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Comparative analysis of renewable energy

Ziyuan Liu

University of Alberta, Alberta, Canada, 10230

ziyuan4@ualberta.ca

Abstract. Our current reliance on non-renewable sources of energy has put a strain on the limitations of our planet and its natural resources. The purpose of this study was to comparatively assess the various physical and socioeconomic factors affecting a city and its residents' ability to effectively transition to renewable energy sources such as solar or wind energy. Using climate datasets to assess the potential of both wind and solar energy for Edmonton, AB, and Columbus, OH. the researcher paired these findings with assessments of urban development, socioeconomic factors present in both cities to fully understand the current challenges we face in transitioning to renewable energy. The findings indicate that while the area of land needed to supply Edmonton with energy from 100% renewable sources would be vast (1815 km^2; 6412 Wind Turbines), it would be possible to accomplish. A change as large as this cannot be made instantaneously and cities will face various challenges in this process, but it is crucial to make this transition in order to become a more sustainable society and live more harmoniously with the natural environment.

Keywords: wind turbine, urban-developing, solar energy.

1. Introduction

With the growth of population and the rapid development of society, the energy demand in cities is persistently growing. Shifting from fossil fuels to renewable energy can avoid environmental and social problems because they are environmentally friendly and do not possess negative social impacts such as the fossil fuel industry [1]. Thus, transitioning to renewable energy has become an ongoing concern for the world, with both energy security and energy sustainability issues being particularly important. Due to Alberta's geographical location, wind and solar energy account for the main share of renewable energy [2]. Resources such as solar and wind energy are considered as clean renewable energy sources that may help to mitigate the impacts of global warming [3]. However, each city needs to evaluate renewable energy production capacity based on internal and external factors such as social acceptance or potential challenges. The following analysis would focus on the comparative study with different distinctive regions in terms of renewable energy application.

2. Literature review

A review of relevant literature on this topic of renewable energy and transitioning to sustainable sources, this research has identified three key themes that will guide author's research further. The first theme for the first research question is Renewable Potential; the achievable energy generation given system

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performance, topographic, environmental, and land-use constraints. For the second research question we identified two relevant themes: Urban Development, Inequality in the transition to renewable energy.

2.1. Renewable potential

Creating an energy grid that is 100% built of Renewable resources is important in a society that is threatened by global warming using fossil fuels and non-renewable energy sources. Geographical differences are relevant in selecting the appropriate renewable energy source as Edmonton's geography does not allow for hydropower, tidal, or wave production. Furthermore, the specific placement of a suitable production facility is very relevant for achieving the maximum potential of renewable energy production. In terms of evaluating the renewable potential of solar energy, the potential is calculated as a function of the average daily solar energy at a given location, and the efficiency of the solar technology, and the available land area [4]. The approach to estimating wind energy potential is similar in that the efficiency of the technology and availability of suitable land are factors, in addition to the climatic assessment of the averaged wind speeds over a given period [5]. Edmonton is in a different geographical region, we cannot make such a conclusion in this sense. An overall assessment of the various renewable energy sources available to the City of Edmonton needs to be completed in order to select an appropriate source or multiple sources that can effectively satisfy the factors of the production potential based on geography and climate, in addition to selecting a suitable land large enough that can be reallocated for this purpose.

2.2. Urban development

To implement renewable energy in a city, energy use policies must be created. The city's energy use is divided into sectors such as residential, commercial and industrial. Statistics show that the industrial sector has the highest energy use in Canada [6]. Urban development plays a large role in the feasibility of implementing energy supply options. Edmonton's Change Homes for Climate Solar Program is offering a rebate of $0.15/Watt up to a maximum of $6,500 to incentivize Edmonton homeowners for adopting solar household use [7]. In terms of employment, clean energy will drive the economy and provide more jobs, such as installing solar panels, wind power plants, and maintaining machinery, all of which require related recruiting. The Renewable Energy and Jobs 2020 annual report from IRENA states that the renewable energy sector can generate three times the employment for the same investment as fossil fuels [8]. Moreover, depending on the region, solar and wind energy can be used in combination as hybrid energy. This complementary effect is more efficient.

