Optimising Scope of Renewable Energy in India

A PROJECT REPORT

SUBMITTED TO
SVKM'S NMIMS (DEEMED- TO- BE UNIVERSITY)

IN PARTIAL FULFILMENT FOR THE DEGREE OF

**BACHELORS OF SCIENCE IN
DATA SCIENCE**

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CERTIFICATE

This is to certify that work described in this thesis entitled "Optimising Scope of Renewable Energy in India" has been carried out by (Achyut Damani, Agrima Jain, Nidhi Karambelkar, Kimaya Shringarpure and Aanchal Singh) under my supervision. I certify that this is his/her bonafide work. The work described is original and has not been submitted for any degree to this or any other University.

Date:

Place: -

SUPERVISOR
(Dr.)

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CONTENTS

ABSTRACT

This research paper presents the mathematical optimization of various sources of renewable energy in the present scenario of India based on the current potentials of each source of energy, capacities of generating sources installed, various government schemes initiated to broaden the scope of its usage, etc. The Big M Simplex method was used to solve the constructed linear programming problems based on two different scenarios in India, one, to inculcate the vision of renewable energy in India in the year 2030 in the current landscape of Maharashtra, and the second, to maximise the power generated by appliances sanctioned by the government under the ‘Off-grid and Decentralised Solar PY Applications Programme in Phase III’ in the financial years of 2018-2019 and 2019-2020, with the budgetary constraints applied. We also made use of the assignment problem by referring to data from reports from Tata Power to optimally allocate each source of energy (from thermal, solar, biofuel, hydro, and wind) in the states of Maharashtra, Jharkhand, Odisha, Rajasthan, and Gujarat, to maximise the combined power harnessed. Our last model integrated Dijkstra’s Algorithm to discern the shortest connection between Pragati Power Corporation and DTL, a sub-station in Delhi.

INTRODUCTION

The intense focus on the sector of renewable energy in India has been expedited in the past few years with major steps being taken by the government of India to reduce the usage of conventional sources of energy. Drawing data from official reports and orders to frame our linear programming problems, we considered four different case studies to apply the theory of optimization to and derived results which are pertinent and calculated representations of what the future of India in the green energy sector will look like.

RATIONALE

“Energy is at the heart of the climate challenge – and key to the solution.” This quote by Dr. Hoesung Lee, Executive director of the International Energy Agency is equipped to tell us a lot about the future of energy generation in the world. India has been treading quickly, despite our developmental constraints, to reduce the damage caused to the planet by conventional sources of energy, by introducing various schemes and programmes, which will not only atone for environmental devastation caused by non-renewable sources, but also help people in the country by creating more jobs, developing rural areas and reduce various ailments which are being caused in high numbers by the poisonous by-products of non-renewable energy. To serve as a helping hand in this important progress, we worked on this project to provide some informative insights which can be used as stepping stones for the future.

AIMS AND OBJECTIVES

- To assess India’s current capacity to harness renewable energy.
- To minimise expenditure on tariffs of renewable energy by finding optimal mix for Maharashtra to harness, based on the vision set for India in 2030.
- To maximise power generated by solar appliances sanctioned by the government scheme ‘Off-grid and Decentralised Solar PY Applications Programme in Phase III’ in 2 years.
- To allocate optimal sources of energy to the states using the assignment problem, to get the maximum power harnessed in total.
- To find the shortest connection between a green power plant and a substation using Dijkstra's Algorithm.
- To promote renewable energies in India

LITERATURE REVIEW

[4] The paper utilises a linear programming model to optimise power generation plants in eastern Mexico, considering real parameters to minimise operating costs and maximise the participation of clean energy sources. In contrast, our research focuses on optimising renewable energy resources in Maharashtra, India, employing similar mathematical modelling techniques to minimise expenditure while promoting renewable energy integration. Both studies emphasise the importance of considering real-world constraints and objectives, aiming to inform decision-making in energy planning. While the referenced paper evaluates power generation infrastructure in a specific region, our research contributes to broader discussions on sustainable energy solutions within the context of Maharashtra's energy landscape. Despite geographical disparities, both studies share a common goal of optimising energy resources and promoting the transition towards cleaner and more cost-effective energy systems.

[5] In this research paper, it employed a linear programming approach to optimise the installation of energy-saving devices in rural areas of developing countries. They aimed to either maximise energy saved for a given subsidy budget or minimise the subsidy amount required to achieve a targeted energy-saving goal. The study considered various factors such as socio-economic conditions, electrification levels, and resource availability in planning device installations. Similarly, our research focuses on optimising renewable energy resources in Maharashtra, India, using similar mathematical modelling techniques to minimise expenditure while promoting renewable energy integration.

[6] We used the structure of the constraints of this model as a very valuable source of inspiration for our respective constraints. Instead of efficiency, we took capacity factor into consideration and adhered to the demand and potential constraints they have formulated.

[7] This paper calculates the capacity factor of generators of renewable energy for districts of Satara, Dhule, Sangli and Nandurbar which is used in model one to calculate the total amount of energy generated by each source of energy from its installed capacity.

[1] The research paper examines the effectiveness for energy resource allocations of Distributed Energy Resources (DER's) in a Microgrid proposed for a village cluster in a rural district located in Uttarakhand state (India) using linear programming (LP) and the Genetic based algorithm (GA), a metaheuristic technique. It also examines how the optimization is affected when the energy resources availability and demand limits are reduced.

DATA COLLECTION

The data used in this project has been derived from various government reports. In the first model, the data for the total electricity generated in the state and source wise generation of electricity is from the Economic Survey of Maharashtra 2022-2023 [8], tariffs for each source has been traced from [2] and the energy capacity of renewable sources of energy has been referenced from a research paper on the same [7], the measures for CO_2 emissions by each source of energy has been referenced from this website [12].

For the second model, the sanctioned number of appliances have been referred to from the Annual report of Ministry of New and Renewable Energy [14] and the budget allocated for its setting up is taken from this order issued by the government [15].

For the third model, the data of the capacity of each source of energy in each state for Tata power is extracted from their own annual report [13].

For the fourth model, the data was collected from Geospatial Data Limited (GDSL) of New (https://data.opencity.in/dataset/delhi-power-grid-data) in KML file format [16] and then was imported to Google Earth to solve the problem. An eco-friendly power plant (Pragati Power Station) located in North Delhi (Sector-5, DSIIDC Industrial Area, Bawana, Delhi, 110039) and a DTCL (Delhi Transco Ltd.) power sub-station - VASANT KUNJ was taken to form a connection.

METHODOLOGY

Model 1

Aims to minimise tariffs (taxes on renewable energy) in the state of Maharashtra.

Energy	Potential Capacity (MW)	Capacity Factor	Hours	Energy (MWh)	Energy (KWh)
Solar	57390	19%	9	188526150	1.8852615 × 10^11
Wind	98210	18%	24	860319600	8.603196 × 10^11
Hydro	732	38%	24	6412320	6.41232 × 10^9
Biomass	781	70%	24	6841560	6.84156 × 10^9
Bagasse	3685	60%	13	17485325	1.7485325 × 10^10

Table 1.1

Energy = Potential Capacity × Hours × 365:

Energy Source	Tariffs (Rs./kwh)
Solar	3.075
Wind	3.275
Small Hydro	5.8
Biomass	9.3386
Bagasse	6.33

Table 1.2: Tariffs levied on each renewable energies by government

Model:

Let

x_1: Number of units of energy in produced by solar
x_2: Number of units of energy in produced by wind
x_3: Number of units of energy in produced by hydro
x_4: Number of units of energy in produced by biomass
x_5: Number of units of energy in produced by bagasse

Objective function:

Minimise tariff = $3.075x_1 + 3.275x_2 + 5.8x_3 + 9.3386x_4 + 6.33x_5$

Constraints:

The value of each energy source should be less than the potential capacity (in KWh) in the state of Maharashtra. The following capacity has been transformed to energy because tariffs are applied at unit energy of kWh.

