SVKM'S NMIMS Deemed to be UNIVERSITY

NILKAMAL SCHOOL OF MATHEMATICS, APPLIED STATISTICS & ANALYTICS

OPTIMISING SCOPE OF RENEWABLE ENERGY IN INDIA

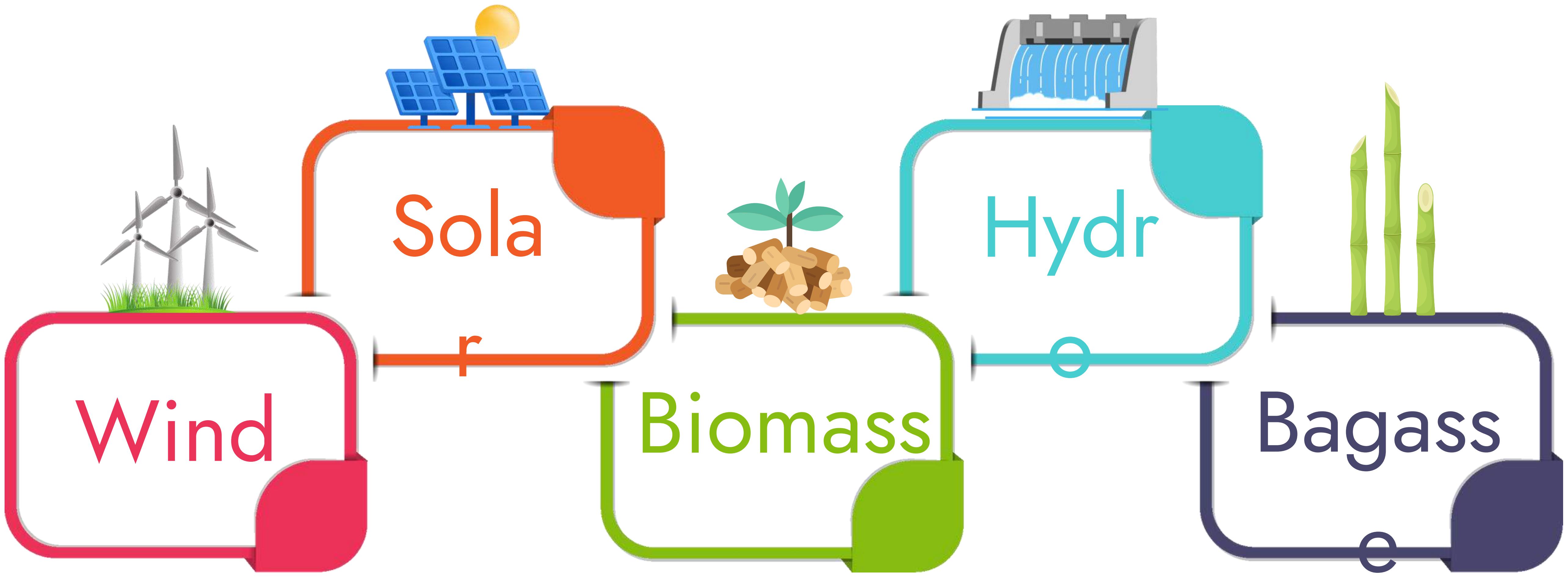
BUILDING A SUSTAINABLE FUTURE

PRESENTATORS: Achyut Damani, A005
Agrima Jain, A007
Nidhi Karambelkar, A010
Kimaya Shringarpure, A023
Aanchal Singh, A024

MENTORED BY: Dr. Debasmita Mukherjee

INTRODUCTION

Green energy refers to energy derived from natural, replenishable resources that have minimal impact on the environment. In today's world, the shift toward green energy has become imperative due to the escalating concerns related to climate change and the depletion of traditional energy resources.