2.3. Inequality in the transition to renewable energy

Inequalities that may be present at the country-level are climate restrictions of the country, income inequality, and inequalities in economic development. At the household level, possible inequalities than can be present will be in relation to income, gender, age, health, occupation, household size, and status of home ownership [9]. Income is a major factor at both levels as a significant barrier in transitioning to renewable energy is its high financial cost of production [10]. In Canada, for provinces such as Alberta which are more sparsely populated and heavily dependent on non-renewable resources, the transition to renewable sources presents substantial impediments that may not be present in neighboring provinces and states [5]. Though an investment in renewable energy might reduce their energy per capita, finding the funds for investment would be the major issue. Both Edmonton and Columbus, OH possess similar socioeconomic demographics and reside in a state/province that heavily relies on non-renewable energy sources.

3. Methods

The researcher evaluated the respective solar irradiance (kwh/m2) based on three different solar panel orientations for Edmonton, AB, and two panel orientations for that of Columbus, OH. Two-way tracking data was not available for Columbus, OH, although for the researcher's comparative analysis of these two cities the alternative orientations (ATaL: Angle Tilt at Latitude, and Horizontal) were sufficient to

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conduct this assessment, as data was presently available for both locations. Solar irradiance measures the power per unit area of the sun in the form of radiation measured in kilowatt-hours per meter squared. The assessment of this variable is crucial in the determination of predicted solar energy generation given a specific city's geographical location and the relationship with the sun. Solar irradiance data for Edmonton was obtained through Natural Resources Canada (2020) and datasets for Columbus, Ohio were collected from the National Renewable Energy Laboratory (2020).

For wind energy analysis, wind speed data for Columbus and Edmonton was acquired from a weather website with wind speed records dating back a decade. The data on the website [11] was available monthly due to which the data for a decade (2013-2022) had to be input manually. The average wind speed was acquired for every month in a year for ten years providing a value wind speed of 14 km/h which is used further to evaluate the power output with this wind speed. Due to the varying nature of wind speed, the researcher analyzed the wind speed average to more accurately assess the potential and eliminate as many uncertainties as possible. Gust wind data was obtained from both cities and compared to further analyze the scale of winds in these cities. Using the average wind speed of 14km/h, an efficiency factor of 40%, and a rotor blade length of 70m power output of a single turbine in Edmonton was calculated. This calculation assumes the least number of mechanical losses and wear and tear. The wind speed of Columbus and Edmonton were compared to derive a relation between the two cities since Columbus has a working wind turbine. Deriving a relation between the wind speeds of two cities will help in determining the feasibility of the wind energy project.

The data for Total Energy Usage, Energy Usage per Household in Alberta, and Number of Residential Homes in Edmonton was acquired from Statistics Canada (2017). Using the number of households present in Edmonton, the total power consumption per household in Edmonton for a year was calculated. Dividing the total power consumption of households calculated earlier by the power output of a single turbine provided the required number of wind turbines needed.

The quantitative values that the researcher used are represented as election/vote results, and proportions provided by Statistics Canada (2017) and the U.S. Census Bureau (2021). Qualitative data present in this research will be displayed as analytical assessments of urban development policies.

4. Research results

Question 1: Can solar or wind energy alone meet the energy requirements of Edmonton households?

The researcher began by evaluating the Solar Irradiance of both Edmonton and Columbus in relation to the current available technology of solar panels to understand the potential strengths of solar power as a major source of energy for our city.

Table 1. Solar Irradiance of Edmonton.