$x_1 <= 1.8852615 \times 10^{11}$
$x_2 <= 8.603196 \times 10^{11}$
$x_3 <= 6.41232 \times 10^{9}$
$x_4 <= 6.84156 \times 10^{9}$
$x_5 <= 1.7485325 \times 10^{10}$

Another constraint would be based on the capacity value of each source of energy which is a unitless ratio which determines how much energy is actually produced by the generators of each source as compared to their capacity rating. The coefficients of capacity factors with the energy produced should be greater than or equal to 55% of the total supply.

55% of current electricity generated in the state of Maharashtra:

$= 101511 \times 1000000 \times 0.55 = 5.583105 \times 10^{10}$ KWh
$\mathbf{0.19x_1 + 0.18x_2 + 0.38x_3 + 0.7x_4 + 0.6x_5 >= 5.583105 \times 10^{10}}$

Carbon Emissions:
The total greenhouse gas (GHG) emissions in 2021-22 were 310 million tonne CO_2 equivalent (CO_2 emissions) in Maharashtra. As an endeavour to reach India's goal of net zero carbon emissions.

Taking less than 2% of total carbon emission,
$\mathbf{42x_1 + 11x_2 + 9.05x_3 + 230x_4 + 890x_5 <= 5000000000000}$

Using Big M Method the L.P.P is solved.

$$\text{Min } Z = 3.075x_1 + 3.275x_2 + 5.8x_3 + 9.3386x_4 + 6.33x_5 + 0S_1 + 0S_2 + 0S_3 + 0S_4 + 0S_5 + 0S_6 + 0S_7 + MA_1$$

subject to

$$\begin{aligned}
x_1 + S_1 &= 188526150000\\
x_2 + S_2 &= 860319600000\\
x_3 + S_3 &= 6412320000\\
x_4 + S_4 &= 6841560000\\
x_5 + S_5 &= 17485325000\\
0.19x_1 + 0.18x_2 + 0.38x_3 + 0.7x_4 + 0.6x_5 - S_6 + A_1 &= 55831050000\\
42x_1 + 11x_2 + 9.05x_3 + 230x_4 + 890x_5 + S_7 &= 5000000000000
\end{aligned}$$

and $x_1, x_2, x_3, x_4, x_5, S_1, S_2, S_3, S_4, S_5, S_6, S_7, A_1 \geq 0$

Iteration-1		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	M	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_1	MinRatio $\frac{X_B}{x_4}$
S_1	0	188526150000	1	0	0	0	0	1	0	0	0	0	0	0	0	---
S_2	0	860319600000	0	1	0	0	0	0	1	0	0	0	0	0	0	---
S_3	0	6412320000	0	0	1	0	0	0	0	1	0	0	0	0	0	---
S_4	0	6841560000	0	0	0	(1)	0	0	0	0	1	0	0	0	0	$\frac{6841560000}{1} = 6841560000 \rightarrow$
S_5	0	17485325000	0	0	0	0	1	0	0	0	0	1	0	0	0	---
A_1	M	55831050000	0.19	0.18	0.38	0.7	0.6	0	0	0	0	0	-1	0	1	$\frac{55831050000}{0.7} = 79758642857.1429$
S_7	0	5000000000000	42	11	9.05	230	890	0	0	0	0	0	0	1	0	$\frac{5000000000000}{230} = 21739130434.7826$
$Z = 55831050000M$		Z_j	$0.19M$	$0.18M$	$0.38M$	$0.7M$	$0.6M$	0	0	0	0	0	$-M$	0	M	
		$C_j - Z_j$	$-0.19M+3.075$	$-0.18M+3.275$	$-0.38M+5.8$	$-0.7M+9.3386 \uparrow$	$-0.6M+6.33$	0	0	0	0	0	M	0	0	

Table 1.1

Iteration-2		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	M	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_1	MinRatio $\frac{X_B}{x_5}$
S_1	0	188526150000	1	0	0	0	0	1	0	0	0	0	0	0	0	---
S_2	0	860319600000	0	1	0	0	0	0	1	0	0	0	0	0	0	---
S_3	0	6412320000	0	0	1	0	0	0	0	1	0	0	0	0	0	---
x_4	9.3386	6841560000	0	0	0	1	0	0	0	0	1	0	0	0	0	---
S_5	0	17485325000	0	0	0	0	1	0	0	0	0	1	0	0	0	$\frac{17485325000}{1} = 17485325000$
A_1	M	51041958000	0.19	0.18	0.38	0	0.6	0	0	0	-0.7	0	-1	0	1	$\frac{51041958000}{0.6} = 85069930000$
S_7	0	3426441200000	42	11	9.05	0	(890)	0	0	0	-230	0	0	1	0	$\frac{3426441200000}{890} = 3849933932.5843 \rightarrow$
$Z = 51041958000M + 63890592216$		Z_j	$0.19M$	$0.18M$	$0.38M$	9.3386	$0.6M$	0	0	0	$-0.7M+9.3386$	0	$-M$	0	M	
		$C_j - Z_j$	$-0.19M+3.075$	$-0.18M+3.275$	$-0.38M+5.8$	0	$-0.6M+6.33 \uparrow$	0	0	0	$0.7M-9.3386$	0	M	0	0	

Table 1.2

Iteration-3		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	M	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_1	MinRatio $\frac{X_B}{x_3}$
S_1	0	188526150000	1	0	0	0	0	1	0	0	0	0	0	0	0	---
S_2	0	860319600000	0	1	0	0	0	0	1	0	0	0	0	0	0	---
S_3	0	6412320000	0	0	(1)	0	0	0	0	1	0	0	0	0	0	$\frac{6412320000}{1} = 6412320000 \rightarrow$
x_4	9.3386	6841560000	0	0	0	1	0	0	0	0	1	0	0	0	0	---
S_5	0	13635391067.4157	-0.0472	-0.0124	-0.0102	0	0	0	0	0	0.2584	1	0	-0.0011	0	---
A_1	M	48731997640.4494	0.1617	0.1726	0.3739	0	0	0	0	0	-0.5449	0	-1	-0.0007	1	$\frac{48731997640.4494}{0.3739} = 130334699341.888$
x_5	6.33	3849933932.5843	0.0472	0.0124	0.0102	0	1	0	0	0	-0.2584	0	0	0.0011	0	$\frac{3849933932.5843}{0.0102} = 378612287292.818$
$Z = 48731997640.4494M + 88260674009.2584$		Z_j	$0.1617M+0.2987$	$0.1726M+0.0782$	$0.3739M+0.0644$	9.3386	6.33	0	0	0	$-0.5449M+7.7028$	0	$-M$	0.0071	M	
		$C_j - Z_j$	$-0.1617M+2.7763$	$-0.1726M+3.1968$	$-0.3739M+5.7356 \uparrow$	0	0	0	0	0	$0.5449M-7.7028$	0	M	-0.0071	0	

Table 1.3

Iteration-4		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	M	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_1	MinRatio $\frac{X_B}{x_2}$
S_1	0	188526150000	1	0	0	0	0	1	0	0	0	0	0	0	0	---
S_2	0	860319600000	0	1	0	0	0	0	1	0	0	0	0	0	0	$\frac{860319600000}{1} = 860319600000$
x_3	5.8	6412320000	0	0	1	0	0	0	0	1	0	0	0	0	0	---
x_4	9.3386	6841560000	0	0	0	1	0	0	0	0	1	0	0	0	0	---
S_5	0	13700594995.5056	-0.0472	-0.0124	0	0	0	0	0	0.0102	0.2584	1	0	-0.0011	0	---
A_1	M	46334438397.3034	0.1617	(0.1726)	0	0	0	0	0	-0.3739	-0.5449	0	-1	-0.0007	1	$\frac{46334438397.3034}{0.1726} = 268474284984.375 \rightarrow$
x_5	6.33	3784730004.4944	0.0472	0.0124	0	0	1	0	0	-0.0102	-0.2584	0	0	0.0011	0	$\frac{3784730004.4944}{0.0124} = 306219064000$
$Z = 46334438397.3034M + 125039389144.449$		Z_j	**$0.1617M + 0.2987$**	**$0.1726M + 0.0782$**	**5.8**	**9.3386**	**6.33**	**0**	**0**	**$-0.3739M + 5.7356$**	**$-0.5449M + 7.7028$**	**0**	**$-M$**	**0.0071**	**M**	
		$C_j - Z_j$	$-0.1617M + 2.7763$	$-0.1726M + 3.1968 \uparrow$	0	0	0	0	0	$0.3739M - 5.7356$	$0.5449M - 7.7028$	0	M	-0.0071	0	

