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Transitioning Connecticut to 100% Clean Wind, Water, and Sunlight (WWS) Energy

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Abstract: Three important issues facing humanity are global warming, air pollution, and finite fossil fuels. Scientists suggest they can be solved by replacing fossil fuel-generated energy with renewable energy. This paper focuses on methods of transferring Connecticut from using fossil fuels to 100% Wind, Water, and Sunlight (WWS) energy based on energy output during 2021. The study will calculate the total energy consumption in Connecticut for residential, commercial, industrial, and transportation sectors based on 2021 data (A total of 61,658 gigawatts hour and 53,733 gigawatts hour needed to be produced from new installations). It will then present a proposal for establishing WWS infrastructure in the state, including the nameplate capacity for rooftop PVs (9.685 GW), utility PVs (9.638 GW), onshore wind turbines (8.945 GW), and offshore wind turbines (4.645 GW). The estimated costs in terms of money are (71,782,612,500 dollars). Connecticut also needs 50.7 square kilometers for rooftop PVs and 117.8 square kilometers for utility PV installations. In the end, the paper analyzes the limitations of the current 100% renewable energy proposal with possible improvements and estimation of prospects of renewable energy in Connecticut.

Key words: Wind, Water, and Sunlight (WWS) energy, Connecticut, Energy Consumption

1. Introduction

Traditional energy sources, fossil fuels, have long been the bedrock of the global economy, providing the fundamental energy for industrialization in the United States and all other countries. However, in recent years, the United States has undertaken a momentous transition to renewable energy alternatives, namely Wind, Water, and Sunlight (WWS). The reliance on industry has been shifting from fossil fuels to renewable energy. Since 2001, the total renewable electricity consumption in the United States has increased from approximately 1,512 GWh/y (gigawatt-hours per year) in 2001 to 3,530 GWh/y in 2021 [1]. Thus, energy consumption doubled within twenty years.

Not only has electricity consumption shifted toward renewable sources, but so has job creation. The renewable energy sector has become a vibrant hub for jobs, attracting investments and fostering innovation. There was a 3.9 percent increase in clean-energy jobs from 2021 to 2022 [2]. Typical jobs within this sector include wind turbine technician, solar photovoltaic (PV) installer, hydroelectric plant technician, and renewable energy engineer.

It is essential to understand the severe concerns that are causing the United States to initiate this transition. One notable concern is the significant contribution to climate change through the release of greenhouse gases during combustion. All ten warmest years on record took place after 2010 [3]. Another concern is that burning fossil fuels releases harmful substances like sulfur dioxide and nitrogen oxides. These lead to air pollution, which causes respiratory diseases. New research from Harvard University found that 1 in 5 death is caused by fossil fuel pollution in 2018 [4]. Additionally, the depletion of finite fossil fuels raises concerns about energy security and potential geopolitical conflicts over access to limited resources. For instance, the price of oil in the United States increases from 80 dollars per barrel on Jan. 24, 2022, to 120 dollars per barrel on March 7, 2022, when the war between Russia and Ukraine starts on Feb. 24, 2022 [5]. The data strongly indicate a direct influence of the war influencing US oil prices.

All these limitations of tradition energy source suggest the installation of technologies that convert energy from the Wind, the Water, and the Sun (WWS) to electricity and using electric appliances and machines instead of combustion ones, to address air pollution health and climate. Wind-water-solar based energy does not generate greenhouse gases or chemicals that cause this issue. Furthermore, the process of transforming from wind-water-solar to electricity is more efficient compared with using fossil fuels to provide electricity. The fundamental methodology of fossil fuel-based power plant is to generate steam that moves the turbine that creates electricity. However, when fossil fuels boils water, more than 60% of energy is lost in this conversion [6]. In a fossil fuel-based power plant, electricity is generated through a process that involves converting the chemical energy into mechanical energy, and then further into electrical energy; Whereas in wind and water-based electricity generation, mechanical energy directly transforms into electrical energy; Solar energy transform directly into electrical energy in solar panels.

