2020 Collegiate Wind Competition Design Proposal

SITING AND PROJECT DEVELOPMENT TEAM REPORT

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INTRODUCTION

This report will provide the preliminary design and development for a wind farm with a target nameplate capacity of 100 MW. The wind farm design was developed by taking into account environmental, social, and economic factors. The wind farm location and layout was based upon available resources in the area along with the market opportunity for the production of wind energy. The windfarm will be constructed with a 20-year lifespan and will be evaluated for its power output and constructability. A financial analysis for this project was performed to determine the feasibility of constructing a large-scale wind farm in the area. All project costs including, turbine manufacturing, site improvements, and all necessary permits were taken into account for this financial analysis.

COLORADO WIND RESOURCES

Colorado is one of the leading wind energy producing states and continues to expand its wind energy industry because of its large amount of space and wind resource. Colorado is already home to many large scale wind farms which reach nameplate capacities up to 600 MW [1]. Wind speeds, especially on the eastern side of Colorado, are high enough to consistently produce wind energy. Most locations in eastern Colorado have an annual average wind speed between 7-8 meters per second at a hub height of 100 meters [2]. The amount of energy produced through wind turbines has steadily increased in Colorado since 2005 and the state is now producing a total of over 3750 MW from wind energy [3]. The constant look to increase wind energy in Colorado makes it an excellent market to propose the production of a wind farm.

SITE DESCRIPTION

The proposed wind farm is located in Peyton, Colorado just northeast of Colorado Springs. The 4,000 square acre site is located along Highway 24 and has multiple existing small roads running through it. At a hub height of 100 meters, the site has an adequate annual wind speed greater than 6 m/s to sustain a wind farm. In this preliminary design, 21 Vestas V150 4.2 MW turbines will be able to produce a nameplate capacity of 88.2 MW. The turbines each have a hub height of 105 meters and a total rotor diameter of 150 meters. This turbine model was chosen because of the wind speeds at the site location and to also limit the number of turbines placed on the property. Each turbine's power curve was compared to the average annual wind speed of 7 m/s in order to determine the most effective turbine for the site.

Access Roads will be constructed for each turbine in order to make them easily accessible for operations and maintenance. Access Roads will be routed to avoid Black Squirrel Creek running through the property. There are high voltage transmission lines in close proximity to the site which will minimize the proposed infrastructure to be constructed. The surrounding area is mostly flat and rolling terrain minimizing the external wake that would affect the turbine's energy production. Property for the wind farm will be leased from and provide an extra source of income for local land owners in the area.

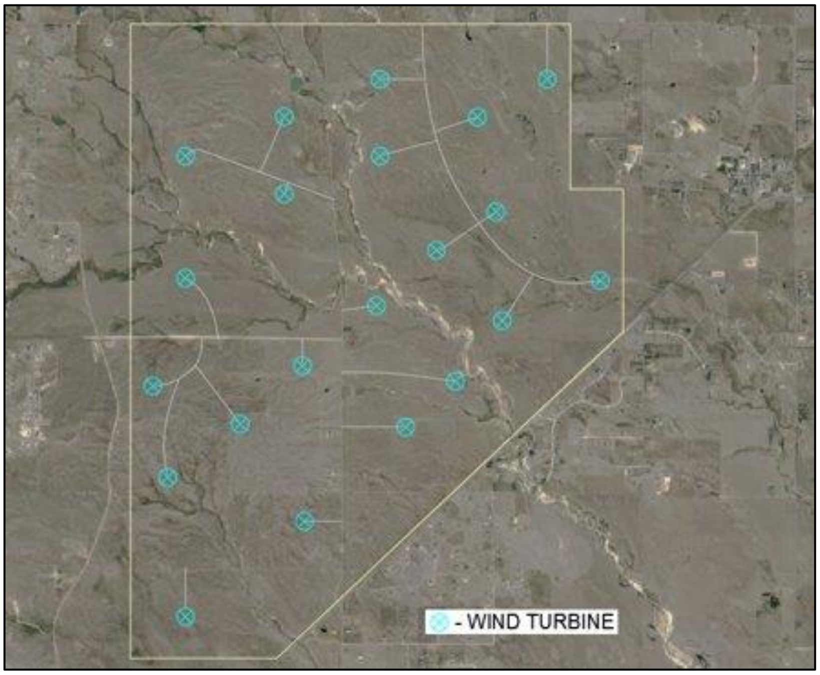

Figure 1. Preliminary Wind Farm Layout

SITE DESIGN PRINCIPLES

When originally searching for adequate wind farm locations throughout Colorado, design principles were established to help narrow down potential sites during the process. These principles were used as guidelines for what features are most important to the wind farm design and how they affect the outcome. The design principles listed below take into account economic and environmental factors involving the project.

