Fall 2022 Capstone Project
Progress Report 1

Staying Ahead of Renewable Energy Curve
And
Analysis on Reusable Blades

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Table of Contents

Chapter 1. Introduction

New York State has committed to taking action through comprehensive legislation to beat "Climate Change" which is a grave challenge to our green planet. Putting these thoughts into action in 2019, the historic Climate Leadership and Community Protection Act ([Climate Act]) was signed into law, which required the State to achieve a 100% carbon-free electricity system by 2040 and to reduce greenhouse gas emissions below 1990 levels by 85% until 2050.
This would be possible by establishing a new standard for states and the nation to expedite the transition to a clean energy economy.

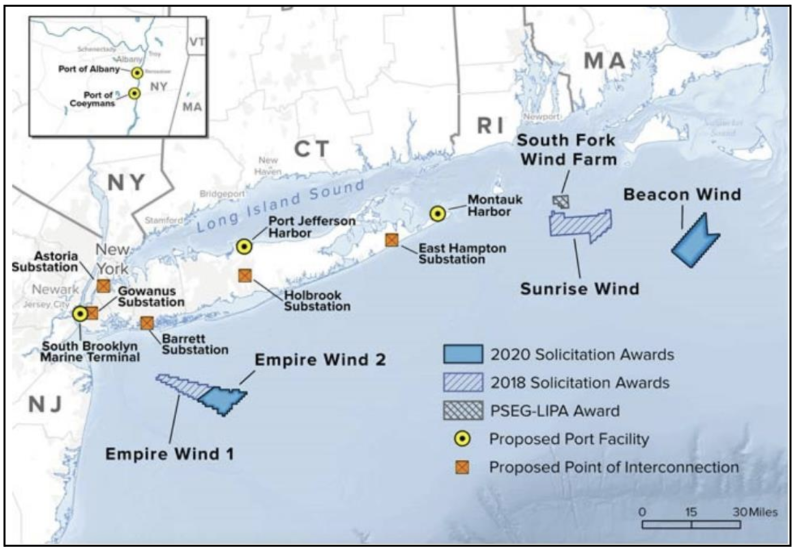


Figure *: NY State Offshore windmills planning and management mapping blueprint*

The law mandates that at least 70% of New York's electricity come from renewable energy sources by 2030 and calls for the development of 9,000 megawatts of offshore wind energy by 2035.

Re-use of Wind Turbine Blade Research, NYC Town+Gown

Wind turbine blades are mainly composed of fiberglass, epoxy resin, balsa wood, and a handful of metals. Because of their composite structure and the high proportion of glass fiber reinforced polymer or carbon fiber reinforced polymer, the blades are among the most difficult components to reintegrate into material circularity. Therefore, our project is a proactive approach to finding more sustainable end-of-life alternatives compared to landfill and incineration. More specifically, we will focus on repurposing the blades.

1.1. Project Scope and Goal

The project scope has two main pieces:

1) Identify turbine blade reuse options, while minimizing GHG emissions
2) Develop a dynamic reporting dashboard for stakeholders

Identify turbine blade reuse options

NYC Town+Gown has identified several locations that want to reuse wind turbine blades to improve their own facilities. While our direct stakeholder will be NYC Town+Gown, we will indirectly drive impact for the following by allocating retired turbine blades:

1) Public Parks
2) Modern Art Enthusiasts
3) Port Authorities
4) Fiberglass Manufacturers

The weight of the blade is required to estimate the GHG emissions involved with transporting blades from project sites to stakeholders. It is difficult to find such data as no contractor makes it publicly available, so we will approximate the weight with models developed by other research papers.

Develop a dynamic reporting dashboard for stakeholders

The dynamic dashboard will be developed in the second phase of our project. The dashboard, as suggested by NYC Town+Gown, would be used to report results descriptively and concisely.

We would focus on using data descriptive analysis to develop this dashboard, utilizing various visualization techniques to track greenhouse emission used for transportation of the decommissioned blades.

We will also develop heat maps, the primary data visualization technique to indicate the highly active greenhouse emitting regions in New York State and with their severity levels. As a result,we can identify the common areas that would be suitable for the stakeholders to focus on. Some potential uses for these wind blades can be recreational art pieces, benches, or small bridges in local parks.