Table 1.4

Iteration-5		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	MinRatio $\frac{X_B}{x_1}$
S_1	0	188526150000	1	0	0	0	0	1	0	0	0	0	0	0	$\frac{188526150000}{1} = 188526150000$
S_2	0	591845315015.625	-0.9368	0	0	0	0	0	1	2.1665	3.1576	0	5.7943	0.0039	---
x_3	5.8	6412320000	0	0	1	0	0	0	0	1	0	0	0	0	---
x_4	9.3386	6841560000	0	0	0	1	0	0	0	0	1	0	0	0	---
S_5	0	17018816495.3125	-0.0356	0	0	0	0	0	0	-0.0166	0.2194	1	-0.0716	-0.0012	---
x_2	3.275	268474284984.375	0.9368	1	0	0	0	0	0	-2.1665	-3.1576	0	-5.7943	-0.0039	$\frac{268474284984.375}{0.9368} = 286571578690.758$
x_5	6.33	466508504.6875	(0.0356)	0	0	0	1	0	0	0.0166	-0.2194	0	0.0716	0.0012	$\frac{466508504.6875}{0.0356} = 13099763495.4296 \rightarrow$
$Z = 983288330374.5$		Z_j	**3.2936**	**3.275**	**5.8**	**9.3386**	**6.33**	**0**	**0**	**-1.1901**	**-2.3912**	**0**	**-18.5229**	**-0.0054**	
		$C_j - Z_j$	$-0.2186 \uparrow$	0	0	0	0	0	0	1.1901	2.3912	0	18.5229	0.0054	

Table 1.5

Iteration-6		C_j	3.075	3.275	5.8	9.3386	6.33	0	0	0	0	0	0	0	
B	C_B	X_B	x_1	x_2	x_3	x_4	x_5	S_1	S_2	S_3	S_4	S_5	S_6	S_7	MinRatio
S_1	0	175426386504.57	0	0	0	0	-28.0804	1	0	-0.4664	6.1609	0	-2.011	-0.0329	
S_2	0	604117814800.731	0	0	0	0	26.3071	0	1	2.6034	-2.6143	0	7.6782	0.0347	
x_3	5.8	6412320000	0	0	1	0	0	0	0	1	0	0	0	0	
x_4	9.3386	6841560000	0	0	0	1	0	0	0	0	1	0	0	0	
S_5	0	17485325000	0	0	0	0	1	0	0	0	0	1	0	0	
x_2	3.275	256201785199.269	0	1	0	0	-26.3071	0	0	-2.6034	2.6143	0	-7.6782	-0.0347	
x_1	3.075	13099763495.4296	1	0	0	0	28.0804	0	0	0.4664	-6.1609	0	2.011	0.0329	
$Z = 980424667492.051$		Z_j	**3.075**	**3.275**	**5.8**	**9.3386**	**0.1915**	**0**	**0**	**-1.292**	**-1.0444**	**0**	**-18.9625**	**-0.0126**	
		$C_j - Z_j$	0	0	0	0	6.1385	0	0	1.292	1.0444	0	18.9625	0.0126	

Table 1.7

Model 2

The objective of model 2: Maximization of power generated by the appliances funded by 'Off-grid and Decentralized Solar PV Applications Program Phase 3' program of the Governmentt of India for the year 2018-2020 according to the budget allocated for 2018-2020

Calculating the average amount of energy produced by these appliances in two years:

Appliance	Average Power Rating	Time per day	Average hours	For 2 years	kWh
Lamp	17.5	3-4 hours	3.5	44712.5	44.7125
Street Light	37.4	10-11 hours	10.5	286671	286.671
Solar Power Plant	25000	24 hours	24	438000000	438000

Table 2.1

The budget allocated for this project for the two fiscal years:

Year	Sanctioning target (MWp)	Proposed Outlay (₹ in Crore)
2018-19	50	276
2019-20	68	380
Total	118	656

Table 2.2

The quantity of appliances sanctioned by the government for this programme:

Appliance	Sanctioned Quantity
Solar power plants	25kW plants totalling to installed capacity of 100 MWp
Solar lamps	2500000
Solar street lights	300000

Table 2.3

According to previous phases of the scheme, only 45-50% of the sanctioned capacity has been installed, so we will consider 40% of the total number of appliances to be the lower end of the constraint of the appliances installed.

Phase	Sanctioned	Installed
Phase-I (2010-13)	252.5 MW	117 MW
Phase-II (2014-17)	713 MW	345.5 MW

Table 2.4

Model:

Let

x_1: No of units of Street Lights

x_2: No of units of Solar Lamp

x_3: No of units 25kW Solar plants

Hence the **objective function** will be:

Maximum Power: $286.671x_1 + 44.7125x_2 + 438000x_3$

The constraints are:

$11040x_1 + 1407.25x_2 + 16,75,000x_3 <= 6,56,00,00,000$

$x_1 <= 3,00,000$

$x_2 <= 25,00,000$

$x_3 <= 4,000$

$x_2 >= 10,00,000$

$x_1 >= 1,20,000$

$x_3 >= 1,600$

Iteration-1		C_j	286.671	44.7125	438000	0	0	0	0	0	0	0	$-M$	$-M$	$-M$	
B	C_B	X_B	x_1	x_2	x_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_1	A_2	A_3	MinRatio $\frac{X_B}{x_3}$
S_1	0	6560000000	11040	1407.25	1675000	1	0	0	0	0	0	0	0	0	0	$\frac{6560000000}{1675000} = 3916.4179$
S_2	0	300000	1	0	0	0	1	0	0	0	0	0	0	0	0	---
S_3	0	2500000	0	1	0	0	0	1	0	0	0	0	0	0	0	---
S_4	0	4000	0	0	1	0	0	0	1	0	0	0	0	0	0	$\frac{4000}{1} = 4000$
A_1	$-M$	1600	0	0	(1)	0	0	0	0	-1	0	0	1	0	0	$\frac{1600}{1} = 1600 \rightarrow$
A_2	$-M$	1000000	0	1	0	0	0	0	0	0	-1	0	0	1	0	---
A_3	$-M$	120000	1	0	0	0	0	0	0	0	0	-1	0	0	1	---
$Z = -1121600M$		Z_j	$-M$	$-M$	$-M$	0	0	0	0	M	M	M	$-M$	$-M$	$-M$	
		$C_j - Z_j$	$M + 286.671$	$M + 44.7125$	$M + 438000 \uparrow$	0	0	0	0	$-M$	$-M$	$-M$	0	0	0	

Table 2.5

Iteration-2		C_j	286.671	44.7125	438000	0	0	0	0	0	0	0	$-M$	$-M$	
B	C_B	X_B	x_1	x_2	x_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_2	A_3	MinRatio $\frac{X_B}{x_1}$
S_1	0	3880000000	11040	1407.25	0	1	0	0	0	1675000	0	0	0	0	$\frac{3880000000}{11040} = 351449.2754$
S_2	0	300000	1	0	0	0	1	0	0	0	0	0	0	0	$\frac{300000}{1} = 300000$
S_3	0	2500000	0	1	0	0	0	1	0	0	0	0	0	0	---
S_4	0	2400	0	0	0	0	0	0	1	1	0	0	0	0	---
x_3	438000	1600	0	0	1	0	0	0	0	-1	0	0	0	0	---
A_2	$-M$	1000000	0	1	0	0	0	0	0	0	-1	0	1	0	---
A_3	$-M$	120000	(1)	0	0	0	0	0	0	0	0	-1	0	1	$\frac{120000}{1} = 120000 \rightarrow$
$Z = -1120000M + 700800000$		Z_j	$-M$	$-M$	438000	0	0	0	0	-438000	M	M	$-M$	$-M$	
		$C_j - Z_j$	$M + 286.671 \uparrow$	$M + 44.7125$	0	0	0	0	0	438000	$-M$	$-M$	0	0	