- Minimize the initial capital cost of the project without compromising the efficiency and safety of the wind farm.
- Locate the wind farm in close proximity to existing infrastructure to reduce the need for new access roads and transmission lines. This is beneficial to both the project cost and effect on the environment.
- Find a wind energy production market which will be suitable for a large-scale wind farm.
- Analyze turbine models to determine which turbine is most effective with onsite wind resources and cost.
- Limit power production losses through siting layout and avoid areas with high potential for wind resource losses.
- Limit interference with the local population and wildlife.
- Maximize the Net Present Value of the wind farm after a 20 year life span.

WIND ENERGY PRODUCTION OPPORTUNITY

While researching locations across the state for a potential market opportunity in wind energy, the city of Colorado Spring in El Paso County became the focal point of what market we would like to pursue. The Martin Drake Power Station in Colorado Springs has been undergoing a gradual decommissioning process since 2015. The 208 MW coal-fired power plant supplies close to a quarter of the entire city with power annually [4]. As the Martin Drake power plant is decommissioned, this is a great opportunity for a wind farm to be implemented to replace the coal energy with a clean, renewable energy source.

Colorado Springs Utilities has begun their process for replacing the lost power from the coal plant by looking into an alternative for energy production. Colorado Springs only has 15.6% of annual power produced by renewable energy sources as of 2019 [5]. This number is very low compared to other cities in Colorado, and the city is developing an Integrated Energy Resource Plan to assess how they can use more renewable resources. As Colorado Spring is developing their energy integrated resource plan, it is a great opportunity to propose a windfarm which can replace the production of the coal plant.

As Colorado Springs plans to revamp their energy production, they also have many existing high voltage transmission lines which enter the city that can potentially be interconnected in by a wind farm. These high voltage transmission lines can be used to bring energy from outside the city's metered boundary to substations that are to be implemented in their design plan. Locating a wind farm close to one of these transmission lines would greatly reduce the infrastructure costs of this project.

Colorado Springs has a COE (cost of energy) of $ 0.0777 per kWh which is a reasonable goal to achieve when producing energy through a wind farm [6]. As the replacement generation of power for Colorado Springs has yet to be decided this is a strong opportunity to implement this windfarm and benefit both the environment and communities of Colorado Springs.

SITE LOCATION

Once Colorado Springs and the surrounding El Paso County were finalized as the market that would be targeted, the site location was chosen to optimize the energy that can be produced for the city. Transmission and geographic maps were cross-referenced as a basis for locations that can be optimal for a wind farm site [7]. Areas close to airports and military bases were avoided to minimize conflict with local air traffic. Also areas close to state parks and wildlife refuges were not considered as the process for acquiring land to construct a wind farm near these sites would involve extensive permitting and expenses.

After researching multiple potential locations, the team decided to locate the wind farm in the town of Peyton. Peyton is a small town with a population of 250 people that is approximately 25 miles from Colorado Springs [8]. The town has a surplus of open land and has relatively flat terrain making it an ideal location for a potential wind farm. The site in Peyton that will be used is a large area of land consisting of over 6000 acres. This land is adjacent to Highway 25, which is beneficial for the transportation of turbines and equipment to the site.

The wind farm site is also located 3.7 miles away from an existing 345 kV transmission line, which will minimize the necessary infrastructure [9]. This high voltage transmission line feeds into the Colorado Springs area. As Colorado Springs looks to construct and renovate its transmission lines within the city's metered boundary, they plan to construct new substations that this existing transmission line would feed into [10]. The construction of this wind farm will be coordinated with Colorado Springs Utilities in order to possibly feed energy produced through the city's proposed substation.

The proposed site has adequate wind speeds for the constant production of wind energy. The site has an annual average wind speed of approximately 7 m/s at 100 meters [11]. This is relatively low compared to other areas in the state, but it is adequate to sustain wind energy production with a turbine model that is effective in lower wind speeds. The prevailing wind direction at the site is consistent all year, which is important when designing an efficient turbine layout.

