OPTIMIZATION OF A RENEWABLE ELECTRICITY SUPPLY SYSTEM FOR IIT KHARAGPUR

19IM10039 – Debraj Chatterjee

End Semester Evaluation Presentation

ABSTRACT

- India's ambitious initiatives in COP 27 supported by "**promoting the usage of renewable energy**, e-mobility, ethanol-blended fuels and green hydrogen as an alternate energy source"

- Generation of electricity is responsible for **40% of all GHG emissions**, although only **20%** of energy finally converted to electricity – wasteful and polluting!

- **80%** of electricity generated from fossil fuels. We need to make a change!

- What better place to start off with than IIT Kharagpur which is a **small ecosystem on its own!**

LITERATURE REVIEW

DOMAIN SELECTION

Renewable energy with applications of Industrial Engineering out of interest

PAPER SCREENING

Done on metrics like **relevance** to the subject and scope of **impact**

PROJECT SELECTION

“Research on the configuration of a hybrid battery-wind-solar system using NSGA-II”

WHY THIS PROJECT?

Best Next Step

After projects with single objective optimization using evolutionary algorithms

Relevant Problem

The problem is highly relevant and widely discussed in all industries now (Scope 2 emissions)

The KGP Connect

Dr. Kalyanmoy Deb’s NSGA-II; Remote location with good sunshine and wind (same as paper)

PROJECT PROPOSAL

The project proposal is to implement a hybrid solar-wind energy system for the IIT Kharagpur campus.

But, why? Doesn't IIT Kharagpur already have solar panels generating power?

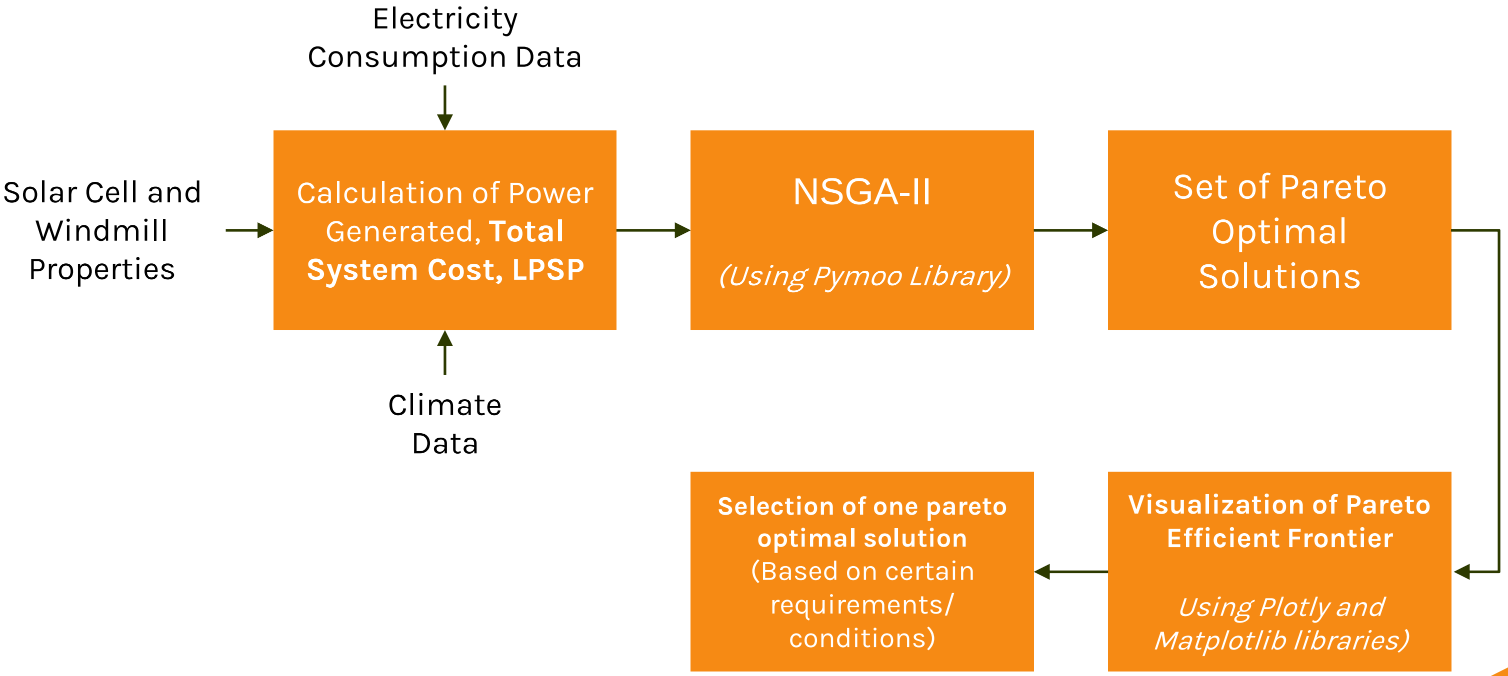
Yes, however they do not seem to be optimized properly for the job at hand, indicated by the **non-functional solar street lamps** and the **dark stretches of road in front of RP and RK Halls of Residences and Nalanda**, after sunset