Table 2.6

Iteration-3		C_j	286.671	44.7125	438000	0	0	0	0	0	0	0	$-M$	
B	C_B	X_B	x_1	x_2	x_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	A_2	MinRatio $\frac{X_B}{x_2}$
S_1	0	2555200000	0	1407.25	0	1	0	0	0	1675000	0	11040	0	$\frac{2555200000}{1407.25} = 1815739.9183$
S_2	0	180000	0	0	0	0	1	0	0	0	0	1	0	---
S_3	0	2500000	0	1	0	0	0	1	0	0	0	0	0	$\frac{2500000}{1} = 2500000$
S_4	0	2400	0	0	0	0	0	0	1	1	0	0	0	---
x_3	438000	1600	0	0	1	0	0	0	0	-1	0	0	0	---
A_2	$-M$	1000000	0	(1)	0	0	0	0	0	0	-1	0	1	$\frac{1000000}{1} = 1000000 \rightarrow$
x_1	286.671	120000	1	0	0	0	0	0	0	0	0	-1	0	---
$Z = -1000000M + 735200520$		Z_j	**286.671**	$-M$	**438000**	**0**	**0**	**0**	**0**	**-438000**	M	**-286.671**	$-M$	
		$C_j - Z_j$	0	$M + 44.7125 \uparrow$	0	0	0	0	0	438000	$-M$	286.671	0	

Table 2.7

Iteration-4		C_j	286.671	44.7125	438000	0	0	0	0	0	0	0	
B	C_B	X_B	x_1	x_2	x_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	MinRatio $\frac{X_B}{S_5}$
S_1	0	1147950000	0	0	0	1	0	0	0	(1675000)	1407.25	11040	$\frac{1147950000}{1675000} = 685.3433 \rightarrow$
S_2	0	180000	0	0	0	0	1	0	0	0	0	1	---
S_3	0	1500000	0	0	0	0	0	1	0	0	1	0	---
S_4	0	2400	0	0	0	0	0	0	1	1	0	0	$\frac{2400}{1} = 2400$
x_3	438000	1600	0	0	1	0	0	0	0	-1	0	0	---
x_2	44.7125	1000000	0	1	0	0	0	0	0	0	-1	0	---
x_1	286.671	120000	1	0	0	0	0	0	0	0	0	-1	---
$Z = 779913020$		Z_j	**286.671**	**44.7125**	**438000**	**0**	**0**	**0**	**0**	**-438000**	**-44.7125**	**-286.671**	
		$C_j - Z_j$	0	0	0	0	0	0	0	$438000 \uparrow$	44.7125	286.671	

Table 2.8

Iteration-5		C_j	286.671	44.7125	438000	0	0	0	0	0	0	0	
B	C_B	X_B	x_1	x_2	x_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	MinRatio
S_5	0	685.3433	0	0	0	0	0	0	0	1	0.0008	0.0066	
S_2	0	180000	0	0	0	0	1	0	0	0	0	1	
S_3	0	1500000	0	0	0	0	0	1	0	0	1	0	
S_4	0	1714.6567	0	0	0	0	0	0	1	0	-0.0008	-0.0066	
x_3	438000	2285.3433	0	0	1	0	0	0	0	0	0.0008	0.0066	
x_2	44.7125	1000000	0	1	0	0	0	0	0	0	-1	0	
x_1	286.671	120000	1	0	0	0	0	0	0	0	0	-1	
$Z = 1080093378.209$		Z_j	**286.671**	**44.7125**	**438000**	**0.2615**	**0**	**0**	**0**	**0**	**323.2729**	**2600.2066**	
		$C_j - Z_j$	0	0	0	-0.2615	0	0	0	0	-323.2729	-2600.2066	

Table 2.9

Model 3

It aims to maximize the power generated by Tata Power in different states by allocating suitable energy resources to the states using assignment problems.

Units in (MW)

Energy\State	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	930	4150	1598	40	M
Hydro	447	M	M	M	M
Biofuel	M	M	120	203	M
Wind	239	194	M	M	185
Solar	524	645	14	M	445

Table 3.0

M-dummy variable is used where renewable energies are not available in the state to harness.

Step 1: Here the problem is of maximization type and converts it into minimization by subtracting it from the maximum value: 4150

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3220	0	2552	4110	M
Hydro	3703	M	M	M	M
Biofuel	M	M	4030	3947	M
Wind	3911	3956	M	M	3965
Solar	3626	3505	4136	M	3705

Table 3.1

Step 2: Find out each row’s minimum element and subtract it from that row

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan	
Thermal	3220	0	2552	4110	M	(-0)
Hydro	0	M	M	M	M	(-3703)
Biofuel	M	M	83	0	M	(-3947)
Wind	0	45	M	M	54	(-3911)
Solar	121	0	631	M	200	(-3505)

Table 3.2

Step 3: Find out each column's minimum element and subtract it from that column.

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3220	0	2469	4110	M
Hydro	0	M	M	M	M
Biofuel	M	M	0	0	M
Wind	0	45	M	M	0
Solar	121	0	548	M	146
	(-0)	(-0)	(-83)	(-0)	(-54)

Table 3.3

Step 4: Make an assignment in the opportunity power table

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3220	**[0]**	2469	4110	M
Hydro	**[0]**	M	M	M	M
Biofuel	M	M	**[0]**	~~0~~	M
Wind	~~0~~	45	M	M	**[0]**
Solar	121	~~0~~	548	M	146

Table 3.4

From the previous table: number of assignments = 4, number of rows = 5, which is not equal, so the solution is not optimal.

Step 5: Cover the 0 with a minimum number of lines.

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan	
Thermal	3220	**[0]**	2469	4110	M	√(3)
Hydro	**[0]**	M	M	M	M	
Biofuel	M	M	**[0]**	~~0~~	M	
Wind	~~0~~	45	M	M	**[0]**	
Solar	121	~~0~~	548	M	146	√(1)
		√ (2)				

Table 3.5

Step 6: Develop the new revised table by selecting the smallest element, among the cells not covered by any line (say k = 121)

Subtract k = 121 from every element in the cell not covered by a line.
Add k = 121 to every element in the intersection cell of two lines.

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	0	2348	3989	M
Hydro	0	M	M	M	M
Biofuel	M	M	0	0	M
Wind	0	166	M	M	0
Solar	0	0	427	M	25

Table 3.6

Repeat steps 4 to 6 until an optimal solution is obtained

Iteration 1:

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	**[0]**	2348	3989	M
Hydro	**[0]**	M	M	M	M
Biofuel	M	M	**[0]**	~~0~~	M
Wind	~~0~~	166	M	M	**[0]**
Solar	~~0~~	~~0~~	427	M	25

Table 3.7

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan	
Thermal	3099	**[0]**	2348	3989	M	√(5)
Hydro	**[0]**	M	M	M	M	√(4)
Biofuel	M	M	**[0]**	~~0~~	M	
Wind	~~0~~	166	M	M	**[0]**	
Solar	~~0~~	~~0~~	427	M	25	√(1)
	√ (2)	√ (3)				

Table 3.8

Subtract k = 25 from every element in the cell not covered by a line.
Add k = 25 to every element in the intersection cell of two lines.

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	0	2323	3964	M
Hydro	0	M	M	M	M
Biofuel	M	M	0	0	M
Wind	25	191	M	M	0
Solar	0	0	402	M	0

Table 3.9

Iteration 2:

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	**[0]**	2323	3964	M
Hydro	**[0]**	M	M	M	M
Biofuel	M	M	**[0]**	~~0~~	M
Wind	25	191	M	M	**[0]**
Solar	~~0~~	~~0~~	402	M	~~0~~

Table 3.10

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan	
Thermal	3099	**[0]**	2323	3964	M	√(6)
Hydro	**[0]**	M	M	M	M	√(5)
Biofuel	M	M	**[0]**	~~0~~	M	
Wind	25	191	M	M	**[0]**	√(7)
Solar	~~0~~	~~0~~	402	M	~~0~~	√(1)
	√ (2)	√ (3)			√ (4)	

Table 3.11

Subtract k = 402 from every element in the cell not covered by a line.
Add k = 402 to every elment in the intersection cell of two lines.