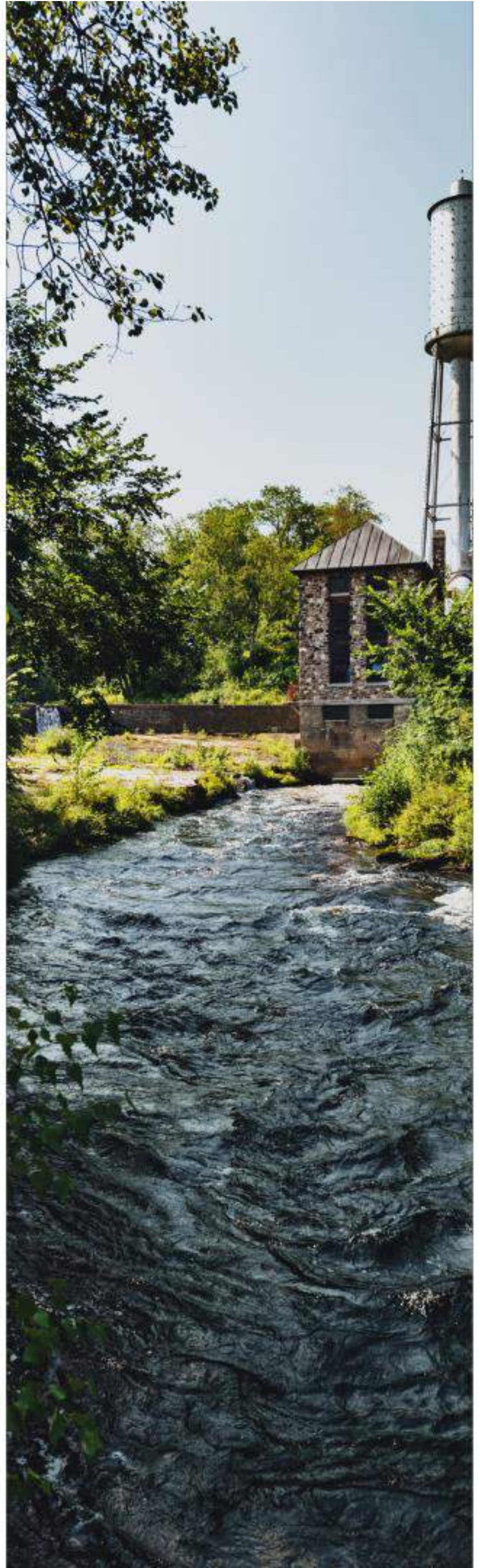


OBJECTIVES

- To assess India’s current capacity to harness renewable energy.
- To minimise expenditure on renewable energies by finding optimal mix for Maharashtra to harness.
- To maximise power generated by solar applicances in India.
- To allocate suitable energy resources to the states using assignment problem.
- To find the shortest connection between a green power plant and a sub-station using Dijkstra's Algorithm.
- To promote renewable energies in India

MODEL 1





EXPANDING RENEWABLE ENERGY IN MAHARASHTRA

In the light of R.K. Singh's statement, we decided to frame a problem where we would try to make renewable energy account for 55% for the electricity demand in Maharashtra based on the potential capacity of the state.

This is a distribution of the green sources of energy to achieve the minimum cost of tariffs required to make this vision seem achievable.

"The share of renewable energy in India's electricity mix is set to increase to around 55% by 2030, as the country continues to expand its installed capacity in the face of growing power demand."

-R.K. Singh, Power Minister of India

DATA

This model is based on the data for the year of 2022. According to various sources the data for tariffs of various renewable sources of energy is as follows:

Table 9.9 Potential and installed capacity of renewable energy in the State

(MW)

Source	Potential capacity	Installed capacity			
		As on 31st March			As on 31st December, 2022
		2020	2021	2022	
Wind	98,210	4,998	4,998	5,011	5,011
Bagasse co-generation	3,685	2,301	2,301	2,339	2,407
Solar	57,390	1,662	1,917	2,522	3,352
Small Hydro Projects (SHP)#	732	370	370	370	370
Biomass	781	215	215	215	215
Industrial waste	350	38	42	42	42
Urban solid waste	287	3	3	3	3
Total	**1,61,435**	**9,587**	**9,846**	**10,502**	**11,400**

potential capacity of various renewable sources of energy and the installed capacity of the same in MW till the date of 31st December, 2022.

DATA

Table 9.2 Sourcewise electricity generated

(MU)

Source	2019-20	2020-21	2021-22	2022-23+	Per cent change in 2021-22 over 2020-21
In the State	**1,23,314**	**1,15,060**	**1,31,682**	**1,01,511**	**14.4**
Thermal	95,460	87,690	1,01,443	79,609	15.7
Renewable$	13,751	15,813	17,970	15,593	13.6
Hydro	6,104	5,593	6,144	4,463	9.8
Natural gas	7,999	5,964	6,125	1,846	2.7
Received from central sector	**34,988**	**36,611**	**39,581**	**32,832**	**8.1**

Note: 1 Unit = 1 Kilo Watt Hour $ including captive power + upto December

Above is the table stating the amount of electricity generated by each source in the state and we take the cumulative i.e. **1,01,511 GWh** as the total electrical energy generated in the state as the total value from which 55% of of the quantity has to be generated by the potential capacity of renewable sources of energy.

