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Applications of Unconventional Statistical and Fermi Estimation Techniques to Study the Economic Feasibility of Micro and Nano Wind Turbine Power Generation

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Abstract: **-- Electrical engineers around the world are researching applicability of micro and nano wind turbines placed around buildings and structures in cities to harvest clean renewable energy. Economic considerations of such endeavours have been studied to a very low extent. The practical non-existence of such functioning systems around the world prevents engineers from performing highly accurate studies of the economic impact of such projects. This paper uses unconventional statistical modelling in conjunction with Fermi estimation techniques to perform an economic analysis for such projects.**

Index Terms **— economic analysis, Fermi estimation, micro/nano wind turbine projects, statistical modelling.**

I. INTRODUCTION

Urban areas, today are rapidly developing, with many tall skyscrapers and houses constructed with narrow alleyways. The specific configuration of buildings in a city allow for passages that can carry wind currents in rapid flows and strange patterns around the base of these buildings. These wind patterns are colloquially called “Skyscraper currents” and the phenomenon is called the “Skyscraper wind effect”. In order to harness electric power from this phenomenon, micro/nano wind turbines need to be mounted in the alleyways around buildings. While technically, such a theory is very much feasible, one will not be able to study economic viability of such projects on a large scale without actual implementation.

In this paper, two similar methods are employed to understand the economics of such projects, namely statistical/central limit based modeling of a city and the Fermi Estimation technique to understand power demand and supply of a city. The central limit theorem, in brief, states that a distribution of sufficiently large samples drawn randomly will follow a normal distribution, i.e., a bell curve. The Fermi approximation method is one in which a series of basal assumptions are made using a valid reference for each assumed quantity. Then, using a deductive process, the parameter to be estimated is obtained. This method was driven to fame by the theoretical physicist, Enrico Fermi.

II. INITIAL ASSUMPTIONS

With respect to a given locality, in a city, the following data needs to be modelled. Suitable assumptions can help in building a statistical/Fermi model of the power system of a city. Text in italics indicates assumptions for the Fermi model.

1. Number of buildings and number of alleyways can be deduced based on the population of the city being modelled. In a city like Bangalore, 20 lakh houses are considered. In order to calculate alleyways, each house, except those next to large streets will be assumed to have 2 alleys. Therefore, 1.8 times the number of houses will be the number of alleys, i.e., 36lakh alleys. 20L houses, 36L alleys.

2. The rated maximum load of each building and, in extension, the load duration curve data of each building can be deduced through both historical data and with random sampling, i.e., manual data collection. Both have been done here. Each building is assumed to have a daily load that forms a Gaussian distribution centred at 5kWh a day. An average load per house, per day is 5kWh.

3. The duration of wind with high enough velocity to allow generation can be obtained from historic and current meteorological data. This is taken at various cases, between 3 hours (worst case) and 18 hours (best case). A linear distribution of wind duration per day is assumed. 3 hours to 18 hours, in multiples of 3.

4. The rating of each turbine is taken to be 20W which corresponds to commercially available models. 20W ratings.

5. The cost of one such turbine and its associated equipment (both power conversion as well as auxiliary structures) is Rs. 40000. This corresponds to roughly USD 600. Rs. 40000 per turbine.

6. Up to a maximum of three turbines can be mounted in one alleyway. A Gaussian distribution of 1-3 turbines is assumed, across all alleyways. Average of two turbines an alley.

7. An increase in wind velocity due to the skyscraper effect can be taken at 20% more power output than without. 20% boost in power output.

8. Cost of 1kWh is Rs. 5. Rs. 5/kWh.

III. MODELLING APPROACH

The normal distributions and linear distributions required for statistical modelling of the power system of a city is carried out using number streams in MATLAB. Each parameter, both in statistical analysis as well as in Fermi is calculated in a similar fashion. Each step is enumerated below.

A. Statistical approach

1. A 5kWh centred normal distribution of 20lakh data points is taken to represent all loads in the city, in one day. This is in line with the assumptions.