Thus, this paper's goal is to propose two roadmaps for 100% renewable energy in Connecticut for all energy purposes. It will consider the total energy consumption in Connecticut in 2021 from the residential, commercial, industrial, and transportation sectors. By using these data, we can calculate the number of rooftop solar panels, utility solar panels, onshore wind turbines, and offshore wind turbines that are needed for Connecticut. Current output of hydroelectric dams will be considered, but additional hydroelectric dams will not be included in the calculation, as new dams are not likely to be established in Connecticut, which is a limited water region. Knowing the amount required, the paper proposes ideal sites to establish solar panels and wind turbines. Two plans, with different types of solar panels and wind turbines, will be compared. The paper will conclude with a discussion of limitation of the study and barriers that need to be overcome in transitioning Connecticut to a 100% renewable energy.

2. Energy Consumption in Connecticut

The primary methodology in this paper is to calculate the total consumption of energy needed in Connecticut for all purposes, then convert that energy to electricity that will be provided by WWS. However, we cannot directly use the data from total consumption section in U.S. Energy Information Administration (EIA) website (this paper primary uses data from that website). The reason is that, when the fuel (coal, distillate fuel oil, hydrogen gas liquid, jet fuel, motor gasoline, petroleum, electricity, natural gas, wood and waste and biofuel) is transformed to electricity or to give power, a percentage of the energy transformation will be wasted. Depending on the usage of the fuel type, the percentage changes. Therefore, we classify the usage into four sectors (industrial, commercial, residential, and transportation). After I assume the usage of each fuel in each sector is for a single purpose, I subtract the fuel waste for that purpose, therefore converting the original total consumption data in that sector to the real energy required for electricity generated by WWS.

2.1. Residential sector

In Connecticut, energy consumption in the residential sector largely depends on hydrocarbon gas liquid, petroleum, electricity, natural gas, wood, and waste. Among these fuels, all of hydrocarbon gas liquid, petroleum, a part of electricity, all wood, all waste, and most natural gas are used for heating. The rest of the electricity is used for lighting, powering household appliance, and charging electric vehicles (EV). Natural gas is also used for cooking.

Calculations in this section involve multiplying the consumption of the fuels in the residential sector (Table 1) by a factor to obtain end-use WWS energy needed (Table 2). Adding up the individual energy sources after conversion results in the total energy needed in the residential sector, which is 17,853 gigawatts hours per year.

2.2. Commercial sector

The commercial sector shares similar appliances and energy use with the residential. Common energy sources include Heating, Ventilation, and Air Conditioning (HVAC). Among HVAC, heating largely depends on natural gas in Connecticut. In many schools, for instance, heating radiators are the primary heating appliance used during winter. Other energy consumers include office equipment; elevators; lighting for restaurants, shopping malls, and businesses that depend on electricity. According to the EIA, only electricity and natural gas are used in the commercial sector in Connecticut [7].

Calculations in this section involve multiplying the total energy consumption in the commercial sector (Table 1) by the factors for commercial sector end-use energy from Table 2. The total energy needed for the commercial sector after conversion is 15,626 gigawatts hours per year.

Table 1. Energy end-use consumption (GWh/y) based on fuel type in each sector during 2021 for Connecticut before conversion to WWS

Sector	Distillate Fuel Oil	Hydrocarbon Gas Liquid	Jet Fuel	Motor Gasoline	Residual Fuel	Petroleum	Electricity	Natural Gas	Wood and Waste	Biofuel
Residential	0	4,958	0	0	0	2,516	13,092	14,617	1,718	0
Commercial	0	0	0	0	0	0	12,388	16,190	0	0
Transportation	30,136	0	2,522	52,540	163	0	0	0	0	889
Industrial	0	0	0	0	0	0	2,799	6,609	1,718	0

The table shown the energy consumption for different fuel type in Connecticut during 2021. Not all fuel types are included in the table. Wind, geothermal, hydropower, solar, coal and nuclear are not included because these fuels are included in the energy consumption for electricity. Wood and waste in the table are not originally separated by EIA's data. The original total energy for wood and waste is 6,870 gigawatts hours. This paper assumes 25 percent of the consumption of wood and waste belongs to the residential sector, where it is used for heating; Another 25 percent is allocated to the industrial sector for melting and heating metals; The remaining 50 percent belongs in the electricity sector. Therefore, wood and waste that is used for electricity is not included [7].