Chapter 2. Data Collection

Sources

- Large-scale_Renewable_Projects_Reported_by_NYSERDA__Beginning_2004:
  Large-scale Renewable Projects Reported by NYSERDA: Beginning 2004
- USGS_data:
  United States Wind Turbine Database

2.1. About the Dataset

Large-scale_Renewable_Projects_Reported_by_NYSERDA__Beginning_2004

The dataset gives us all the existing and future wind farms in NY state starting in 2004 provided by New York State Energy Research and Development Authority (NYSERDA). The dataset has a well-defined structure with 33 columns and 228 rows. The dataset includes project names, geographic locations, different types of electricity quantity and capacity, contract duration, project status, year of delivery start date, etc. Our goal is to predict the decommission time of windmills with this dataset.

USGS_data

The dataset provides us with the location, project characteristics, and turbine characteristics of existing wind farms in the United States obtained directly from organizations, project developers and turbine manufacturers. The dataset has a well-defined structure with 27 columns and 72,357 rows. The dataset includes turbine manufacturer, turbine model, turbine capacity, etc. Our goal is to approximate greenhouse gas emissions to find the best repurposing location with low greenhouse gas emissions for transporting the blades with this dataset.

2.2. Data Dictionary

Large-scale_Renewable_Projects_Reported_by_NYSERDA__Beginning_2004

Project Name	Renewable Technology	Project Status	Year of Delivery Start Date	Contract Duration	New Renewable Capacity (MW)	Bid Capacity (MW)	Bid Quantity (MWh)	Max Annual Contract Quantity (MWh)	Georeference
Heritage Wind, LLC	Land Based Wind	Under Development	2023.0	20	147.0	147.0	393100.0	471720.0	POINT (-78.208094 43.232126)

Column Name	Description	Data Type	Missing Value
Renewable Technology	The type of renewable energy technology for the project	String	0
Project Status	The phase the project is in as of the Data Through Date	String	0

Year of Delivery Start Date	Date NYSERDA's payments started or are expected to start	Float	15
Contract Duration	Number of years of performance under the Agreement	Integer	0
Georeference	Open Data/Socrata-generated geocoding information based on supplied address components	Point	7

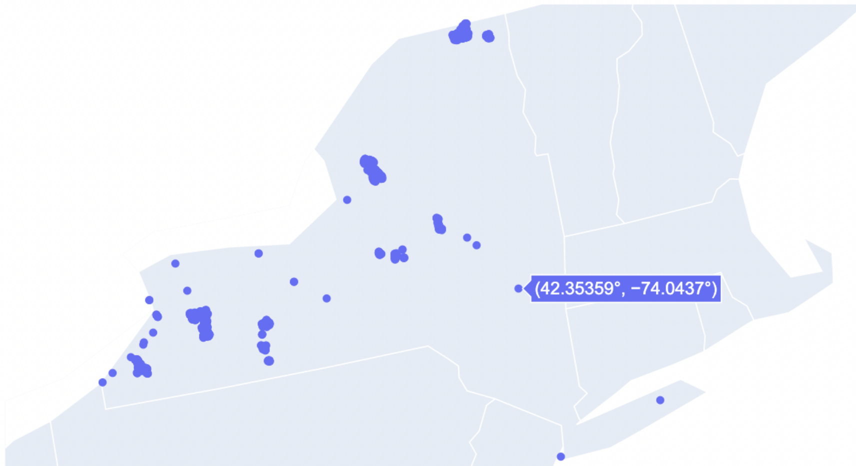
We are only concerned about Renewable Technology with Land Based Wind and Offshore Wind. We assume that the decommissioned year for turbine blades is the addition of the year of delivery start date and contract duration confirmed by NYSERDA. Therefore, we create a new column called decommission time, which is the combination of the column year of delivery start date and the column contract duration.

USGS_data

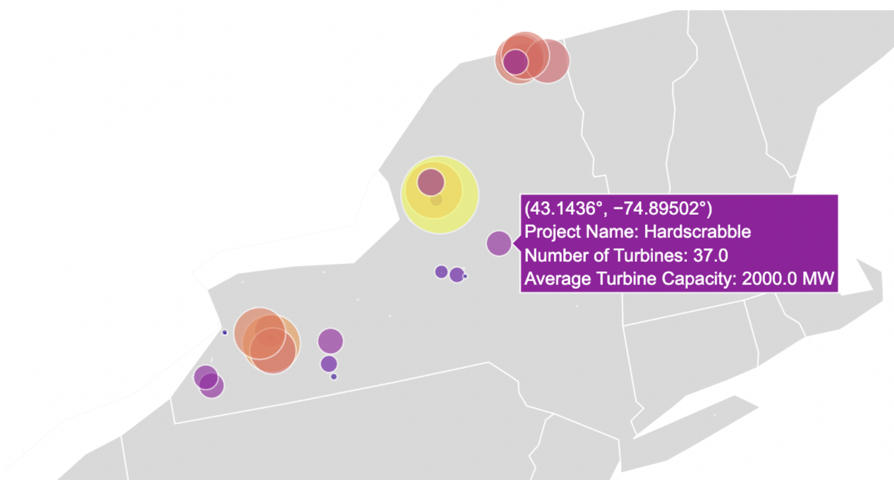
case_id	t_state	t_county	p_name	p_year	p_tnum	p_cap	t_manu	t_model	t_cap	t_hh	t_rd	t_rsa	t_ttlh	xlong	ylat
3075458	NY	Chautauqua County	Arkwright Summit	2018.0	36	78.4	Vestas	V110-2.0	2200.0	95.0	110.0	9503.3	150.0	-79.2097	42.382