SITE AND TURBINE LAYOUT

After choosing a potential wind farm site, the focus turned to select an effective turbine model that would best fit the location. Multiple wind turbine manufacturers were considered, such as Vestas, GE, and Siemens. These three companies are some of the largest manufacturers of wind turbines in the country and can handle the potential production of a large scale wind turbine. After analyzing potential costs and turbine models, we decided to use Vestas V150 4.2 MW turbines for our proposed wind farm. Vestas was chosen as a manufacturer because of its close proximity to the wind farm site. As both of its manufacturing facilities are within 100 miles from the site, transportation costs will be minimized for each turbine. Blades and Nacelles will be transported from manufacturing facilities in the Denver area while the turbine structures will be transported from the facilities in Pueblo, CO [12].

Turbine Model	Rated Power Output (MW)	Turbine Quantity for 100 MW Capacity	IEC Wind Class	Cut-In Wind Speed (m/s)	Cut-Out Wind Speed (m/s)
Vestas V-110 2 MW	2.0	50	IIA	3	21
Vestas V-120 2.2 MW	2.2	45	IIB/S	3	20
Vestas V-150 4.2 MW	4.2	24	IIIB/S	3	22.5

Table 1. Turbine Selection Parameters

The V150 4.2 MW turbine was selected because of its performance in lower wind speeds and to minimize the turbines necessary to reach our target capacity [13]. Other models of turbines from Vestas were considered such as the V110 2.0 MW and V120 2.2 MW turbines [14]. The V150 was decided upon in order to reduce the amount of siting improvements and construction needed for fewer turbines on site.

As the site would be leased from land owners and also has a creek that runs through it, we decided that placing as fewer turbines on the property would minimize their effect on locals and the environment.

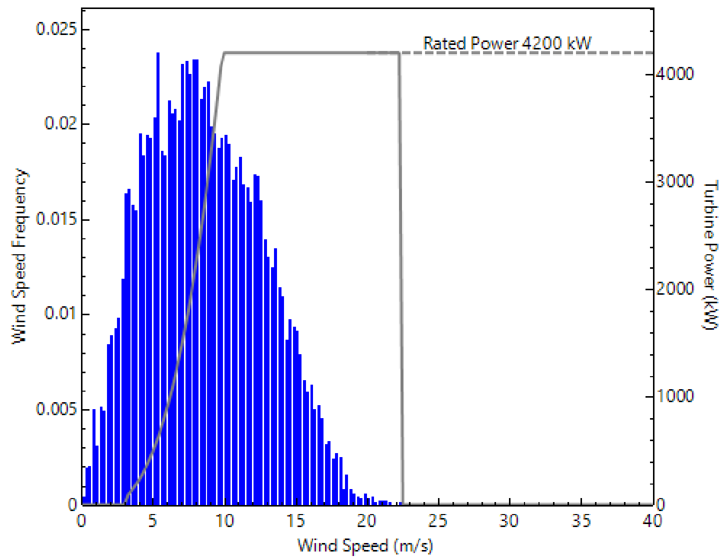

Figure 2. V150 Turbine power curve vs. wind speed frequency on site

With the turbine selection process completed, the turbine layout was designed to maximize the power output of the wind farm. The surrounding terrain of the site is relatively flat and there are no neighboring structures that can impede the wind resources of the area. Although this may reduce the external wake loss on the project, the layout was designed considering the internal wake loss each turbine may have on the adjacent turbines. As the prevailing wind direction is consistently at SSE year-round [11], the turbines were placed in order for each turbine to be able to capture as much energy while limiting wake effects [15].

The wind farm will have a total of twenty-one (21) V150 4.2 MW turbines. Each turbine is spaced at a minimum of seven rotor diameters from the next. This will provide adequate spacing to reduce internal wake [16]. Where possible, the turbines were also offset three rotor diameters from the angle of prevailing winds to avoid being aligned directly behind another turbine. Where turbines could not be offset from behind other turbines, a rotor diameter of 8-10 was used to reduce the wake from that turbine.

The proposed wind farm layout would be constructed on approximately 4000 acres of land that would be leased from local farmers. This land leasing opportunity can be beneficial for both the wind farm project and the land owners. As agriculture in eastern Colorado can yield a level of uncertainty from year to year, the income these farmers would get from partially leasing their land to wind farm can become a steady profit for them.

While designing the turbine layout on the site, the creek that runs through the site, Black Squirrel Creek, was considered and affected the layout of each turbine. Turbines were positioned so that they are positioned at least 1000 feet away from the creek to avoid disturbance of wildlife that may inhabit the area. Ideally, during the construction process this distance will give the turbine installation crew enough room to erect the turbines without affecting the creek.