A non-functional solar street lamp in front of Nalanda

The roads in front of Nalanda are usually pitch dark after sunset

A dark stretch of road in front of RP Hall of Residence

METHODOLOGY

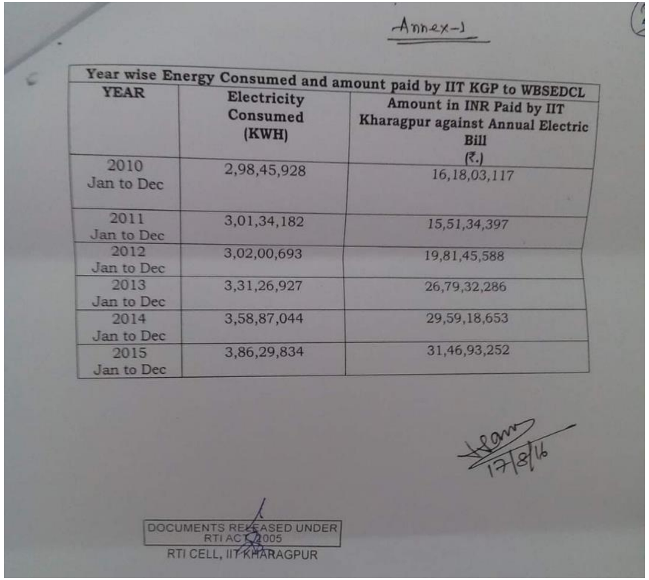


DATA COLLECTION

Data that was required for the model was collected from various reliable sources. Some of the data that was not available was guesstimated based upon logical assumptions.

- IIT Campus Electricity Consumption Data
- Kharagpur Climate Data
- Solar Cell and Windmill Properties

ELECTRICITY CONSUMPTION DATA



Annex-I

Year wise Energy Consumed and amount paid by IIT KGP to WBSEDCL

YEAR	Electricity Consumed (KWH)	Amount in INR Paid by IIT Kharagpur against Annual Electric Bill (₹.)
2010 Jan to Dec	2,98,45,928	16,18,03,117
2011 Jan to Dec	3,01,34,182	15,51,34,397
2012 Jan to Dec	3,02,00,693	19,81,45,588
2013 Jan to Dec	3,31,26,927	26,79,32,286
2014 Jan to Dec	3,58,87,044	29,59,18,653
2015 Jan to Dec	3,86,29,834	31,46,93,252

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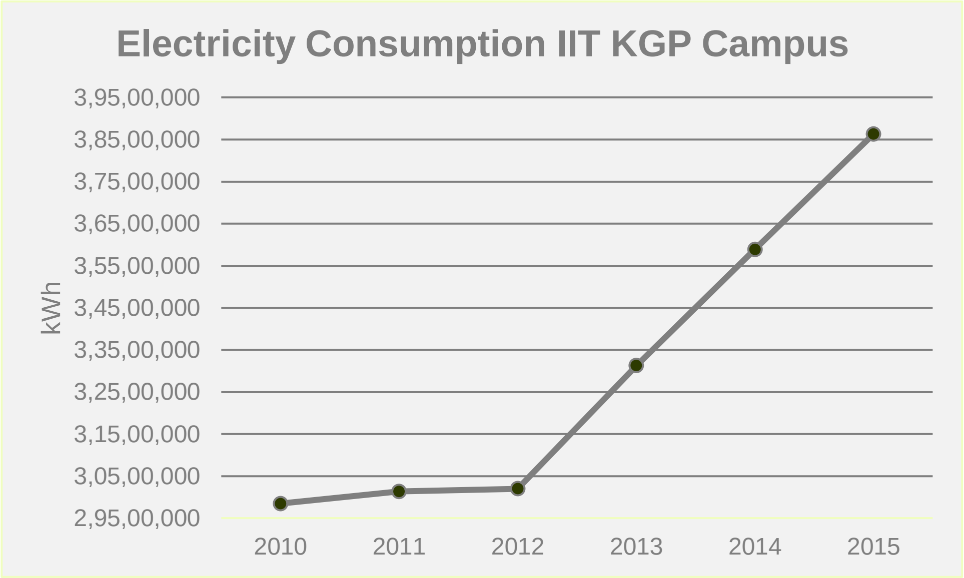
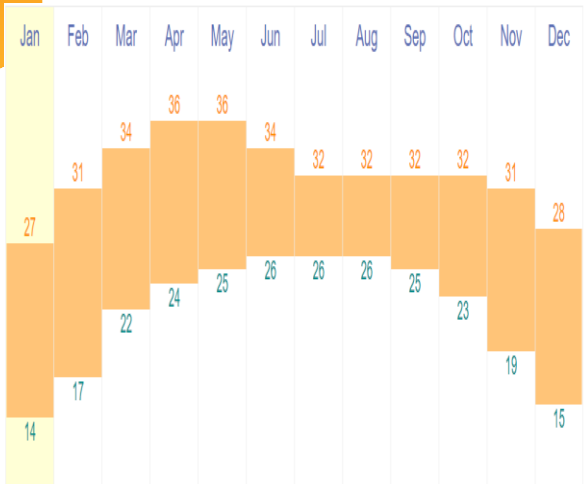
DOCUMENTS RELEASED UNDER RTI ACT, 2005
RTI CELL, IIT KHARAGPUR