Column Name	Description	Data Type	Non-missing Value
case_id	Unique uswtdb id	Long	72357
t_state	State where turbine is located	String	72357
t_county	County where turbine is located	String	72357
p_name	Project name	String	72357
p_year	Year project became operational	Integer	71790
p_tnum	Number of turbines in project	Integer	72357
p_cap	Project capacity (MW)	Double	69270
t_manu	Turbine original equipment manufacturer	String	68111
t_model	Turbine model	String	67974
t_cap	Turbine capacity (kW)	Integer	68282
t_hh	Turbine hub height (meters)	Double	67785
t_rd	Turbine rotor diameter (meters)	Double	67844
t_rsa	Turbine rotor swept area (meters^2)	Double	67844
t_ttlh	Turbine total height - calculated (meters)	Double	67785
xlong	Longitude (decimal degrees - NAD 83 datum)	Double	72357
ylat	Latitude (decimal degrees - NAD 83 datum)	Double	72357

We are only concerned about turbine blades located in New York State.



New York Wind Turbine Locations



New York Wind Turbine Projects

Chapter 3. Modeling Approach

3.1 Estimating Blade Weight

The first goal of this project is to emphasize the amount of potential waste from turbine blades in New York if all of them are landfilled. It is important that stakeholders do not procrastinate to research other end-of-life alternatives for wind turbine blades, which could be more environmentally sustainable.

The weight and the decommissioned year of turbine blades are the two key elements in achieving this goal. Unfortunately, blade weights are neither directly available in current datasets nor publicly shared by most manufacturers. Therefore, the next step is to find reasonable ways to approximate the blade weight.

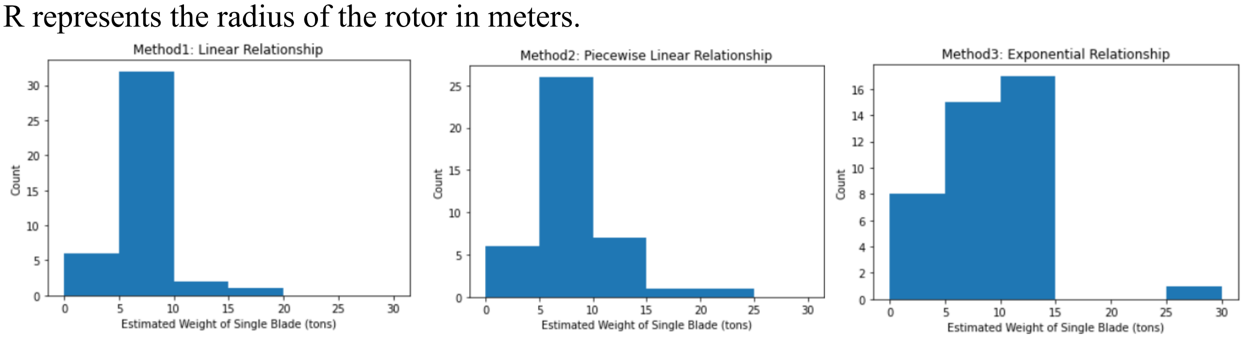
One study focuses on an integrated geospatial approach for repurposing wind turbine blades in Ireland. The authors investigate the relationship between blade weights as a function of blade length, rotor diameter, and rated power for Irish wind farms. They discover a linear relationship between the blade mass per turbine and rated power of a turbine to be the strongest statistical relationship, with R^2 of 0.95. More specifically, blade mass per turbine in tonnes = 10.33 * rated power of the turbine.