2. Number of windmills per alley is taken to be a linear distribution between 1 and 3. That implies a total of 1 to 3 windmills across 36 lakh alleys.

3. The wind duration per day is a normal distribution between 3 and 18 hours a day.

4. The fraction of boost in power output provided due to the skyscraper effect is taken to be a normal distribution centred at 1, with a standard deviation of 0.2 on either side, giving a bell curve centred at 1 with windmills in certain alleys gaining a boost of 20% and those in certain other alleys getting a reduction of 20% due to updrafts that reduce the skyscraper currents in that region.

5. Total power output per day, per alley is obtained by multiplying the data sets obtained in steps 2, 3 and 4. The units are adjusted in terms of kWh.

6. Cost of power generated by the windmills is calculated, as is that consumed by the city, per day. The difference is the cost incurred per day, with windmills.

7. The cost of power generated by the windmills is the total saving per day. The time for payback is calculated by taking the number of years to get the money spent on the windmills back by power generation. Inflation is not taken into account in this method. Inflationary studies are carried out using the Fermi approximation techniques.

If the payback time is within the lifetime of the windmill, it is taken to be economically feasible..

IV. FERMI APPROXIMATION

This section deals with the actual calculation of parameters based on the Fermi methods of estimation of parameters. It is treated as a step-by-step process, as opposed to the bulk vector calculations of the statistical methods.

B. Initial calculations

1. Number of houses in Bengaluru = 20, 00,000

2. Number of alley ways = 20, 00,000*1.8 = 36, 00,000 (20, 00,000*2 – 20%)

3. Number of windmills/alleyway = 2
Therefore, total number of windmills = 36,00,000*2 = 72,00,000

4. Cost of each windmill (Inclusive of auxiliary equipments) = □ 40,000 Therefore, total cost = □ 28,800 crores (As on 2016)

At the end of 10 years, adjusting to an annual inflation of 7.31% (which is the average inflation in India over the past 24 years), the total cost would be equivalent to □ 28,800* (1.0713)^10 = □ 58317 crores B. Energy produced by 1 such wind turbine in a year

1. Wind blows at the rated speed for 3hrs a day (Worst case) Energy produced per day = 20W*3h*1.2(boost due to alley ways) = 72Wh/day = 0.072KWh/day = 0.072*365= 26.28KWh/year. Return/year = 26.28*5 = □ 131.4

2. Wind blows at the rated speed for 6hrs a day Energy produced per year = 26.28*2 = 52.56KWh/year Return/year = 52.56*5 = □ 262.8

3. Wind blows at the rated speed for 9 hrs a day Energy produced per year = 78.84KWh/year Return/year = 74.84*5 = □ 374.2

4. Wind blows at the rated speed for 12 hrs a day Energy produced per year = 105.12KWh/year Return/year = 105.12*5 = □ 525.6

5. Wind blows at the rated speed for 15 hrs a day Energy produced per year = 131.4KWh/year Return/year = 131.4*5 = □ 657

6. Wind blows at the rated speed for 18 hrs a day (Best case) Energy produced per year = 157.68KWh/year Return/year = 157.68*5 = □ 788.4

C. Return per year from all the wind mills put together

1. Wind blows at the rated speed for 3hrs a day (Worst case) □ 131.4*72,00,000 = □ 94.608 crores At the end of 10 years, return = □ 946.08 crores

2. Wind blows at the rated speed for 6hrs a day □ 262.8*72,00,000 = □ 189.216 croresAt the end of 10 years, return = □ 1892.16 crores

3. Wind blows at the rated speed for 9hrs a day □ 374.2*72,00,000 = □ 269.424 croresAt the end of 10 years, return = □ 2694.24 crores

4. Wind blows at the rated speed for 12hrs a day □ 525.6*72,00,000 = □ 378.432 croresAt the end of 10 years, return = □ 3784.32 crores

5. Wind blows at the rated speed for 15hrs a day □ 657*72,00,000 = □ 473.04 croresAt the end of 10 years, return = □ 4730.4 crores