Table 2. Factors to multiply BAU end-use energy by to obtain WWS energy needed

Fuel type	Residential	Industrial	Transportation	Commercial
Oil	0.2	0.82	0.19 or 0.36	0.2
Natural gas	0.2	0.82	0.19 or 0.36	0.2
Biofuels/ Waste	0.2	0.82	0.19	0.2
Electricity	1	1	1	1

When fuel transforms to the desired application, some of the energy is lost. The factors in this table are multiplied by the end-use business-as-usual energy in Table 1 to obtain the WWS electricity needed in Table 3. For electricity, the factor is 1, since electricity will directly be used for power, and no loss occurs. For transportation, two factors are included, depending on which type of battery is used. The factor 0.36 is used for hydrogen fuel cell vehicles, often abbreviated as HFCVs, which use hydrogen gas as a fuel source to generate electricity through a chemical reaction within a fuel cell. HFCVs are less efficient than traditional Battery Electric Vehicles (BEVs), but HFCVs emit only water vapor as a byproduct, making them a potential solution for reducing greenhouse gas emissions and air pollution from transportation along with BEVs [8].

Table 3. Consumption of energy (GWh/y) based on fuel type in each sector during 2021 for Connecticut before conversion

Sector	Distillate Fuel Oil	Hydrocarbon Gas Liquid	Jet Fuel	Motor Gasoline	Residual Fuel	Petroleum (Other)	Electricity	Natural Gas	Wood and Waste	Biofuel
Residential	0	992	0	0	0	503	13,092	2,923	344	0
Commercial	0	0	0	0	0	0	12,388	3,238		0
Transportation	7,434	0	908	9,983	59	0	0	0	0	169
Industrial	0	0	0	0	0	0	2,799	5,420	1,408	0

Table 3 shows the end-use electricity needed to be provided by WWS after today's end-use energy consumptions in Connecticut (Table 1) is multiplied by each factor for the appropriate sector and fuel type in Table 2. For instance, hydrocarbon gas liquid is used in the residential sector, and its consumption has been multiplied by 0.2. Something to notice is the different calculation in the transportation sector. Depending on the transportation mode (BEVs or HFCVs) fuel supports, the factor changes (either 0.19 or 0.36). On one hand, jet fuel and residual fuel are assumed to be converted to HFCVs. Thus, 0.36 is used in those cases. On the other hand, energy produced by motor gasoline and biofuel is multiplied with 0.19, as vehicles using those fuels are assumed to be converted to BEVs. However, since some short distance public buses (HFCVs) and long-distance public buses (BEVs) both use distillate fuel oil, 33 percent is assumed to be converted to HFCVs, while the rest, to BEVs. The actual calculation is 3,616 gigawatts hours plus 3,817 gigawatts hours [7].

2.3. Industrial sector

Popular industry in Connecticut includes healthcare, manufacturing, food and beverage production, and software development. Three fuels have been used in this sector: electricity, natural gas, wood, and waste. Specifically, natural gas, wood and waste are used more often in heating, chemical prosses, and melting metals. Electricity is used for general lighting and appliances

Total energy needed for the industrial sector is calculated by multiplying the factors for industrial sector end-use energy (Table 2) by total energy consumption in the industrial sector (Table 1). The total energy needed for industrial sector after conversion results is 9,627 gigawatts hours per year.

2.4. Transportation sector

Five fuels are used in transportation sector – distillate fuel oil, jet fuel, motor gasoline, residual fuel, and biofuel. Distillate fuel oil is used for both long distance and short distance public transportations; Jet fuel is used for airplanes; motor gasoline is used for motorcycles, trucks, passenger vehicles, and boats; residual fuel is used mainly for marine vessels; biofuel is used mostly for ethanol passenger vehicles.

Total energy needed for the transportation sector is calculated by multiplying the factors for industrial sector end-use energy (Table 2) by total energy consumption for the transportation sector (Table 1). The total energy needed for commercial sector after conversion results in 18,552 gigawatts hours per year.

2.5. Total energy needed for WWS transition calculation

The calculation for total energy needed for WWS does not include only adding up energy consumption in the four sectors, which is 61,658 gigawatt hours per year. We must also consider the existing renewable energy production in Connecticut. Since the paper focuses on proposing plans to establish new WWS based electricity generation, existing renewable energy production (Table 4) must be subtracted from the total energy consumption for the four sectors (Existing geothermal, solar, wind, and hydropower-based electricity production). According to this calculation, the final total energy needed for WWS transition is 53,733 gigawatts hours per year.