OBJECTIVE FUNCTION

Our objective function will be to minimize the total cost of tariffs:

Minimize Z = 3.075x1+3.275x2+5.8x3+9.3386x4+ 6.33x5

x1:Number of units of energy in produced by solar
x2:Number of units of energy in produced by wind
x3:Number of units of energy in produced by hydro
x4:Number of units of energy in produced by biomass
x5:Number of units of energy in produced by bagasse

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

CONSTRAINTS

The unit of each energy generated 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.

I) $x1<=1.8852615 \times 10^{11}$

II) $x2<=8.603196 \times 10^{11}$

III) $x3<=6.41232 \times 10^{9}$

IV) $x4<=6.84156 \times 10^{9}$

V) $x5<=1.7485325 \times 10^{10}$

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

$$\text{Energy} = \text{Potential Capacity x Hours x 365}$$

CONSTRAINTS

The **capacity factor** of each source of energy 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 current in Maharashtra.**

55% of current electricity supply=101511*1000000*0.55 =5.583105×10^{10} KWh
VI) $\boldsymbol{0.19x1+0.18x2+0.38x3+0.7x4+0.6x5>=5.583105 \times 10^{10}}$

Energy	Capacity Factor
Solar	19%
Wind	18%
Hydro	38%
Biomass	70%
Bagasse	60%

CONSTRAINTS

Carbon Emissions

The total greenhouse gas (GHG) emissions in 2021-22 were 310 million tonne CO_2 equivalent(CO_2e) in Maharashtra. As an endeavour to reach India's goal of net zero carbon emissions.

Taking less than 2% of total carbon emissions,

VII) $\mathbf{42x_1 + 11x_2 + 9.05x_3 + 230x_4 + 890x_5 <= 5000000000000}$

$x_1, x_2, x_3, x_4, x_5 >= 0$

Energy Type	CO_2 emissions
Solar energy	42 gms/kWh
Hydro Energy	9.05gms/kWh
Wind Energy	11 gms/kWh
Biomass Energy	230 gms/kWh
Bagasse Energy	890 gms/kWh

SOLUTION

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	

SOLUTION

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	

FINDINGS

On solving this problem with the Big M method, we get the values of each renewable source of energy as:

Hence, optimal solution is arrived with value of variables as :

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**

Min tariff= **Rs. 98042.4667 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

DATA

'The Off-grid and Decentralized Solar PV Applications' Programme as part of the National Solar Mission is primarily focused on providing energy access solutions in the rural and remote areas Under Phase-III of the Programme, it is targeted to create 118 MWp equivalent solar power capacity by 31.03.2020 through off grid solar PV applications. The Phase-III of the Programme, for which approval was issued on 7 August 2018 covers installation of (i) 3,00,000 solar street lights; (ii) off-grid solar power plants of individual size up to 25 kWp and total aggregated capacity of 100 MWp for providing electricity to schools, hostels, panchayats, police stations and other public service institutions; and (iii) distribution of 25,00,000 solar study lamps to school going children in North Eastern States and LWE affected districts.

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

OBJECTIVE FUNCTION AND CONSTRAINTS

Maximization of power generated by the appliances funded by ‘Off-grid and Decentralised Solar PV Applications Program Phase 3’ program of govt of India for the year 2018-2020 according to the budget allocated for 2018-2020.

Energy generated (kWh) in two years = (power rating in W x Hours a day x 365 x 2)/1000

Variables

x1	Solar street light
x2	solar lamp
x3	solar power plant

OBJECTIVE FUNCTIONS AND CONSTRAINTS

Objective Function

Maximizing Z = 286.671x1+ 44.7125x2+ 438000x3

subject to constraints:

11040x1+ 1407.25x2 +16,75,000x3<=6,56,00,00,000

x2>=1000000

x1>=120000

x3>=1600

x1<=3,00,000

x2<=25,00,000

x3<=4,000

[The lower constraint is about 40% of the sanctioned capacity because the generally about 46-50% of the sanctioned capacity is installed in other phases of off-grid programmes.]