6. Wind blows at the rated speed for 18hrs a day (Best case) □ 788.4*72,00,000 = □ 567.648crores At the end of 10 years, return = □ 5676.48 crores

D. Return period for various cases (Not accounting for inflation)

1. Wind blows at the rated speed for 3hrs a day (Worst case) Return period = (28800/94.608) = 304.41 years

2. Wind blows at the rated speed for 6hrs a day 3 Return period = (28800/189.216) = 152.20 years

3. Wind blows at the rated speed for 9hrs a day Return period = (28800/269.424) = 106.89 years

4. Wind blows at the rated speed for 12hrs a day Return period = (28800/378.432) = 76.10 years

5. Wind blows at the rated speed for 15hrs a day Return period = (28800/473.04) = 60.88 years

6. Wind blows at the rated speed for 18hrs a day (Best case) Return period = (28800/567.648) = 50.73 years

E. Calculation with inflation (best case)

1. 2016 - □ 567.648 crores.

2. 2026 equivalent = □ 567.648*(1+(7.31/100))^10 = □ 1149.42 crores

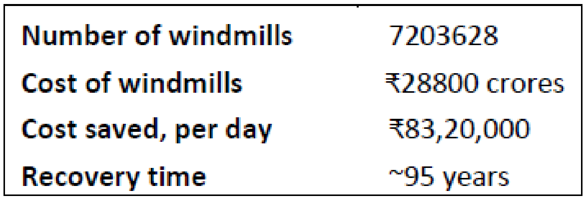
3. 2017 - □ 788.4*(1.073)*0.72 = □ 609.08 crores.

4. 2026 equivalent = □ 609.08*(1+(7.31/100))^9 = □ 1149.42 crores. This can be extended till: 10. 2026 - □ 1149.42 crores

The 2026 equivalent for any year between 2016 and 2026 is □ 1149.42 crores as the inflation in electricity price will counter balance the loss of exponential power of the term (1+(7.31/100))^k where k-> [0,10]

V. RESULTS

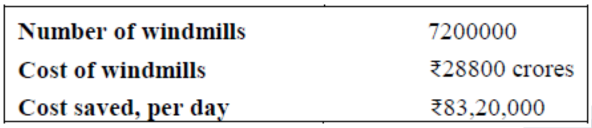
A. Statistical methods:



Number of windmills	7203628
Cost of windmills	₹28800 crores
Cost saved, per day	₹83,20,000
Recovery time	~95 years

Table 1.

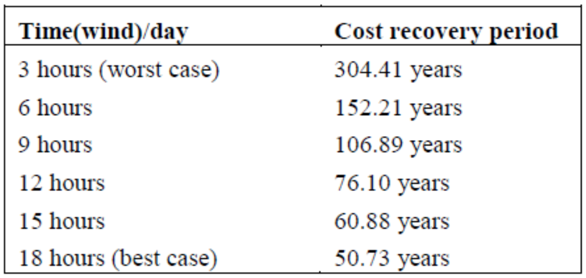
B. Fermi Methods



Number of windmills	7200000
Cost of windmills	₹28800 crores
Cost saved, per day	₹83,20,000

Table 2.

C. Recovery Time



Time(wind)/day	Cost recovery period
3 hours (worst case)	304.41 years
6 hours	152.21 years
9 hours	106.89 years
12 hours	76.10 years
15 hours	60.88 years
18 hours (best case)	50.73 years

Table 3.

The above tables 1 and 2 confirm that both the methods of analysis will produce similar results. It can be seen that the recovery time of 95 years for a normal distribution of wind durations lies in the exact average region of table 3, thereby verifying the accuracy of the Fermi method. As it is evident from the above figures, the equivalent investment at the end of 10 years would be around □ 58317 crores, while the return from the micro wind turbines would be a paltry □ 11494.42 crores. Hence, micro/nano wind turbine projects are not economically viable. However, this proves that it is a much better alternative for governments to invest in large scale wind farms.

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