Turbine Rated Capacity (MW)	Unit Blade Mass Per Turbine (tons/MW)
≤ 1	8.43
1 - 1.5	12.37
1.5 – 2	13.34
2 – 5	13.41
≥ 5	12.58

Table.1. Total blade mass in tons per megawatt of rated capacity

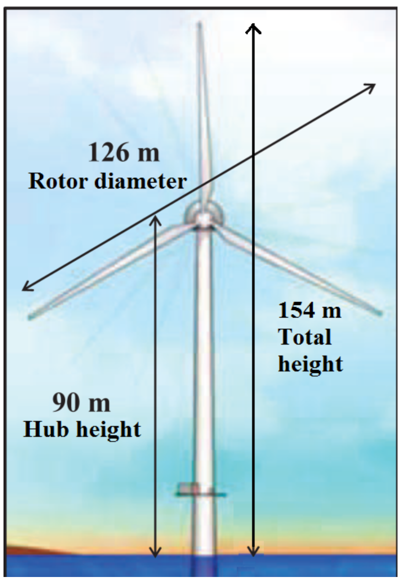
Another study, which looks at wind turbine blade waste in 2050 around the globe, verifies an average ratio of 10 between blade mass per turbine and rated power. More precisely, the authors segment turbine rated power into five classes. Table 1 shows each class and its corresponding blade mass (tons) per megawatt of rated capacity.

The last study, which focuses on wind turbine design cost and scaling model, gives us another reasonable approximation for blade weight. The authors discuss an exponential relationship between turbine rotor radius and blade mass. More specifically, for rotors that are less than 100 meters in diameter, mass per blade (kg) = $0.1452\, R^{2.9158}$; for rotors that are larger or equal to 100 meters in diameter, mass per blade in (kg) = $0.4948\, R^{2.53}$. In both cases, R represents the radius of the rotor in meters.



The histograms depict the distributions of New York State turbine blade weight estimates with the three different methods mentioned in the previous studies. The distribution of method 1 and 2 are quite similar since both assume a linear relationship between total blade mass per turbine and turbine rated capacity. However, method 3 gives a relatively high estimate of blade mass, with an average estimate of 8.53 tons per blade, compared to an average estimate of 7.67 tons from method 2 and 6.11 tons from method 1. Before receiving further feedback from our client and relevant industry people about the weight estimates, we will proceed by averaging the blade estimates from three methods.

3.2 Estimating Transport Emissions



Our primary goal is to find the optimal reuse location for decommissioned windmill blades. Reusing the turbine blades is beneficial only when the environmental cost is cheaper than the cost associated with landfilling the turbine. Given the size of turbine blades, most of the environmental cost will be primarily due to transportation requirements. Thus, our goal for this section will be to model the greenhouse gas (GHG) emissions to transport a windmill from its origin to a potential destination.

We assume that any relevant origin and destination can be expressed in terms of latitude and longitude. Finding the travel distance between two locations is not a novel problem; several commercial and open source solutions already exist. Initially, we attempted to use open street maps, however, there were several issues. To keep our work self-contained, we attempted to download the relevant New York state data. Unfortunately, loading the data into Python led to memory issues. Thus, the next best option was to make REST API calls, so we only process the relevant data in each run. Open Street Maps gives free keys; however, when we share the code online, we would not want to share private API keys. Thus, we moved to another solution: Open Source Routing Machine (OSRM). This allows us to make API calls without using a private key. Using OSRM, we can estimate travel distance and driving time.

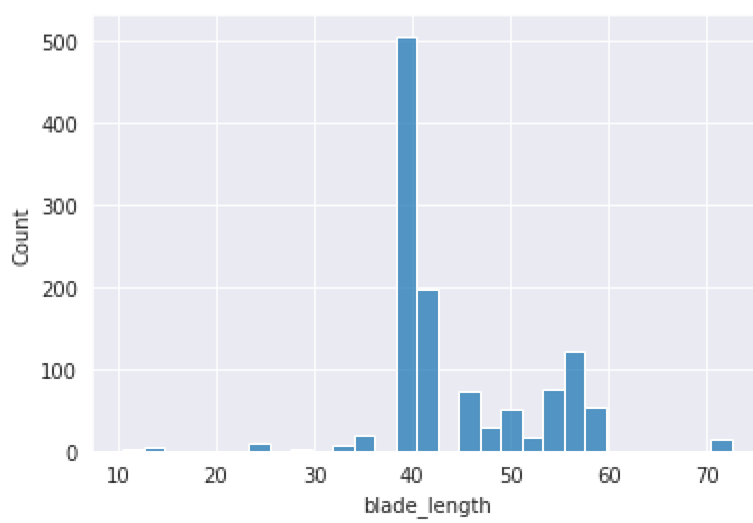


Figure X

Next, we must consider the size and weights of the turbine blades. **In the previous section, we have already highlighted methods to estimate blade weights.** Regarding blade size, the USGS dataset does not include any information about rotor length. However, we do have rotor diameter, hub height, and total height. Given these measurements, we can try to approximate turbine length in two ways. First, we can argue that the turbine length is half the rotor diameter as seen in **Figure X.** Another valid option would be to subtract the hub height from the windmill total height. After experimenting with both methods, we found that the difference between the two were negligible. Ultimately, we chose the first method because it is slightly more intuitive than the latter.