SOLUTION

Iteration-1		Cj	286.671	44.7125	438000	0	0	0	0	0	0	0	-M
B	CB	XB	x1	x2	x3	S1	S2	S3	S4	S5	S6	S7	A1
S1	0	6560000000	11040	1407.25	1675000	1	0	0	0	0	0	0	0
S2	0	300000	1	0	0	0	1	0	0	0	0	0	0
S3	0	2500000	0	1	0	0	0	1	0	0	0	0	0
S4	0	4000	0	0	1	0	0	0	1	0	0	0	0
A1	-M	1600	0	0	-1	0	0	0	0	-1	0	0	1
A2	-M	1000000	0	1	0	0	0	0	0	0	-1	0	0
A3	-M	120000	1	0	0	0	0	0	0	0	0	-1	0
Z=-1121600M		Zj	-M	-M	-M	0	0	0	0	M	M	M	-M
		Cj-Zj	M+286.671	M+44.7125	M+438000 ↑	0	0	0	0	-M	-M	-M	0

Iteration-5		Cj	286.671	44.7125	438000	0	0	0	0	0	0	0	
B	CB	XB	x1	x2	x3	S1	S2	S3	S4	S5	S6	S7	MinRatio
S5	0	685.3433	0	0	0	0	0	0	0	1	0.0008	0.0066	
S2	0	180000	0	0	0	0	1	0	0	0	0	1	
S3	0	1500000	0	0	0	0	0	1	0	0	1	0	
S4	0	1714.6567	0	0	0	0	0	0	1	0	-0.0008	-0.0066	
x3	438000	2285.3433	0	0	1	0	0	0	0	0	0.0008	0.0066	
x2	44.7125	1000000	0	1	0	0	0	0	0	0	-1	0	
x1	286.671	120000	1	0	0	0	0	0	0	0	0	-1	
Z=1080093378.209		Zj	286.671	44.7125	438000	0.2615	0	0	0	0	323.2729	2600.2066	
		Cj-Zj	0	0	0	-0.2615	0	0	0	0	-323.2729	-2600.2066	

FINDINGS

On solving this problem with the Simplex method, we get the values of each renewable Appliance as:

Since all $C_j - Z_j \leq 0$

Hence, optimal solution is arrived with value of variables as :

Number of street lights= **120000**

Number of solar lamps=**1000000**

Number of 25kW solar plants=**2285**

Hence the maximum power generated by these appliances would be **1.080093378209 TWh**

MODEL 3

DATA

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

Assign energy resources each state to tata power company in such a manner to maximise power

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

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

Step 2: Find out the each row 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)

Step 3: Find out the each column 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)

Step 4: Make assignment in the opportunity cost 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

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

Step 5: Cover the 0 with 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)				

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

Repeat steps 4 to 6 until an optimal solution is obtained

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

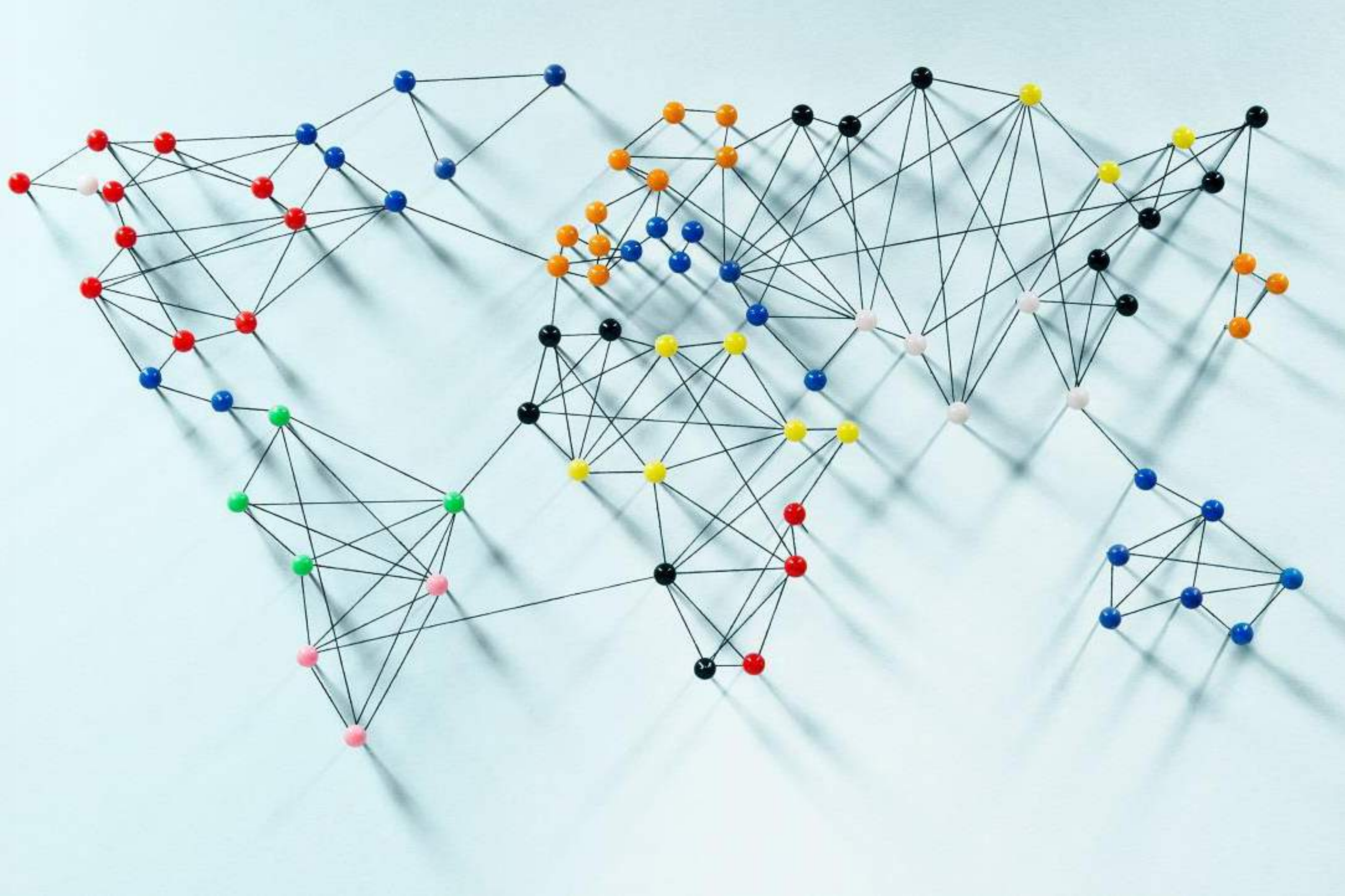
Number of assignments = 5, number of rows = 5 which is equal, so solution is optimal