SITE DEVELOPMENT AND INFRASTRUCTURE

For each turbine on the wind farm site, an access road will be constructed to easily transport materials to the site during the construction process, and to also provide turbine access for all operations and maintenance during the lifespan of the wind farm. The access roads will be constructed to route between multiple turbines whenever possible to reduce unnecessary land grading and construction costs. The access roads are also to be routed around the existing creeks. Each access road will have a width of 16 feet in order to accommodate the trucks that will transport each turbine and the necessary construction material. There are multiple existing roads that intersect through the proposed wind farm layout which can be useful in accessing each turbine. The existing roads will reduce the number of access roads needed and allow easy transportation of materials. In total, approximately 9 miles of gravel access roads will be constructed for the wind farm. All access road entrances will be placed on side roads and not interrupt the flow of traffic along Highway 25.

Each turbine will be constructed atop a concrete foundation in order to stabilize the structure and also resist all lateral wind forces that they will resist. The land will be graded around the foundation to ensure a completely plum turbine. The soil conditions at the proposed site will be tested in order to determine the type of foundation and amount of concrete needed for each turbine. With a creek running through the proposed site, it is possible that some turbines will require deeper foundations such as piers or piles to stabilize the turbine on potentially saturated soil conditions close to the water source.

Overhead feeder transmission lines will be constructed for each turbine to collect energy and feed into the nearby existing high voltage lines. Each turbine will be equipped with a transformer in order to step up the voltage output to flow through feeder transmission lines with minimal electrical loss. These feeder lines will then run to a centralized substation in order to be stepped up to 345 kV before being interconnected the existing high voltage transmission line 3.7 miles away from the site. The energy will run through the existing lines and to the Colorado Springs Utilities substation where it will be stepped down for consumer use.

An operations and maintenance facility will also be constructed to centralize all operations on site. Both the onsite substation and operations facility will be located upon approval of preliminary wind farm layout and design.

ENVIRONMENTAL FACTORS AND PERMITS

One of our major design principles for the proposed wind farm was to limit the effect on the existing community and wildlife in the area. We believe this turbine can positively affect the surrounding population. The construction, operation, and maintenance of wind farms can create jobs for local workers while also producing a sustainable energy source. As the wind turbines are also manufactured in Colorado, this wind farm can help the local economy continue to grow.

Limiting our impact of local wildlife will also be a major priority as there are multiple endangered species in El Paso County. A Habitat Conservation Plan will be implemented to ensure that local animal populations are affected as little as possible. An Incidental Take Permit along with a Habitat Conservation Plan will be submitted to local and federal governments for their approval of the project. A permit for all land-based renewable energy generation facilities is also required by the US Army Corps of Engineers [17].

PROJECT COSTS

After taking into account all manufacturing, construction, financial, and legal costs of this 88.2 MW wind farm, the initial capital cost of the project is approximately $148 million. This initial cost includes all facets of the wind farm discussed in this report and along with financing and markup costs. The cost estimate for this wind farm was generated using NREL's System Advisory Model (SAM) for onshore wind energy production along with multiple resources from NREL's database.

The total cost of the turbines to no surprise is a majority of the cost of the wind farm. The wind turbine manufacturing cost was estimated to be $1,011 per kW which came to a total of over $89,000,000 for the 21 turbines needed for the site [18]. Costs for the transportation of turbine components and erection of the turbines were also accounted for. Foundation cost for the turbine was estimated considering an average size of foundation for each turbine but may be affected by inspection of site soil conditions.

Balance of Systems was also a major cost of the turbine as it accounts for all infrastructure costs that will be coordinated for the project. The balance of system cost is estimated at over $20 million and is a crucial part to effectively connect the wind farm to the existing electrical grid. This cost includes all feeder transmission lines to the substation and the interconnection into the existing transmission network. All necessary access roads and siting improvements are also accounted for in the balance of system cost.

Although not included in the preliminary layout of the windfarm, all O&M facilities and collector substation considered in the capital cost estimate. Once the wind farm has acquired an approved interconnection location, the substation and facilities will be efficiently designed and located in the wind farm layout.

Land leasing was also included as a cost for the initial construction phase of the project. This value was increased for the first year of the project in order to account for the necessary equipment staging areas that may be needed.