After calculating the blade lengths, we analyzed the distribution and found it had a mean of **44.135**, with a significant number of blades being over 50 meters long. For the sake of the project, we can assume that the turbine blades will be cut when they are taken off the windmill on-site. As per a meeting with NYSERDA representatives, this is a fair assumption. It follows that we may need three to five flatbeds for transport. So, when calculating the emissions, we will have to consider one truck and then multiply by the number of necessary flatbeds.

		count	mean_length	var_length
t_manu	t_model			
GE Wind	GE1.5-77	506	38.500000	0.000000
Vestas	V82-1.65	194	41.000000	0.000000
	V110-2.0	76	55.000000	0.000000
	V112-3.075	70	56.000000	0.000000
GE Wind	GE1.62-100	52	50.000000	0.000000
Gamesa	G90-2.0	37	45.000000	0.000000
	G114-2.1	37	57.000000	0.000000
Clipper	C96	29	48.000000	0.000000
REpower	MM92	27	46.240741	0.002315
Nordex	N117/3675	27	58.500000	0.000000
GE Wind	GE2.5-116	27	58.000000	0.000000
	GE1.5-70.5	19	35.250000	0.000000
	GE1.62-103	16	51.500000	0.000000
Siemens Gamesa Renewable Energy	SG-2.625-114	15	57.000000	0.000000
	SG-4.5-145	15	72.500000	0.000000
Vestas	V47-0.66	10	23.500000	0.000000
Clipper	C93	8	46.500000	0.000000
Vestas	V66-1.65	7	33.000000	0.000000
Vergnet	GEV MP-R	4	14.500000	0.000000
Hyundai	HQ1650	2	41.000000	0.000000
Gamesa	G58-0.85	1	29.000000	NaN
Goldwind	GW82	1	41.000000	NaN
Northern Power Systems	NPS-100	1	10.500000	NaN
	NW100	1	10.500000	NaN
Vensys	Vensys82	1	41.150000	NaN
Fuhrlander	FL250	1	14.500000	NaN

Given all these details, we are finally ready to calculate GHG emissions using the emissions factor of a flatbed. The formula to calculate GHG emissions = *Distance * Weight * Emissions Factor.*

We have the distance from the windmill origin to its destination, calculated using ORSM API calls. Additionally, we have already estimated the weight of the blades in 4.1. The emissions factor for the flatbed is 1800. To decide how many flatbeds are necessary, we divide the blade length by the size of a flatbed, then multiply that by the number of windmill blades for transport. Inputting these variables into the above equation, we are able to estimate the GHG emissions.

Chapter 4. Conclusion and Next Steps

At the time of writing, we have a solid baseline model for predicting GHG emissions from turbine blade transport.

The next step will be to create a dataset of material recovery facilities as well as reuse locations in New York state. Once the dataset has been created, we can develop an algorithm that returns the optimal reuse location. Additionally, we will identify a geospatial boundary for each wind farm where the turbine can be sent and still have less carbon footprint than the landfilling the blade.

With these algorithms prepared, the final steps will be to create a one-stop-shop dashboard for presenting our results. Ideally, NYC Town+Gown will be able to select a specific wind turbine that is being retired or decommissioned, and our dashboard will return the optimal reuse location as well as the amount of emissions prevented.

References (links used to prepare the report)

- URR 7 Recording: New Frontier for Construction Materials
- Material Composition of Wind Turbines
- Environmental Analysis of End-of-Life Alternatives for Wind Turbine Blades
- An Integrated Geospatial Approach for Repurposing Wind Turbine Blades
- New York State Energy Research and Development Authority
- NYSERDA: Offshore Wind
- Construction Begins on New York's First Offshore Wind Farm
- An integrated geospatial approach for repurposing wind turbine blades
- Wind Turbine Blade Material in the United States: 2 Quantities, Costs, and End-of-Life Options
- Wind turbine blade waste in 2050