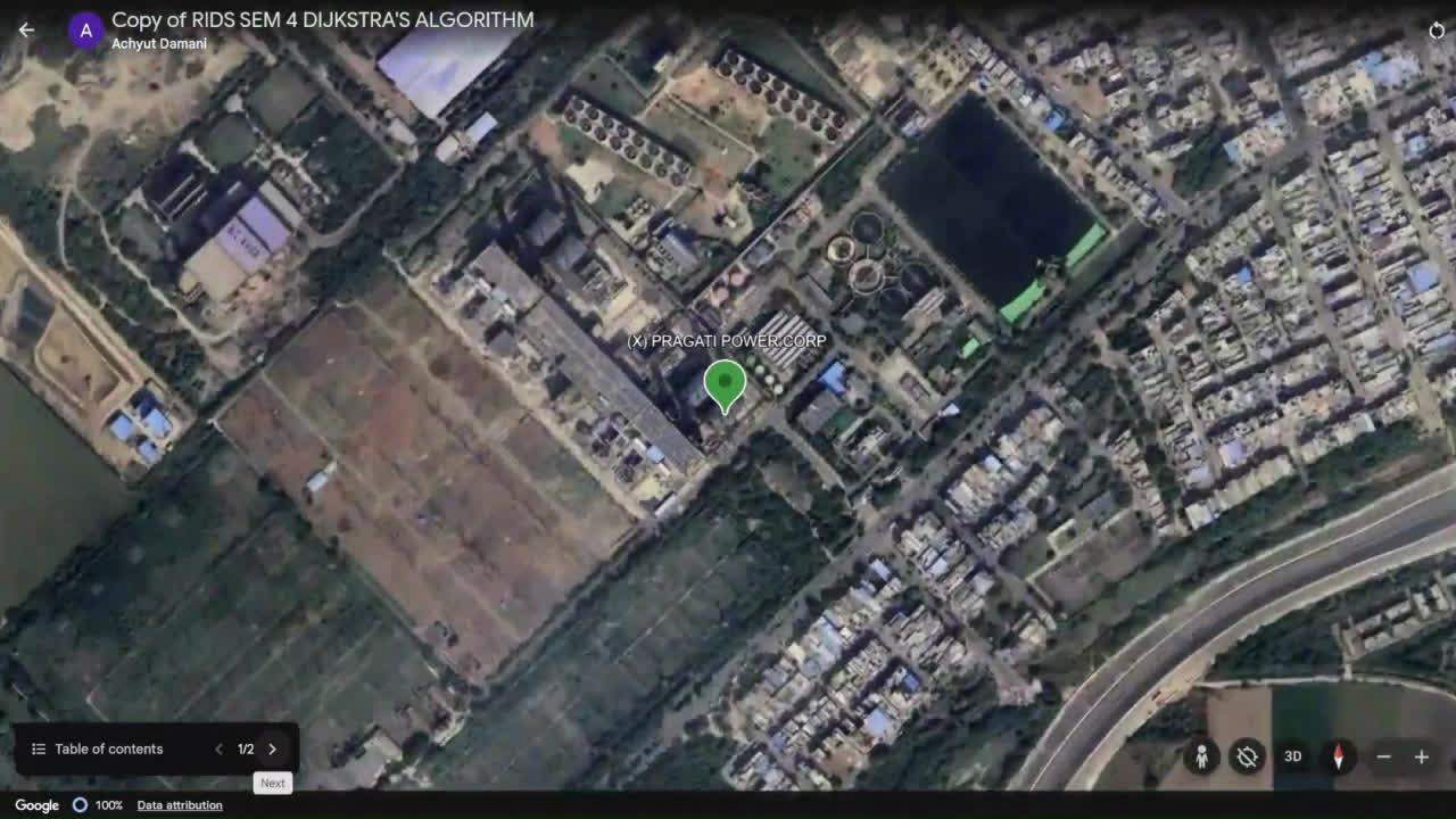
Maximum Power = **4999 MW**

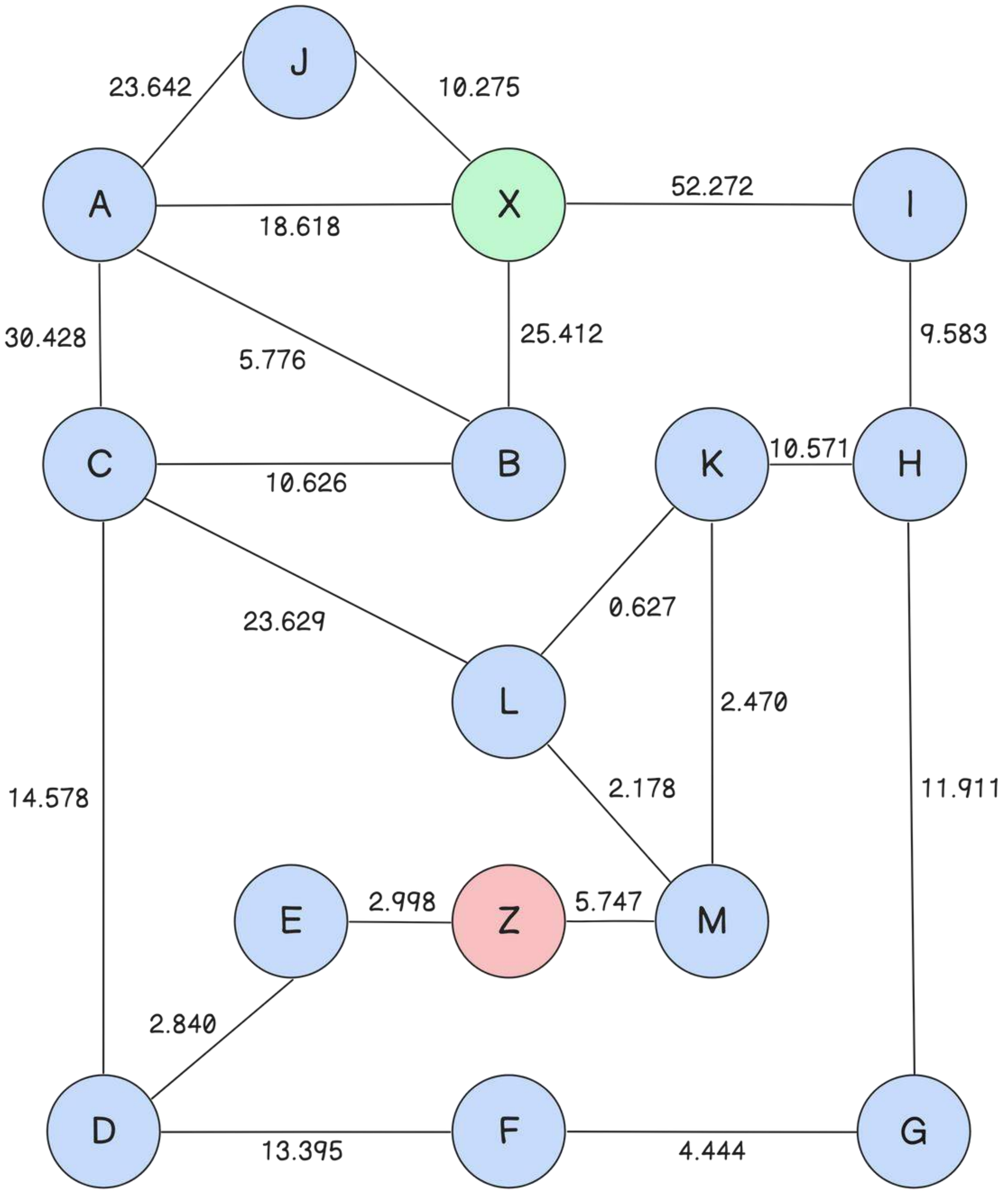