Solar Irradiance of Edmonton, AB as a function of the angle of solar panel placement

Month	Mean daily global insolation(kWh/m)- **Average Tilt at Latitude (ATaL)**	Mean daily global insolation (kWh/m) - **Horizontal (0 Degrees)**	Mean daily global insolation (kWh/m)- **2-Axis Tracking**
January	**2.68**	**0.96**	**3.63**
February	**4**	**1.91**	**5.31**
March	**5.23**	**3.42**	**6.96**
April	**5.92**	**4.8**	**8.39**
May	**5.77**	**5.72**	**8.63**
June	**5.91**	**6.12**	**9.15**
July	**5.96**	**6.1**	**9.18**
August	**5.51**	**5.06**	**8.07**
September	**4.76**	**3.38**	**6.56**

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Table 1. (continued).

October	**4**	**2.09**	**5.33**
November	**2.76**	**1.06**	**3.73**
December	**2.16**	**0.71**	**2.98**
Annual Avg.	**4.56**	**3.45**	**6.5**

Table 2. Solar Irradiance of Columbus.

Solar Irradiance of Columbus, OH as a function of the angle of solar panel placement

Month	**Mean daily global insolation (kWh/m)- Average Tilt at Latitude (ATaL)**	**Mean daily global insolation (kWh/m) - Horizontal (0 Degrees)**
January	**3.06**	**1.82**
February	**3.64**	**2.51**
March	**4.42**	**3.48**
April	**5.07**	**4.8**
May	**5.29**	**5.58**
June	**5.49**	**6.08**
July	**5.46**	**5.91**
August	**5.36**	**5.36**
September	**5.34**	**4.51**
October	**4.28**	**3.1**
November	**3.2**	**2.01**
December	**2.73**	**1.57**
Annual Avg.	**4.45**	**3.89**

(source :https://open.canada.ca/data/en/dataset/8b434ac7-aedb-4698-90df-ba77424a551f and https://www.nrel.gov/gis/solar-resource-maps.html.)

In Edmonton, three different orientations of solar panels accurately display the varied potential depending on the panel's angle towards the sun and whether it could be adjusted throughout the course of a day, as in the case of those with 2-Axis Tracking. While this option has the greatest potential to achieve renewable energy independence, the costs associated with more advanced technologies decreases an individual or municipality's ability to afford these types of panels. The data for 2-Axis Tracking was not available for Columbus, Ohio, but the other 2 factors (Average Tilt at Latitude, and Horizontal) were both like those found in Edmonton.

The figure below displays a visual representation of the tables presented above to compare the solar irradiance potential through monthly averages over the course of a year. While it is apparent that the addition of 2-Axis Tracking technology significantly increases the potential, both Edmonton and Columbus display similar curves under the two factors that are held constant through both assessments.

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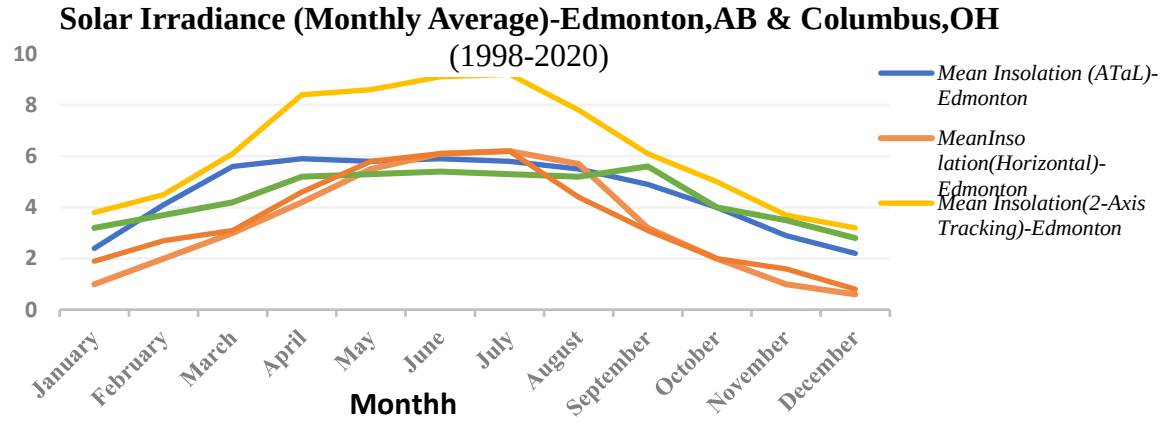

Figure 1. Solar Irradiance of Edmonton.
(source: https://open.canada.ca/data/en/dataset/8b434ac7-aedb-4698-90df-ba77424a551f; https://www.nrel.gov/gis/solar-resource-maps.html.)