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	0	1921	3562	M
Hydro	0	M	M	M	M
Biofuel	M	M	0	0	M
Wind	25	191	M	M	0
Solar	0	0	0	M	0

Table 3.12

Iteration 3:

	Maharashtra	Gujarat	Jharkhand	Odissa	Rajasthan
Thermal	3099	**[0]**	1921	3562	M
Hydro	**[0]**	M	M	M	M
Biofuel	M	M	~~0~~	**[0]**	M
Wind	25	191	M	M	**[0]**
Solar	~~0~~	~~0~~	**[0]**	M	~~0~~

Table 3.13

Number of assignments = 5, number of rows = 5
Which is equal, so solution is optimal

Model 4

Electricity has to be transmitted from the power source to various users ranging from heavy industries to the local households. This is done so with the means of transmission lines that are laid across the city. Transmission lines are usually set up underground and overground (with the help of electricity poles and pylons). The power plants/stations produce high voltage electricity which has to be stepped-down for it to be accessible for the local consumer. This is done with the help of power transformers.

The longer the transmission line, the more power is lost. This model aims to minimize power loss by finding the shortest connection between the power source (Pragati Power Plant) and the power destination (DTCL Sub-station Vasant Kunj) using **Dijkstra's Algorithm.**

The data for New Delhi is taken considering the high AQI (Air Quality Index) of 372 in December 2023, which is more than three times the recommended index of 100, there is a need to minimize power loss during transmission by fulfilling our objective of Model 4.

Converting the KML data:
The KML files were imported to Google Earth Software to convert the data into usable format. In Fig.1 the yellow markers indicate pylon locations and the red lines indicate the existing power grid network of New Delhi.

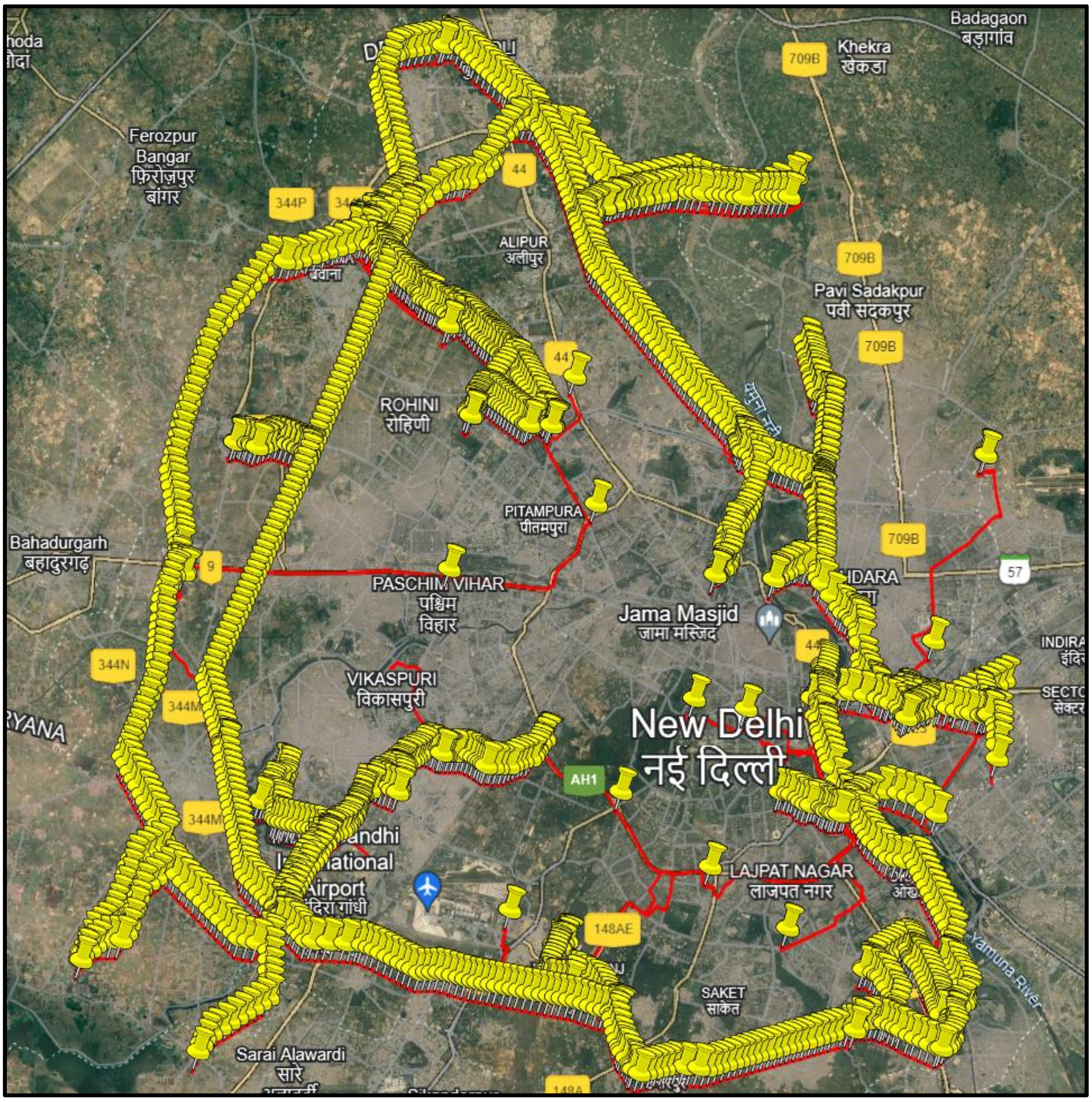


Fig 1: KML files imported into Google Earth

Analyzing the existing power grid of New Delhi:

The KML files having the location data of Underground & Overground Transmission Lines, Pylons, Transformers and Power sub-stations were analyzed and the possible paths (colored lines) and nodes (blue markers) were marked.

