefits ($15,928, not $25,500). All metrics, driven by wind speed, were lower than predicted.

In Seadrift, both the utility provider (Direct Energy) and the transmissions and distribution company (American Electric Power) cooperated with the city so that the wind turbine could be integrated in the grid system. The electricity firms also agreed to purchase power from the wind turbine. This case study hence demonstrates that more integration of renewable energy into energy systems is possible.

Overall, Seadrift installed a 100-kW wind turbine to displace some grid energy for its WWTP. The turbine's contribution allowed the city to realize a financial benefit of $15,928 per year on average while realizing a net present value of $211,493 over the 20-year design life of the turbine at the city level. The state's contribution is an example of its effort to share in the public good of all Texas residents, including those in smaller rural communities. Though due to study parameters, life cycle analyses could not be performed, they could be used in projects where wind projects are part of the original plant design rather than an addition to a pre-existing water-energy system. This case study provides an example for small communities looking for ways to manage their energy costs while providing basic services to their residents.

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