Optimal solution

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

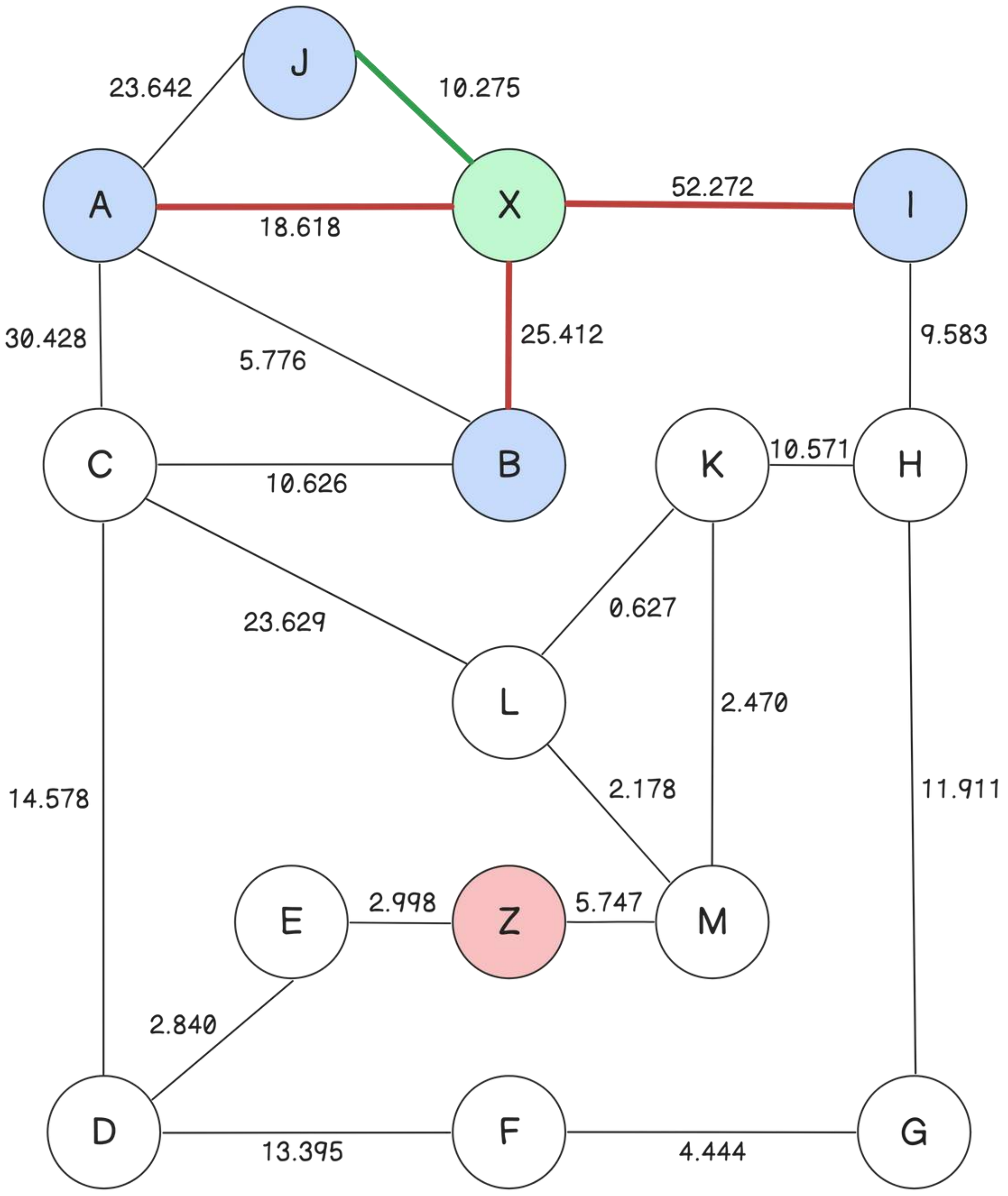