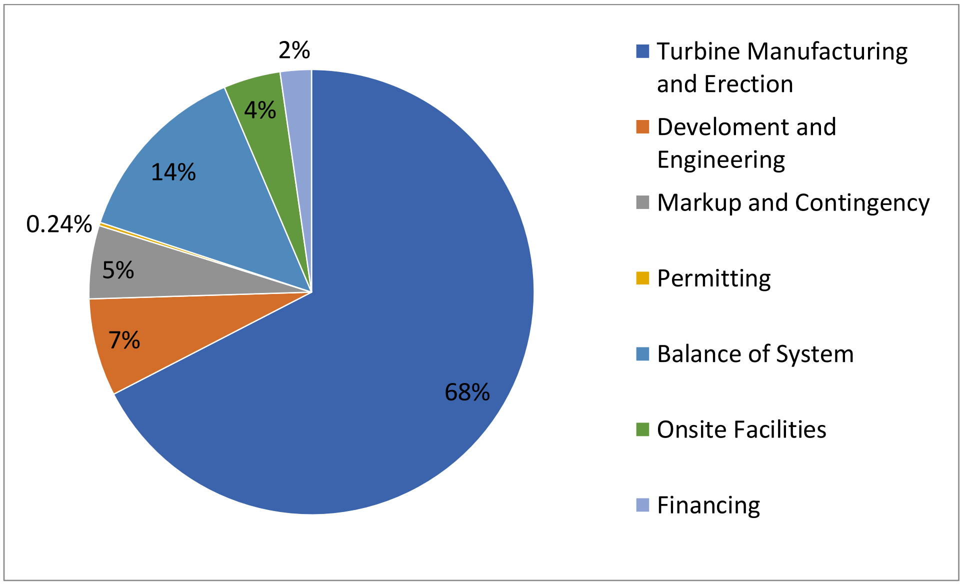

Figure 3. Initial Capital Cost Breakdown

Once the initial capital cost was estimated, the total annual operating expenses per year were estimated to be approximately $4.2 million per year. This cost includes all maintenance, daily operation, and land leasing costs. The land leasing cost was estimated on an energy production basis. The leasing cost will be $4,000 per MW annually which will amount to a total of approximately $350,000 per year [19]. This leasing payment will be split among the land owners of the property dependent on the number of turbines constructed on each plot. The operation and maintenance annual cost was also based on the wind farm capacity at a fixed rate of $44,000 per MW. These costs will be an annual expense for the entire lifespan of the wind farm. As the lifespan of the project continues, the turbines will begin to degrade which may gradually increase the total maintenance costs for the wind farm.

For both the Initial Capital Cost and Annual Expense estimates, all federal and state taxes were considered for all revenue and costs. A federal income tax rate of 21% was used for the lifespan of the project. A state income tax of 4.5% and a sales tax rate of 4% for the state of Colorado were used. An insurance rate of 0.5% was accounted for in all annual costs. Over the lifespan of the windfarm, an annual inflation rate was determined to be 2.3%. This will affect both the cost and revenue of the wind farm as the lifespan of the windfarm increases. Refer to Figure 4 for a breakdown of all capital and annual costs for the wind farm.

WIND FARM COMPONENT	CAPITAL COST
TURBINE CAPITAL COST	
Turbine Manfucturing	$ 89,170,200.00
Turbine Transportation	$ 1,044,897
Foundations	$ 3,575,893
Erection	$ 5,576,192
DEVELOPMENT AND ENGINEERING	
Engineering	$ 367,034
Site Development	$ 5,000,000
Project Management	$ 3,431,342
Met Mast Power Performance	$ 1,654,000
MARKUP AND CONTINGENCY	$ 7,844,586
INSURANCE BONDS AND PERMITS	$ 349,924
BALANCE OF SYSTEM	
Site Compund and Security	$ 884,667
Access Road and Site Improvements	$ 2,594,929
Transmission Interconnection	$ 5,240,436
Electrical Materials	$ 3,897,333
Electrical Installation	$ 7,317,795
ONSITE FACILITIES	
Collector Substation	$ 5,292,296
O& M Facilities	$ 801,125
FINANCING	
Acquire Financing Cost	$ 500,000
Construction Period Debt Interest	$ 2,836,662
LAND LEASING	$ 400,000
TOTAL CAPITAL COST	**$ 147,779,311**
ANNUAL OPERATING COSTS	
Land Leasing Cost	$ 352,800.00
Operations and Maintenance	$ 3,880,800.00
TOTAL ANNUAL COST	**$ 4,233,600.00**

Table 2. Capital and Annual Cost by Component

FINANCIAL ANALYSIS

A financial analysis was performed on the proposed wind farm to determine the feasibility of funding an 88.2 MW wind farm in this location. NREL's System Advisory Model was used to analyze this renewable energy project and consider all expenses and help develop a payment structure.