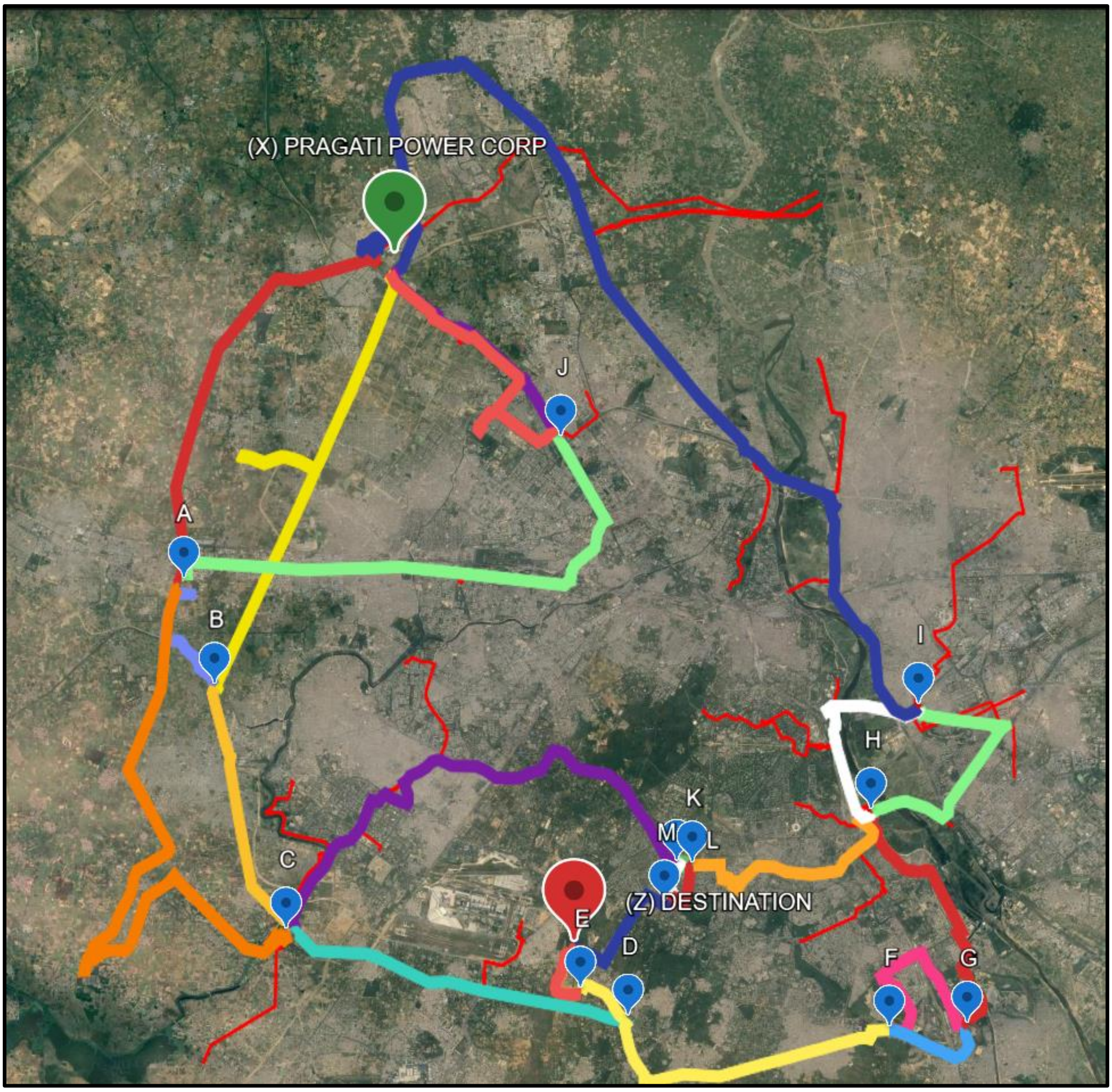


Fig 2: All possible transmission lines that can connect the Power source and Destination.

Converting the graph into simplified form:
For applying the algorithm and ease of calculations the possible paths marked in Google Earth are converted into a simplified form having straight lines as edges and nodes (A to M).

- The **nodes** are colour coded in the simplified graph with green as the source, red as the destination and blue as the nodes having degree more than one.
- The Green coloured **path** indicates selected shortest path, Red indicating eliminated path and the Yellow colored path indicating the shortest path until the current step.
- The **weights** assigned to various edges are the distances (in km)

Note: The simplified graph is not to scale i.e. a weight of 23.642 and 10.275 can be depicted with the same line length.

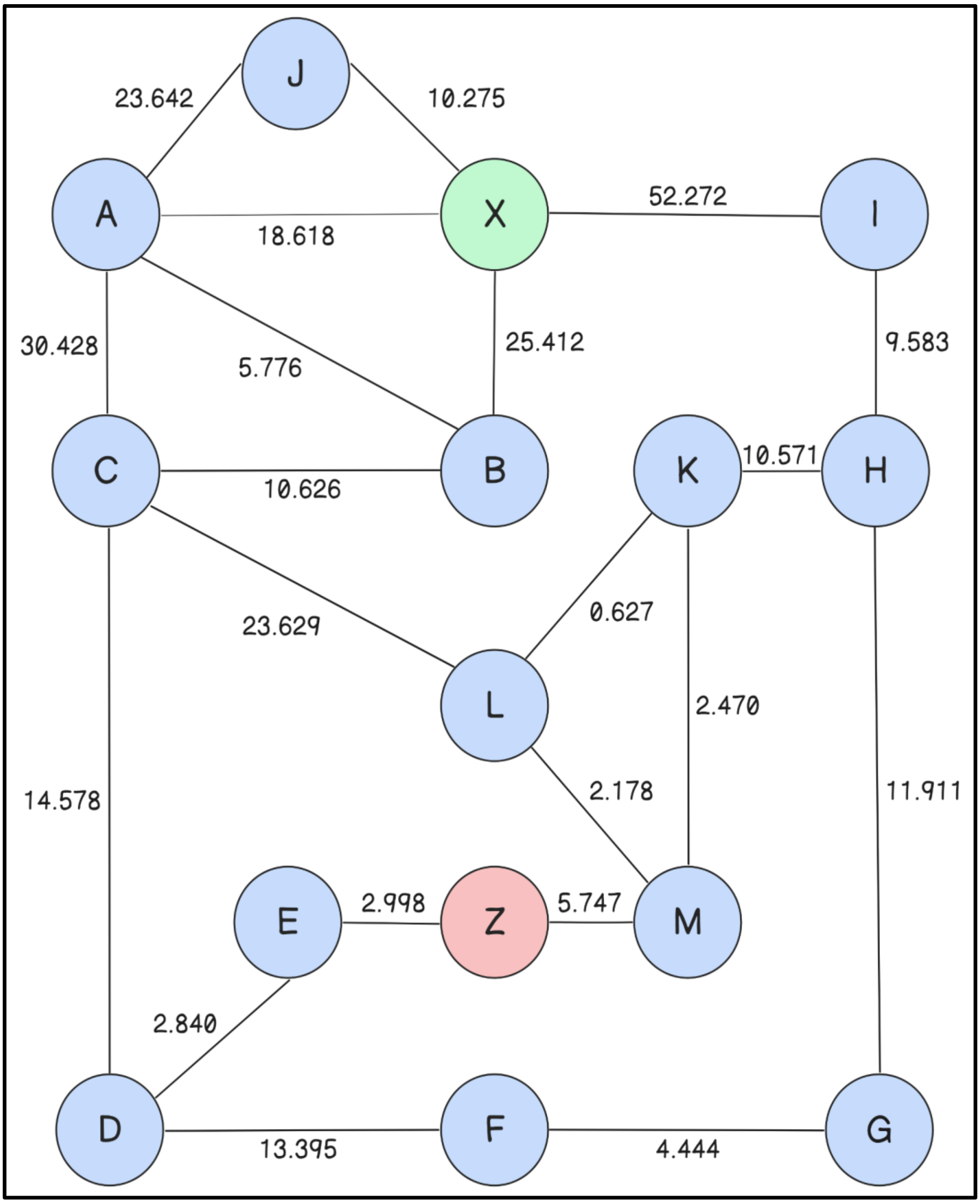
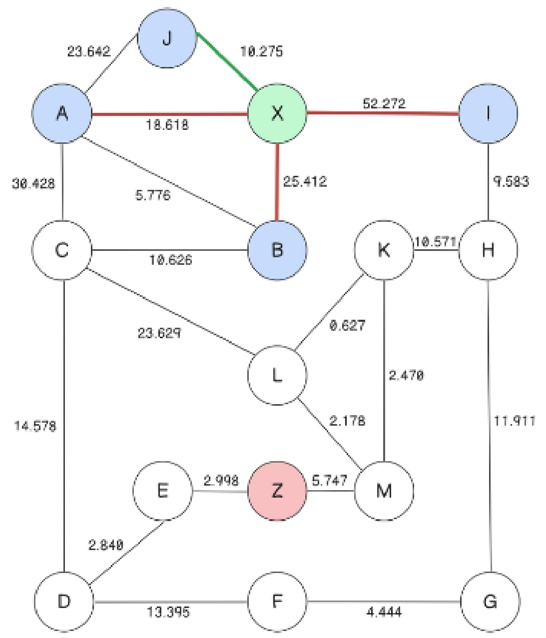


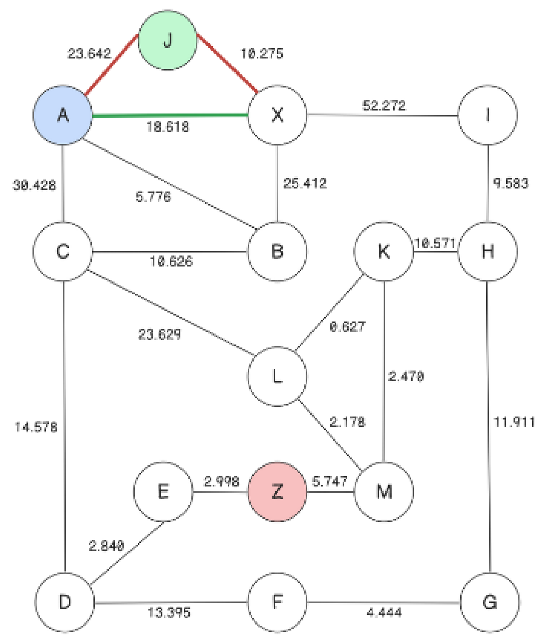
Fig 3: Simplified Graph

Solving the problem using Dijkstra's Algorithm:
The problem is solved using the algorithm step by step until the shortest path is obtained.