Wind Energy:

Next, the researcher evaluated the average wind speed and gusty winds experienced by Columbus, Ohio and Edmonton, Alberta. This was done to measure the potential wind energy capabilities Edmonton might possess. Columbus has a residential wind turbine that is used to provide power for many households [12]. Comparing the wind and gust speeds of Columbus with Edmonton would provide us with an insight on whether Edmonton has similar wind energy production capabilities or not.

Table 3. Historical Wind Data of Edmonton.

Historical Wind Data for Edmonton, .AB, Canada

Month	Average Wind Speed (km/h)	Gust Winds (km/h)
January	13	40
February	13	38
March	14	37
April	17	40
May	16	39
June	16	37
July	15	38
August	14	36
September	16	38
October	14	39
November	13	38
December	12	37
Annual Avg.	**14.33**	**38.08**

Table 4. Historical Wind Data for Columbus.

Historical Wind Data for Columbus, OH, USA.

Month	Average Wind Speed (km/h)	Gust Winds (km/h)
January	14.74	67.78
February	14.6S	67.64
March	14.94	72.02
April	14.64	76.06
May	12.19	74.3

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Table 4. (continued).

June	11.48	78.66
July	9.88	78.02
August	9.23	64.21
September	9.44	61.98
October	11.89	61.87
November	12.76	72.72
December	1322	71.69
Annual Avg.	**12.42**	**70.58**

(source: https://www.windfinder.com/windstatistics/edmonton_city_airport.https://www.wunderground.com/history/monthly/us/oh/columbus/KCMH/date/2012-12.)

Columbus, Ohio experiences similar average wind speed as compared to Edmonton, Alberta. However, Columbus does experience gust winds which are stronger as compared to Edmonton. In Edmonton the average wind speed experienced throughout the year is 14.33km/h whereas in Columbus the average wind speed is 12.42km/h. Currently, many of the residential wind turbines on the market generate approximately 2-10 kW, with a 10 kW turbine measuring about 50-60 feet in height. In Columbus, the average residence requires about 5-15 kilowatts (kW) to power their home, only requiring the higher end of this range during short intervals during spikes in consumption such as using central air conditioning [12].

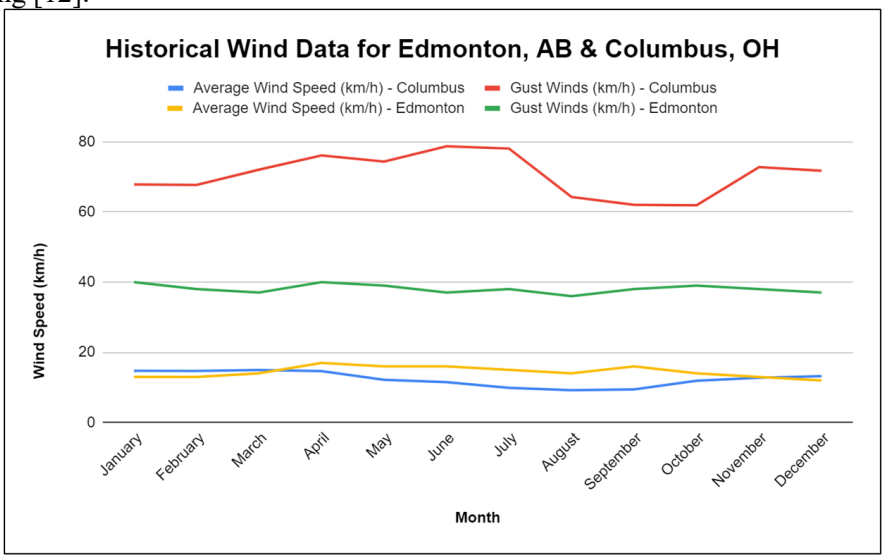

Figure 2. Monthly wind speed and wind gusts.
(source:https://www.windfinder.com/windstatistics/edmonton_city_airport;
https://www.wunderground.com/history/monthly/us/oh/columbus/KCMH/date/2012-12.)