Table 4. Renewable energy (GWh/y) already used for generating electricity in Connecticut during 2021

Sector	Geothermal	Hydropower	Solar	Wind	Wood and Waste
Electricity Produced	6	1,238	3,213	33	3,435

Solar Energy refers to electricity generated from photovoltaic solar panels; Wind energy refers to electricity generated from wind turbines; Hydroelectric Power utilize flowing water that spins turbines to generate electricity; Biomass Energy include electricity generated by burning organic materials like wood, agricultural residues, and waste to heat water to spin a turbine; Geothermal Energy refers to electricity generated from heat extracted from the Earth's interior. All renewable energy in this table is already included as a part of electricity. Therefore, values in this table are not needed in Tables 1 or 3. However, for calculating final energy needed to transform Connecticut to WWS, existing geothermal, hydropower, solar, and wind energy production must be subtracted from total consumption, and new WWS generators will be used to provide the difference in energy. Wood and Waste (produce carbon dioxide) is excluded, as this paper propose plan for clean, renewable energy [7].

3. Proposal 1: Wind, Solar, and Water Implementation

This section will be introducing the suitable sites for the establishment for new wind turbines and solar panels in Connecticut by analyzing how to maximize their efficiencies. Proposal 1 assumes the total energy needed for WWS transition (53,733 gigawatts hours per year) will be divided equally (25% for each) among offshore wind turbine, onshore wind turbine, utility Photovoltaics, and rooftop Photovoltaics. Each technology will need to produce 13,433 gigawatts hours per years to satisfy the demand.

3.1. Solar energy

To convert solar energy to electricity, we need photovoltaics, solar panels, which convert photons of light energy to electrical voltage. [8]. The central of the photovoltaics system is solar cells, which are composed of semiconductor material–silicon (Si). When sunlight hit the cells, it excited the electron in the material that generated an electrical current. This photovoltaic effect is a direct conversion of sunlight into electricity without the need for moving parts or fuel consumption.

Solar panels can be categorized into two types: utility photovoltaics and rooftop photovoltaics. On one hand, utility photovoltaics contains vast solar power installations designed to generate electricity on a larger scale. However, these utility-scale arrays make use of extensive land areas, strategically positioned to maximize sun exposure. On the other hand, rooftop photovoltaics produce less energy, but it takes less land area by placing solar panels on residential, commercial, and industrial rooftops. Furthermore, these installations empower individual consumers to acquire solar energy for their own needs, reducing dependence on traditional energy sources.

3.1.1. Rooftop Photovoltaics (PVs)

When choosing the location for the installation of rooftop PVs, two aspects must be considered. First, Rooftop Photovoltaics, as its name, is established on the rooftop. Therefore, cities will be the best for installation. Second, theoretically, the southern location for the installation of PVs, the more energy it produced. Nevertheless, Rooftop PVs might not be able to be established in a single city and produce a mass amount of energy, as there's a limited number of rooftops for installation. Three cities in Connecticut are proposed on the list, Hartford, New Haven, and Stamford.

Assuming each city has available rooftops for installation, the required energy (13,433 gigawatts hour per year) is distributed among the three cities based on their relative land size (Table 6). Then, according to Table 5, the module type that produces the largest CF value in each location is chosen as a sample. Using the CF value, we obtain the nameplate capacity for each city.

This paper uses the three cities only as a reference for calculation. Therefore, to prove it is feasible to establish rooftop PV in Connecticut and produce 25% of the consumption needed, another calculation need to Connecticut has enough rooftops for installations. Adding up all nameplate capacity which is the total nameplate capacity in Connecticut required to be produced, which is 9.685 GW. Diving the total nameplate capacity with how much energy is produced with each square kilometer for rooftop PVs (0.191 GW/ km^2), it results in 50.7 square kilometers needed for producing 9.685 GW [8]. The current area for potential installation of rooftop PV is 74.3 square kilometers (Only the area of the roof with enough space to install 4 adjacent solar panels are included) [11]. Thus, it is proved there's enough rooftops in Connecticut for installing rooftop PVs for producing 25 % of energy consumption.