There are multiple federal incentives that are offered for wind energy generation projects in the United States. The Production Tax Credit (PTC) is a federal incentive that acts as a tax deduction for the production of wind energy. Although the federal government is no longer offering the PTC at its full value ($0.24 per kWh), the credit is still being offered at a reduced rate of $.096 per kWh. This tax incentive was used on this project and will be active for the first 10 years of the wind farm's lifespan and will have an escalation rate of 2.5% per year [21].

In order to finance the capital cost of the wind farm, a Power Purchase Agreement (PPA) will be proposed to Colorado Springs Utilities. The PPA is an agreement between an energy generator and an energy distributor which defines the terms for energy production and sale [18]. Once the PPA is agreed upon with an acceptable levelized cost of energy (LCOE), the developer can look to finance the project through equity and construction loans.

After accounting for all losses that affect the wind farm including, internal wake, environmental, and turbine performance losses, the net annual energy produced in Year 1 will be 339 GWh. The wind farm operates with a capacity factor of 43.8%. Using the factored annual energy production of the wind farm, an LCOE was determined to be $0.0618 per kWh with Colorado Springs Utilities. This LCOE should be acceptable for the PPA as it is less than the current cost of energy for residents in the city ($0.0777 per kWh). The project will be financed by both a tax equity investor and through construction loans. The construction loan will cover 63% of the initial capital cost with an interest rate of 4%. The construction loan for the project was estimated to be $94 million and would cover most of the construction and development costs. The sponsor equity will then cover 37% of the capital cost which comes to a total of $55 million. The construction loan will be paid off annually at the start of the project to avoid the buildup of interest. With revenue coming from the PPA each year, the construction debt will be paid off over the 20-year lifespan of the project. Annual operation cost will be taken from the revenue each year. After all federal, state, and property taxes are applied to the revenue, the remaining returns will pay off the sponsor equity. After 20-years, the sponsor will see an Internal Rate of Return (IRR) of 12.0% and a Net Present Value of $13.3 million. Refer to Figure 4. for after-tax cash flow diagram.

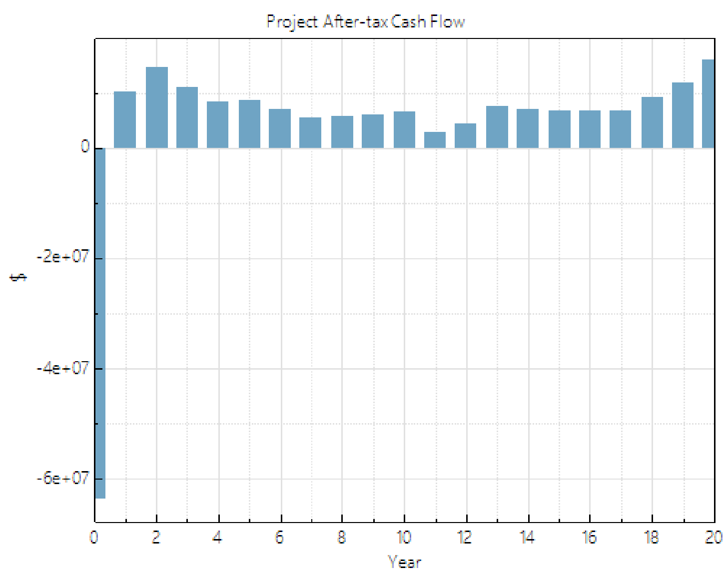

Figure 4. Wind Farm After-tax Cash Flow Diagram

CONCLUSION

The continuing increase of wind energy production in Colorado provides a great market opportunity to develop wind farms. This wind farm will provide the city of Colorado Springs with a financially feasible renewable energy source to replace the coal power plants used in the past that negatively affect the environment. This preliminary wind farm design is a viable way to generate green energy while also producing sustainable revenue for all investors involved. With an IRR of 12% and a Net Present Value of $13.5 million dollars after the 20-year project lifespan, the development of a wind farm for Colorado Springs can be a strong investment opportunity.

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