The electricity consumption data was gotten from an **RTI** that was conducted recently. The electricity consumption for 2025 was forecasted from the linear model. It came out to be **66,715,796 kWh**

The reason why a linear model is appropriate is evident from the graph from 2012 – 2015 which has an almost linear trend

KHARAGPUR CLIMATE DATA

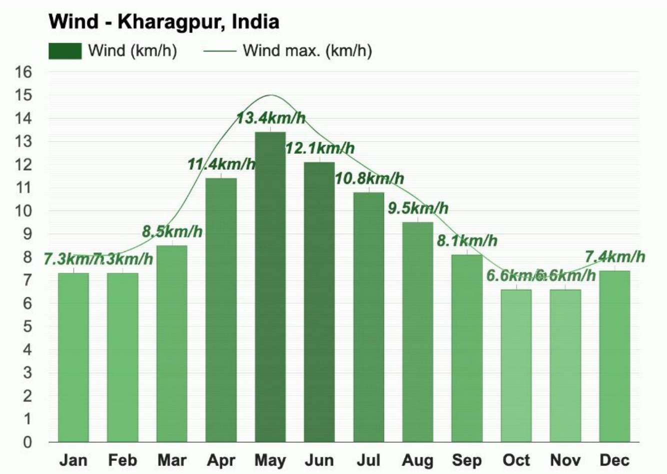


Average temperatures during day and night in Kharagpur

Source – timeanddate

Solar intensity in KGP based on Earth's position on November 29

Source – engaging-data/solar intensity
Renewable and Efficient Electric Power Systems – Gilbert Masters