$$\text{Energy Output per year} = N \times CF \times H \tag{1}$$

$$N = \text{Nameplate Capacity} \qquad CF = \text{Capacity Factor } H = \text{Hours per Year}$$

Table 5. Fixed (Roof Mount) comparison in different cities

Location	Lat, Lng	Modul Type	Tilt (deg)	Energy Output (kWh/Year)	CF Value
Hartford	41.77, −72.66	Standard	37	5,426	0.1549
New Haven	41.29, −72.94	Standard	35 or 36	5,462	0.1559
Stamford	41.05, −73.54	Standard	35 or 36	5,591	0.1596
Hartford	41.77, −72.66	Premium	37	5,422	0.1547
New Haven	41.29, −72.94	Premium	35 or 36	5,457	0.1557
Stamford	41.05, −73.54	Premium	35 or 36	5,575	0.1591
Hartford	41.77, −72.66	Thin Film	37	5.467	0.1560
New Haven	41.29, −72.94	Thin Film	35 or 36	5.502	0.1570
Stamford	41.05, −73.54	Thin Film	35 or 36	5.612	0.1602

Various factors may influence the production of electricity from solar energy. The southern the location (the closer to equator), the higher energy production; The tilt angle of the solar panel should be approximately the same as latitude. The tilt angles in the graph all maximized energy production in each location [9]. System loss is calculated based on values account for performance losses in a real system. The paper assumes a total of 10 % system loss –2% might loss due to soiling (dirt preventing solar radiation), 3 % due to shading, 2% due to manufacturing imperfection (causing current-voltage differentiation), 2% due to resistive losses in wires, and 1% due to required maintenance; The regular dc system size is 4 kW; the azimuth is 190 degrees. Based on these information, data for energy output is obtained from PVWatts Calculator [9]. The CF value is calculated using Eq. (1). We use energy output divided by DC system size (in kW, representing N) and 8670 (hours in a year, representing H).

Table 6. Land Area of new haven, Hartford, and Stamford

	New Haven	**Hartford**	**Stamford**
Land Area (Square Mile)	18.68	17.38	37.62
Ratio in Percentage	26	24	50
Required Energy Production (GWh/ y)	3,493	3,224	6,717
Capacity Factor	0.1570	0.1560	0.1602
Nameplate Capacity (GW)	2.539	2.359	4.787

Stamford has a total area of 52.09 square mile, but 37.62 square miles is land, and 14.41 square mile is water [10]; Ratio in percentage is calculated by the ratio from New Haven to Hartford to Stamford, which is approximately 10:9:19 and convert them to percentage; Required Energy production is calculated by percentage times energy required to produce 13,433 gigawatts per hours. Then, using Eq. (1), we divide energy production (GWh/y) in each city (Table 6) by CF value and 8670 (representing H), which is 2.539 GW (New Haven), 2.359 GW (Hartford), and 4.787 (Stamford).

3.1.2. Utility Photovoltaics (PVs)

Compared with rooftop PV, utility PV has more potential sites for installation, as it only requires flat land with no shade covering above. Therefore, to maximize the energy production, the southern area of Connecticut is chosen – Greenwich.

The CF value is first been calculated. It is found that premium module type works best for utility PV in Greenwich. The CF value (0.15910) for Premium module type in Greenwich is chosen. Dividing 13,433 GWh/y (energy output per year) by 0.15910 (CF) and 8,760 (hours per year) results in 9.638 GW (N) (from Eq. (1)).

For land usage, dividing the total nameplate capacity by the installed power density of utility PV (0.0818 GW/ km^2) results in 117.8 square kilometers needed for producing 9.638 GW [8].

Table 7. Fixed (Open Rack) comparison in different module type

Location	**Lat, Lng**	**Array Type**	**Module Type**	**Tilt (deg)**	**Energy Output (kWh/Year)**	**CF**
Greenwich	41.05, −73.63	Fixed (Open Rack)	Standard	31 or 32	5,544	0.15821
Greenwich	41.05, −73.63	Fixed (Open Rack)	Premium	31 or 32	5,575	0.15910
Greenwich	41.05, −73.63	Fixed (Open Rack)	Thin Film	31 or 32	5,555	0.15853

31 or 32 degrees for tilt produces the largest output energy [9]. The default calculation assumes the azimuth is 180 degrees; system losses is 10 % (reasons refers to Table 5); DC system size is 4 kW. CF value is calculated CF using Eq. (1). We use energy output divided by DC system size (in kW, representing N) and 8670 (hours in a year, representing H).