Energy Consumption in Edmonton:

Table 5. Household energy consumption per year in Alberta.

Energy Usage	2015
GJ (Gigajoules) Total Usage	181,736,467 GJ
GJ (Gigajoules) per Household	117.7 GJ
Edmonton Household Usage (360,825 Private Households)	42,469,105 GJ/year

Source: Statistics Canada. Table 25-10-0060-01 Household energy consumption, Canada and provinc

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Table 6. Land Area to supply Edmonton Households.

Renewable Source	Land Area/# of Wind Turbines
Solar Farm	1815 km2
Wind Farm	6412 Wind Turbines

Source: Statistics Canada. 2021 Census of Population.

Using the above estimates of household energy consumption, the researcher can assess the potential number of solar panels (or area of solar panels), and wind turbines required to supply the City of Edmonton with 100% solar energy. In the most efficient case, 2-Axis Tracking solar panels would require about 1815 km2 of coverage to meet the yearly energy requirements of Edmonton.

Using the wind energy calculator, the output of a wind turbine with 70m rotor radius, 14km/h average wind speed and 40% efficiency results in 210 kilowatts. Calculating for one year gives us 1,839,600 kwh. Converting this into gigajoules gives us short of 6622.60 GJ. To meet the total household energy demand, it would require 6412 wind turbines to produce the required energy demand for one year. Additional assessments of the average rooftop area (2000 m^2) and number of households in Edmonton results in a total area of approximately 68 km2 available for rooftop solar panels. This would reduce the overall land area needed for an industrial-sized solar energy production facility.

5. Discussion

Based on the research above, the conversion of Edmonton and Columbus to renewable energy is highly feasible in terms of economics, policy, and human life. Results show that social inequalities limit the development of renewable energy in Edmonton and Columbus. Our data and analysis show that the energy capacity generated by solar and wind energy can basically meet Edmonton's urban energy demand. Comparing Alberta to other regions of the world, it is possible in terms of building renewable energy sources. For example, by the end of 2021, there were 28,230 onshore wind turbines with a combined capacity of about 56GW in operation in Germany [13]. However, our study calculates that Edmonton needs approximately 6,412 wind turbines to meet energy demand, which creates a total of 1,839,600 kWh in one year. Compared to Germany's land area of 360,000 km² [14], Alberta's land area is approximately 642,317 km² [15]. The fact that Germany has approximately 30,000 wind turbines in a smaller area of land than what is presently available in Alberta suggests that implementing the required number of wind turbines to meet Edmonton's energy needs is very much attainable. Therefore, Alberta's renewable energy strategies are feasible.

6. Conclusion

Introducing renewable energy as Edmonton’s sole source of energy is a very complicated task, inclusive of selecting the appropriate form and technology and perturbed by socioeconomic issues such as urban development, societal inequalities resulting in unfair access to such resources. At this point, it is likely unfeasible that Edmonton can fully transition over to a 100% renewable energy source without making drastic changes to the city infrastructure and political leadership in the province. Although, our analysis has identified Edmonton as a very good location to begin the development of renewable resources such as wind and solar power due to its geographical location and subsequent climate conditions allowing for strong, direct sunlight and relatively consistent wind speeds. Through research, the researcher was able to learn that there is a huge data gap in the assessment of the possibilities of the implementation of renewable energy sources in Edmonton. During this research, the researcher have faced a few shortcomings while obtaining wind data for the cities of Columbus and Edmonton. The data was acquired from a weather website which while accurate is not as reliable as official historical statistics from the government. For future research, acquiring more accurate data from official government sources will help in later calculations of solar and wind power output.

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