Monthly maximum and average wind speeds in Kharagpur

Source – weather-atlas

SOLAR PANEL AND WINDMILL PROPERTIES

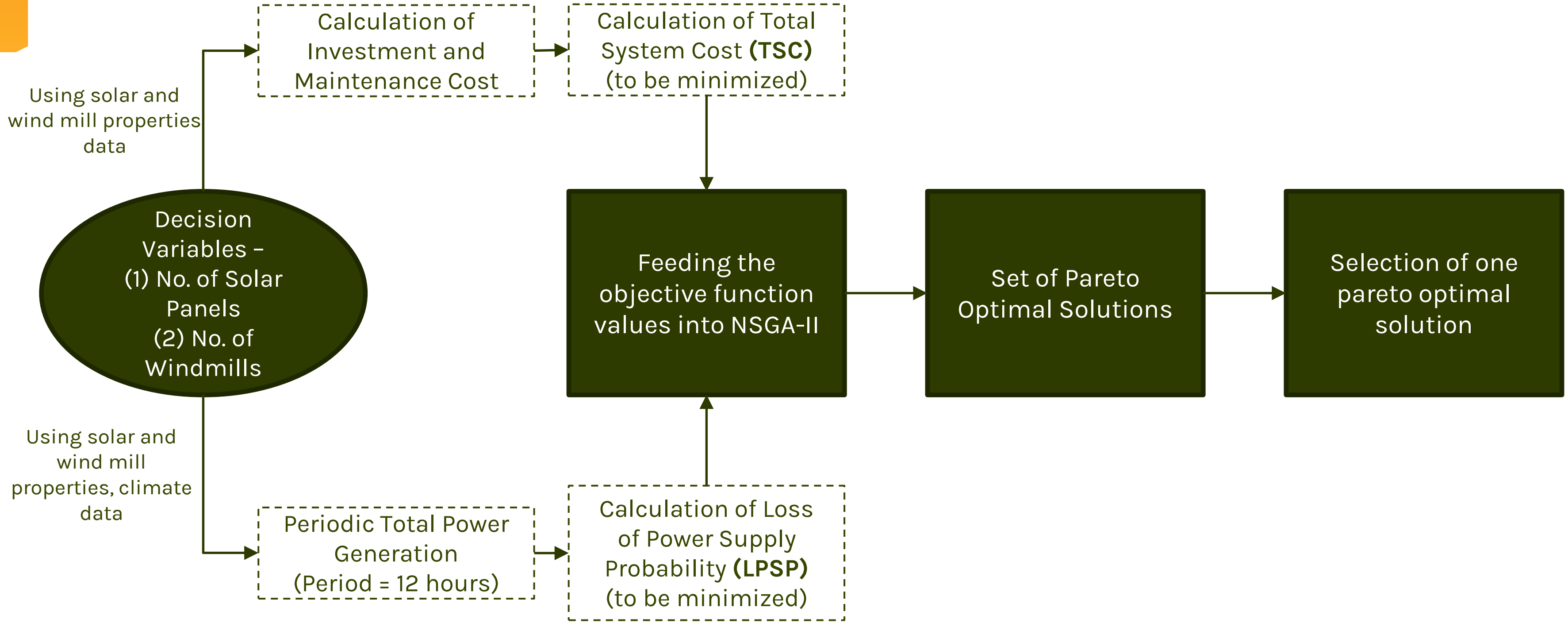
SOLAR PHOTOVOLTAIC CELL PROPERTIES		
Property	**Symbol**	**Value**
Rated Power (kW)	$P_{pv,r}$	0.1
Derating Factor (Dust)	f_{pv}	0.9
Standard Solar Radiation Conditions (W/m^2)	G_{stc}	1000
Temperature Influence Coefficient ($1/^0C$)	T_{α}	-0.0037
Standard Temperature (^0C)	T_{stc}	25
Normal Operating Cell Temperature (^0C)	N_{oct}	45
Investment Cost ($/kW)	IC_{pv}	350
Maintenance Cost ($/yr)	MC_{pv}	2.5

Source –
(1) IndiaMart – Solar Panels,
(2) Reference Research Paper

AC WIND TURBINE PROPERTIES		
Property	**Symbol**	**Value**
Rated Power (kW)	$P_{W,r}$	6
Cut-in Speed (m/s)	$V_{cut\text{-}in}$	2.5
Rated Wind Speed (m/s)	$V_{rated\text{-}in}$	10
Cut-out Speed (m/s)	$V_{cut\text{-}out}$	65
Investment Cost ($/kW)	IC_W	520
Maintenance Cost ($/yr)	MC_W	30

Source –
(1) IndiaMart – Wind Turbines,
(2) Reference Research Paper

MODELLING


Decision Variables –
(1) No. of Solar Panels
(2) No. of Windmills
Using solar and wind mill properties data
Calculation of Investment and Maintenance Cost
Calculation of Total System Cost **(TSC)** (to be minimized)
Using solar and wind mill properties, climate data
Periodic Total Power Generation (Period = 12 hours)
Calculation of Loss of Power Supply Probability **(LPSP)** (to be minimized)
Feeding the objective function values into NSGA-II
Set of Pareto Optimal Solutions
Selection of one pareto optimal solution

THE OPTIMIZATION PROBLEM

Power Generation Equations

Equation for power generated by a solar cell in a period –

$$T = T_a + \frac{NOCT - 20}{800} G_{STC}$$

$$P_{pv}(t) = f_{pv} P_{pv,r} \frac{G}{G_{stc}} (1 + \alpha_t (T - T_{stc}))$$

Equation for power generated by an AC wind turbine in a period –

$$P_w(t) = \begin{cases} 0, & V < V_{cut-in} \\ P_r \left(\frac{V^3}{V_r^3 - V_{cut-in}^3} \right) - P_r \left(\frac{V_{cut-in}^3}{V_r^3 - V_{cut-in}^3} \right), & V_{cut-in} \leq V < V_{rated} \\ P_r, & V_{rated} < V \leq V_{cut-out} \\ 0, & V > V_{cut-out} \end{cases}$$

Equation for total power generated in a period –

$$P(t) = (N_w \times P_w(t) \times \eta_{con}) + (N_{pv} \times P_{pv}(t) \times \eta_{con} \times \eta_{inv})$$