3.2. Wind energy

A wind turbine is a technology that transforms the kinetic energy of wind into clean, renewable electricity. As the wind flows over the blades, their aerodynamic design ensures optimal efficiency, causing the rotor to spin. This rotational motion is then converted into electrical power through a generator housed within the turbine's nacelle. The wind turbine is separated into two types based on their locations–onshore and offshore.

Onshore wind turbines are installed on land, typically in areas with strong wind patterns. One of the key advantages of onshore wind turbines is their relatively lower installation costs than offshore wind turbines. They are also generally easier to access for maintenance and repair, which can lead to reduced downtime. However, onshore wind turbines also have some limitations. They may face more variability in wind speed and turbulence due to factors like topography and obstacles on land. Additionally, there can be challenges in finding suitable locations for onshore wind farms without causing significant visual impacts in populated areas.

Offshore wind turbines are in bodies of water, such as oceans. These turbines are often positioned farther from shore in areas with strong and consistent offshore winds. Offshore wind farms have gained increasing attention due to their potential for being exposed to consistently higher wind speeds than onshore farms. The higher wind speeds at sea can lead to greater energy production for offshore wind turbines. One significant advantage of offshore wind turbines is the potential to reduce noise-related concerns that can arise with onshore installations. However, offshore wind turbines do come with certain challenges. Installation and maintenance in offshore environments can be expensive, requiring specialized equipment. Exposure to harsh marine conditions, such as saltwater corrosion can also pose maintenance challenges, potentially leading to higher operational costs over time.

Connecticut has space for both onshore and offshore wind turbines. The paper assumes each onshore and offshore wind turbine will produce 25% of the total electricity consumption required in the state (13,433 gigawatts hours per year).

3.2.1. Onshore wind turbine

To calculate the nameplate capacity of an onshore wind turbine, it is necessary first to calculate the CF for an onshore wind turbine in Connecticut. According to the U.S. Department of Energy, the average wind turbine blade diameter and wind turbine nameplate capacity at the start of 2021 in Connecticut is 124.8 meters and 2,750 kW, respectively, while the mean annual wind speed at hub height is 4 meters per second [12, 13]. Plugging the data in Eq. (2) results in CF=0.171 for Connecticut. Then, from Eq. (1), the nameplate capacity of onshore wind turbines in Connecticut is 8.945 GW.

$$\text{Wind Turbine CF Value} = 0.087 \times \mathrm{V} - \frac{\mathrm{P}}{\mathrm{D}^2} \tag{2}$$

$\mathrm{V} = $ mean annual wind speed at hub height (m/s)

$\mathrm{D} = $ wind turbine blade diameter (m) $\mathrm{P} = $ wind turbine nameplate capacity (kW)

3.2.2. Offshore wind turbine

The same calculation procedure is required for offshore wind turbines. A CF value is needed. According to the Chamber of Commerce of Connecticut, the wind turbine blade diameter is on average 220 meters and the offshore wind turbine nameplate capacity is between 12,000 kW and 15,000 kW (in the calculation, the paper averages the nameplate capacity, which is 13,500 kW) [14]. The mean annual wind speeds in Connecticut for locations installing offshore wind turbines is 7 meters per second [15]. Using Eq. (2), the offshore wind turbine CF value in Connecticut is 0.3301. Dividing the output required to produce (13,433 gigawatts hours per year) by the CF (0.3301) and hours per year (8,760) gives the nameplate capacity of offshore wind turbines needed in Connecticut, 4.645 GW.

4. Cost Analysis

As the paper discussed in previous section, cost varies depending on type of renewable energy technology. Government needs to consider the budget for a 100% clean renewable energy proposal. Therefore, it is important to quantify the cost for the proposal.

To calculate the total cost of the proposal, the paper assumes the average cost of each renewable energy technology represents all the costs of each technology will be used in the proposal. Then, we acquire the data for capital cost (U.S. dollar per kW) and multiply it by the nameplate capacity (kW) found for each technology to find the total cost of each technology. Among these costs, solar panel have the largest overall cost ($20.9 billion); onshore wind turbine has the lowest cost ($10.1 billion) (Table 8). The total cost of all sections adding up together is $71.8 billion.