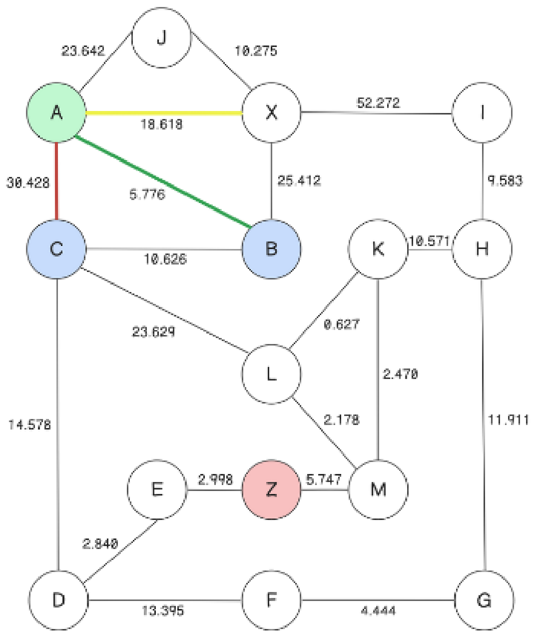
Node	Distance	Previous Node
X	0	
A	18.618	X
B	25.412	X
C	∞	
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	

Fig 4: Step 1, Current Node X, path XJ is selected and other paths are eliminated.



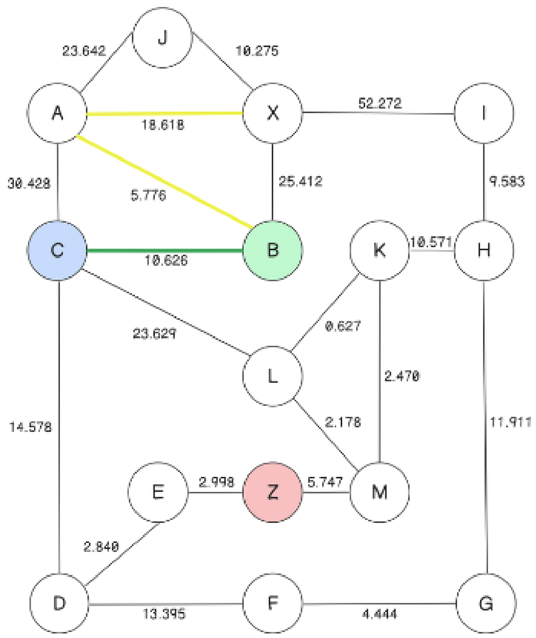
Node	Distance	Previous Node
X	0	
A	18.618	X
B	25.412	X
C	∞	
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	

Fig 5: Step 2, Choosing path XA rather than XJA as the shortest cumulative path.



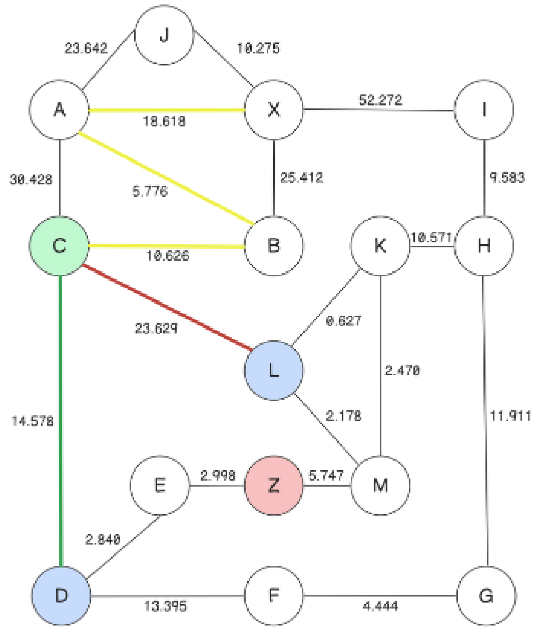
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	49.046	A
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	

Fig 6: Step 3, Current Node A, Path AC eliminated.



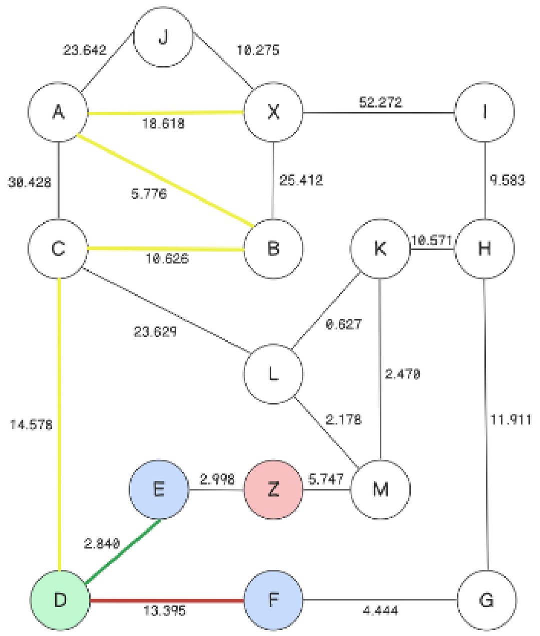
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	

Fig 7: Step 4, Current Node B, only one possible path BC.



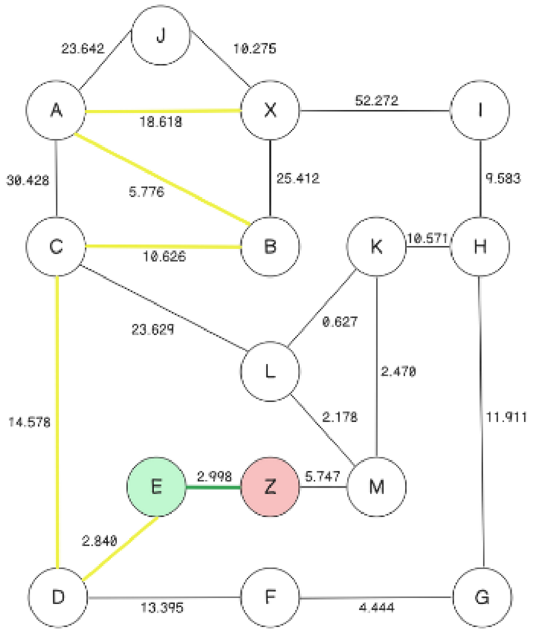
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	49.598	C
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	58.649	C
M	∞	
Z	∞	

Fig 8: Step 5, Current Node C, Path CL eliminated.



Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	49.598	C
E	52.438	D
F	62.993	D
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	58.649	C
M	∞	
Z	∞	

Fig 9: Step 6, Current Node D, Path DF eliminated.



Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	49.598	C
E	52.438	D
F	62.993	D
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	58.649	C
M	∞	
Z	55.436	E

Fig 10: Step 7, Current Node E, only one possible path EZ; Final Distance is 55.436 km

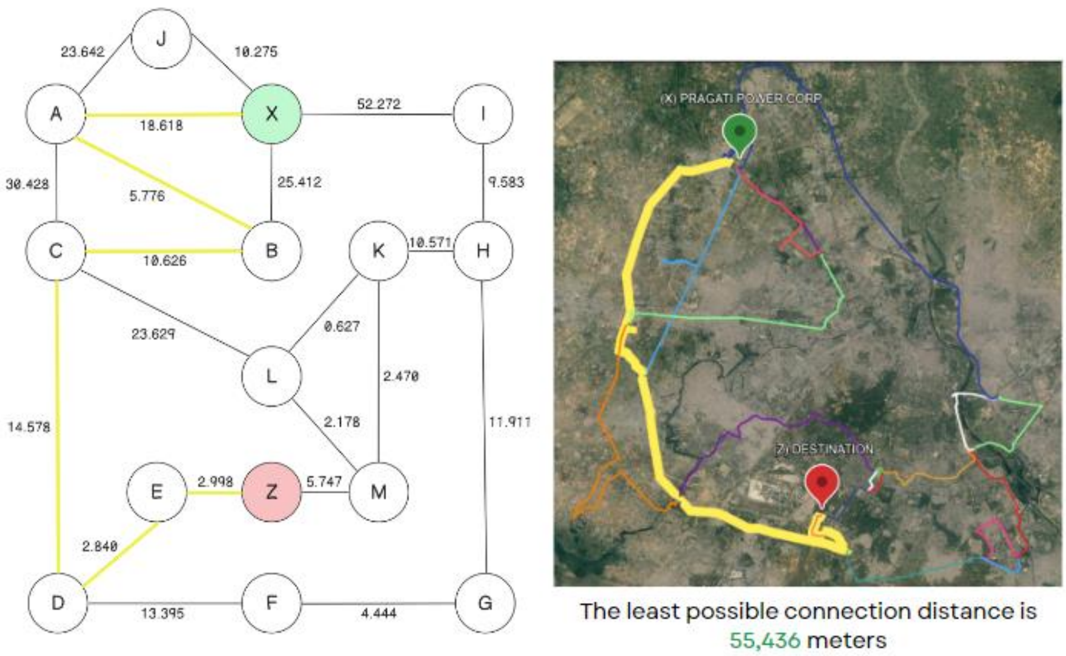


Fig 11: Final Path (yellow) is XABCDEZ, with distance 55436 meters.

RESULTS AND DISCUSSION

Model 1

The optimal energy mix for satisfying the energy vision for 2030 and bringing the carbon dioxide emission value to less than 20% of the original is satisfied by the following value of each source of energy.

Solar energy = 13.0998 TWh
Wind energy = 256.20 TWh
Small hydro energy = 6.41232 Twh
Biomass energy = 6.84156 Twh
Bagasse energy =0 Twh

Minimum expenditure on tariffs for the above renewable energy resources is :
Rs. 98,042 crores.

Bagasse poses challenges due to its carbon emissions and high cost. Hence, it may not be the most suitable option for Maharashtra's energy needs.

Model 2

Hence the number of each solar appliance installed under the 'Off-grid and Decentralised Solar PV Applications Programme Phase III' is:

Number of street lights = 120000
Number of solar lamps = 1000000
Number of 25kW solar plants = 2285.3433
Maximum power generated by these appliances is : 1.080093378209 TWh

Model 3

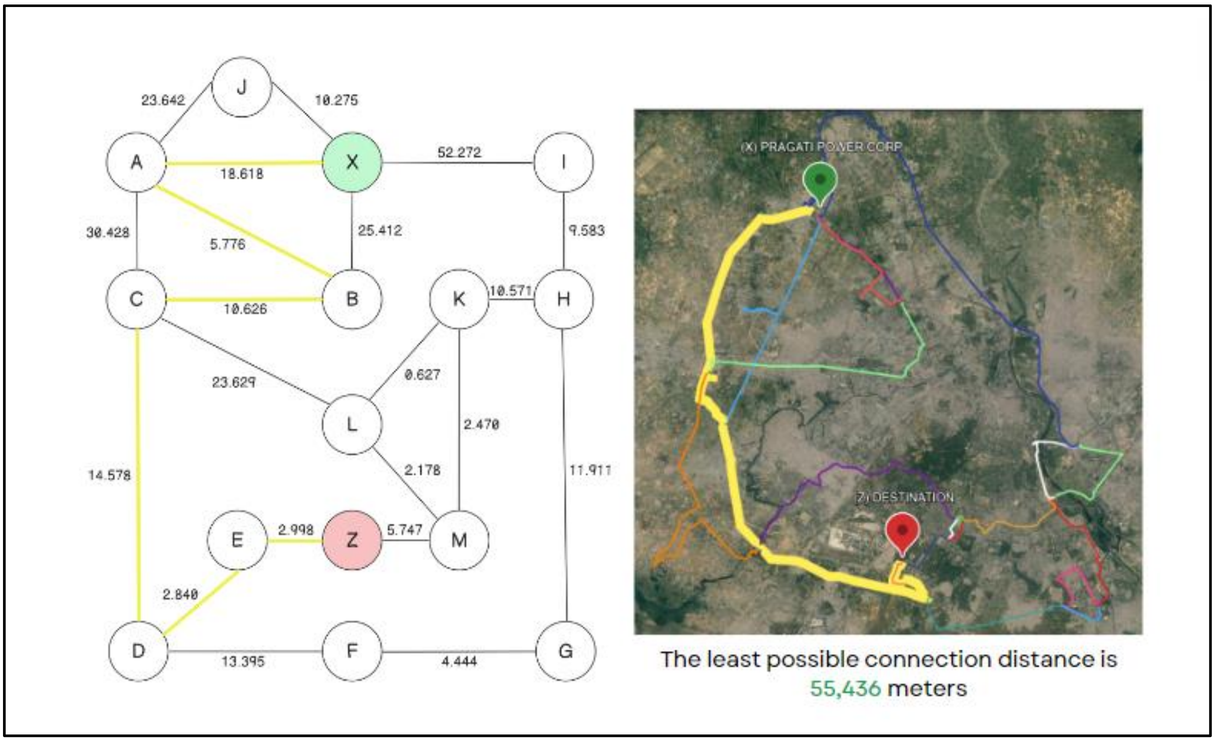
Energies	States	Power
Thermal	Gujarat	4150
Hydro	Maharashtra	447
Biofuel	Odissa	203
Wind	Rajasthan	185
Solar	Jharkhand	14
	Total	4999

The ideal solution to the above assignment problem suggests that Tata Power Company should assign Gujarat to generate thermal energy, Maharashtra to generate hydropower energy, Odisha to generate biofuel energy, Rajasthan to generate wind power energy, and Jharkhand to generate solar energy in order to maximize their power generation of 4999 MW.

Therefore, Maximum Power generated by Tata Power = **4999 MW**

Model 4

The shortest connection between the power source and the destination is found to be 55,436 meters or 55.436 km. The final path to be followed is XABCDEZ depicted by a yellow line in both the simplified graph and google earth graph.



FUTURE SCOPE

- Customised Modelling for Each State: The model can be tailored to incorporate specific data and parameters relevant to each state, such as geographical features, existing energy infrastructure, and policy frameworks. This customization ensures that the recommendations generated by the model are contextually appropriate for each state's unique circumstances.

- Localised Forecasting and Planning: The model can integrate localised weather forecasting data to predict renewable energy generation potential in each state with higher accuracy. This enables more precise planning and scheduling of energy production and distribution activities, taking into account variations in solar irradiance, wind patterns, and other environmental factors.

- Real-time Monitoring and Decision Support: The model can be coupled with real-time monitoring systems to continuously assess the performance of renewable energy installations in each state and provide decision support for optimising operational parameters such as energy dispatch, storage utilisation, and grid balancing. This ensures efficient and reliable operation of green energy infrastructure at the state level.

- Policy Simulation and Impact Assessment: Using the model, researchers can simulate the potential impact of different policy interventions and incentive schemes on renewable energy adoption in each state. By analysing various scenarios, policymakers can identify the most effective policy measures for accelerating the transition to green energy while minimising socio-economic disruptions.

LIMITATIONS

Model 1:

Capacity factors of each source of energy have been generalised and averaged out and might not be the perfect representation of extreme values of capacity factors of certain generators.

Time of functionality of each type of energy source is an idealistic one and does not represent time lost due to certain situational constraints like weather damage etc.

Model 2:

Lack of information about the quality of appliances installed has led us to rely on average wattage and average price of the said appliances in the market.

Efficiency of the appliances installed is assumed to be 100%.
We haven't taken the limitations of installation areas into consideration due to lack of information available.

Model 3:

The energy scenario of that state is not completely represented by Tata Power's position.
Assignment problem limits the solution to the allocation of only one source of energy in each state.

Model 4:

The data used is from June 2020 and more power lines might have been connected after that period that could give us a shorter distance connection.

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