Where η_{con} = convertor efficiency = 0.95

η_{inv} = inverter efficiency = 0.95

Objective Function Equations

Equation for Loss of Power Supply (LPS) Indicator in a period –

$$LPS(t) = 1, if\ P(t) < D(t)$$

$$0, otherwise$$

Where D(t) = Electricity Power Demand in period t

(1) Total System Cost (TSC): (To be minimized)

$$IC = (6 \times N_w \times IC_w) + (0.1 \times N_{pv} \times IC_{pv}) \quad \text{(Implementation Cost)}$$

$$MC = (N_w \times MC_w) + (N_{pv} \times MC_{pv}) \quad \text{(Maintenance Cost)}$$

$$TSC = IC + MC \quad \text{(Total System Cost)}$$

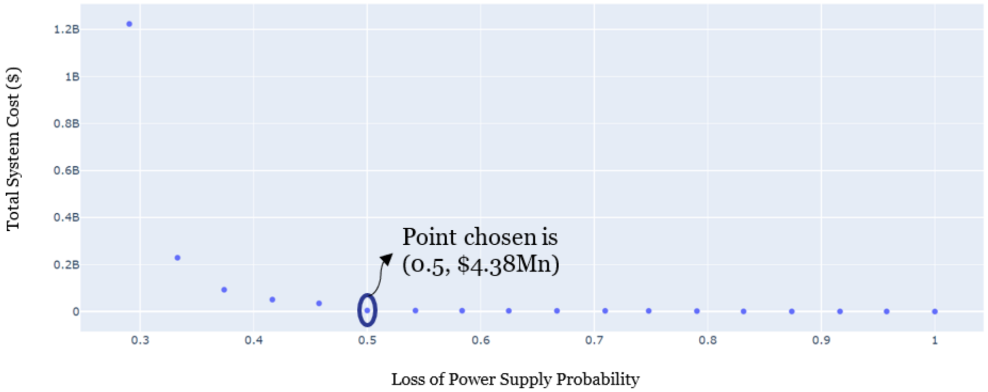
(2) Loss of Power Supply Probability (LPSP): (To be minimized)

$$LPSP = \frac{\sum_{t=1}^{n=730} LPS(t)}{\sum_{t=1}^{n=730} t}$$

Constraints

$$N_w, N_{pv} \geq 0$$

RESULTS AND DISCUSSION

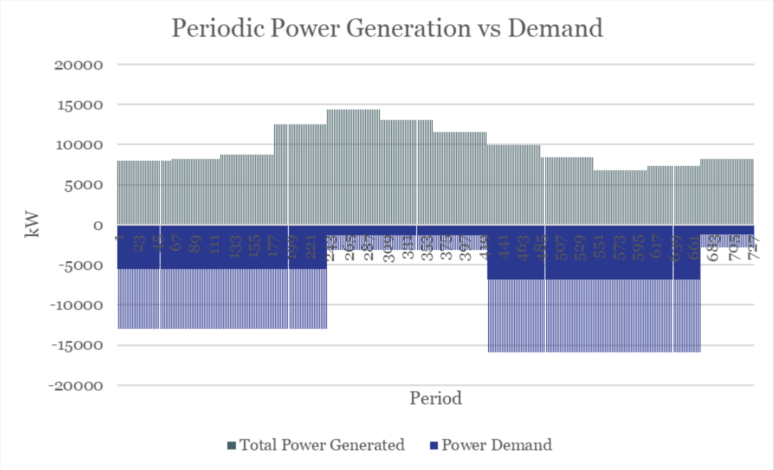


The Pareto Frontier

Point chosen – **50%** LPSP (Means 50% of KGP power supplied through the renewable energy system)

1) No. of solar panels = **974**
2) No. of wind turbines = **1**

Cost = **$4.38 Mn**



Power Generation and Demand

- Demand on negative y-axis
- Power generation on positive y-axis
- 50% of the times generation is greater than demand

Financial Results

- Annual savings in electricity after maintenance costs = **$3.1 Mn**
- Breakeven Period = **1.32 Years**

LIMITATIONS AND FUTURE SCOPE

Limitations

- Main limitation was with the lack of granular data available, some assumptions had to be made which might have affected the accuracy of the model
- The implementation costs are representative of the price of the setup. However, they may not be standard in all situations. Other costs such as labour and materials also keep on fluctuating

Future Scope

- A more accurate model with hourly data recorded by primary means in Kharagpur
- Integration of a storage mechanism for generated power (to remove reliance on on-grid power further)
- Multi-year analysis with accurate forecasts, integration of inflation and discount rates, and calculation of NPV
- After getting the optimal number of solar panels/windmills – deciding and optimizing where they should be set up

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THANKS!