Table 8. Cost of renewable energy by type

	Solar Panal-Rooftop residencial	**Solar PV-Utility Scale**	**Wind Turbine-Onshore**	**Wind Turbine-Offshore**
Minmum Cost ($/ kW)	2,230	700	1,025	3,000
Maximum Cost ($/ kW)	4,150	1,400	1,700	5,000
Average Cost ($/ kW)	3,190	1,050	1,362.5	4,000
Namplate Capacity (kW)	9,685,000	9,638,000	8,945,000	4,645,000
Total Cost ($)	30,895,150,000	10,119,900,000	12,187,562,500	18,580,000,000

Lazard provides the minimum cost and maximum cost data for Table 8 [16]. To calculate the total cost, we multiply the average cost per kW to nameplate capacity (kW) each technology need.

5. Discussion

The EIA data used here account for most of the energy consumption in Connecticut for the year 2021. According to the trend of energy consumption in the past year, the future year's energy consumption will be on a steady upward trajectory for two reasons: recovering and development. Although the year 2021 is characterized by a relatively stable economy with the COVID-19 pandemic exerting a lesser impact on energy consumption than in 2020, 2021's consumption in Connecticut still had not recovered compared with its consumption in 2018 [7]. Therefore, the energy consumption will at least be increased to the consumption in past years before the pandemic. Furthermore, as cities are developing, the consumption of energy will increase due to more industrial factories, commercial businesses, and residential houses. For these two reasons, our proposal might need more solar panels and wind turbines to satisfy future energy consumption.

Nevertheless, renewable technologies are improving as well generating more electricity in a more efficient manner. Lower system loss might be able to be obtained in the future; wind turbines might be able to reach higher hub heights, thereby acquiring faster wind speeds. Wind turbine nameplate capacity and wind blade diameter might also increase. Even as energy consumption increases, technological improvement might be able to satisfy energy consumption in the future. I am optimistic for 100% clean renewable energy in Connecticut.

Many improvements to this study can be made. The current proposal assumes each sector produces 25% of total consumption in Connecticut. However, it will be more cost-efficient to develop technologies that produce more and have a relatively lower cost in the region. In Connecticut, one should establish more offshore wind turbines to generate a higher portion of the total consumption in Connecticut. Offshore wind turbine required a lower nameplate capacity to provide the same energy compared with the other three types.

As a result, it is more effective in producing electricity. Especially when the offshore wind turbine is compared with rooftop solar PVs, it is almost half the cost; Utility solar PVs can also be installed in a greater amount to generate more portion of the consumption, mainly because it is the cheapest; An improved proposal should be avoiding installing a lot of rooftop PVs since it is almost tripled compared to the cheapest technology.

The cost of the current proposal also neglects details. For instance, the cost of storage energy, labor, and maintenance are not included in this paper's calculation. One should be aware that the real cost will only be larger than the cost proposed in the study. Furthermore, considering the total land cost of the rooftop PVs, public engagement and policy are required to acquire installing rooftop PVs on 68% of the current available rooftop area.

6. Conclusion

The paper provides a proposal for transitioning from traditional fossil fuel-based energy sources to renewable alternatives, wind, water, solar, and geothermal. The paper assumes the addition of only wind turbines (onshore and offshore) and solar PV (rooftop and utility) in Connecticut. It is calculated that we need 50.7 square kilometers of existing rooftop for installing rooftop PV for a total nameplate capacity of 9.685 GW and 117.8 square kilometers for installing utility PV for a total nameplate capacity of 9.638 GW. The results also show we need 8.945 GW of nameplate capacity for onshore wind turbines and 4.645 GW of nameplate capacity for offshore wind turbines. The total capital cost for the technologies is $71.8 billion dollars. However, the transition to 100% renewable energy is not without its challenges, including increasing energy consumption each year and the high cost of capital and land. Both public and government support are needed to acquire a 100% clean energy future for Connecticut. The proposed roadmap, despite its limitations, offers valuable insights into the challenges and opportunities of achieving a renewable energy transformation at the state level.

Conflict of Interest

The author declares no conflict of interest.

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