MODEL 4



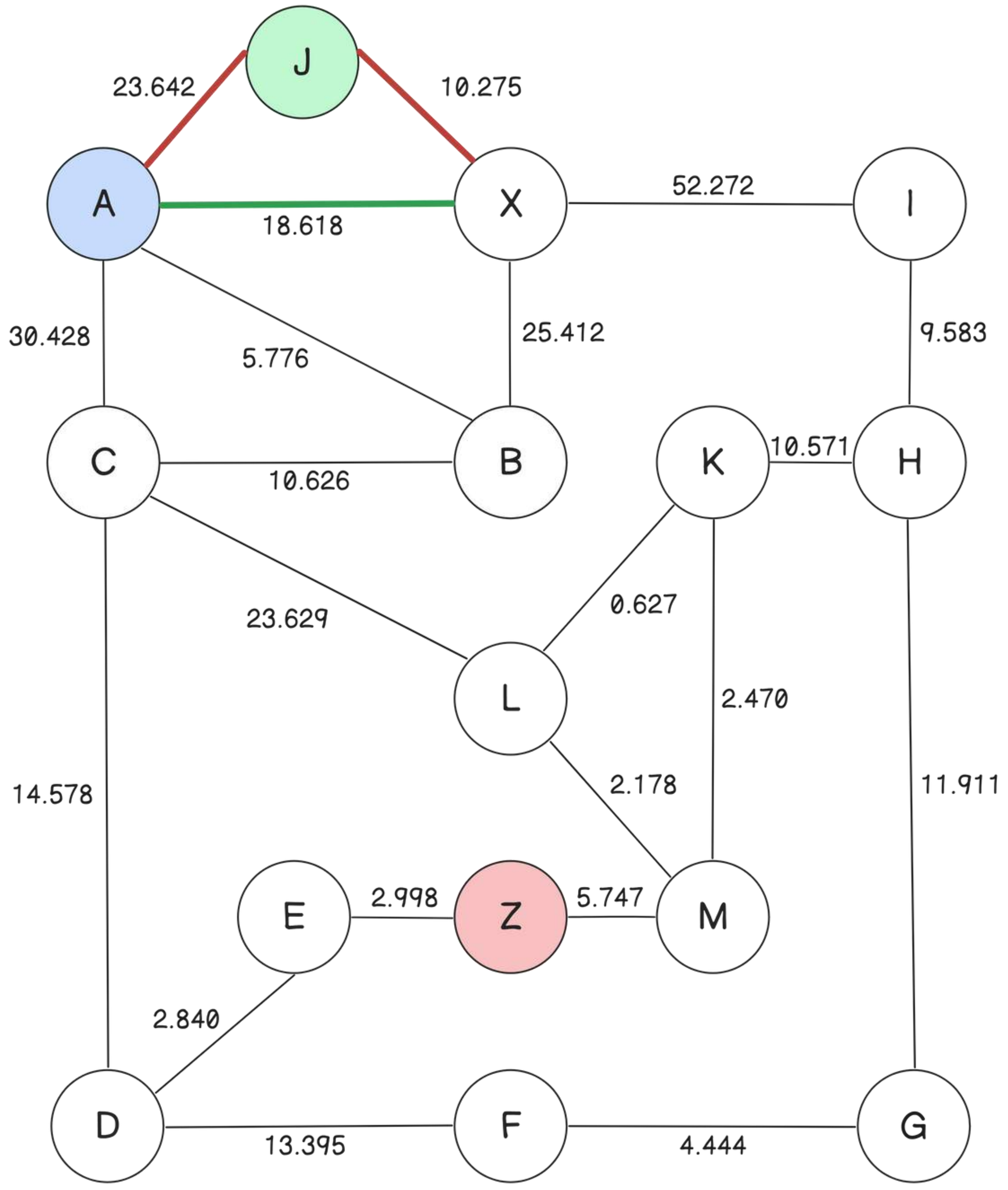

Copy of RIDS SEM 4 DIJKSTRA'S ALGORITHM
Achyut Damani
(X) PRAGATI POWER CORP
Table of contents
1/2
Next
3D
Google
100%
Data attribution



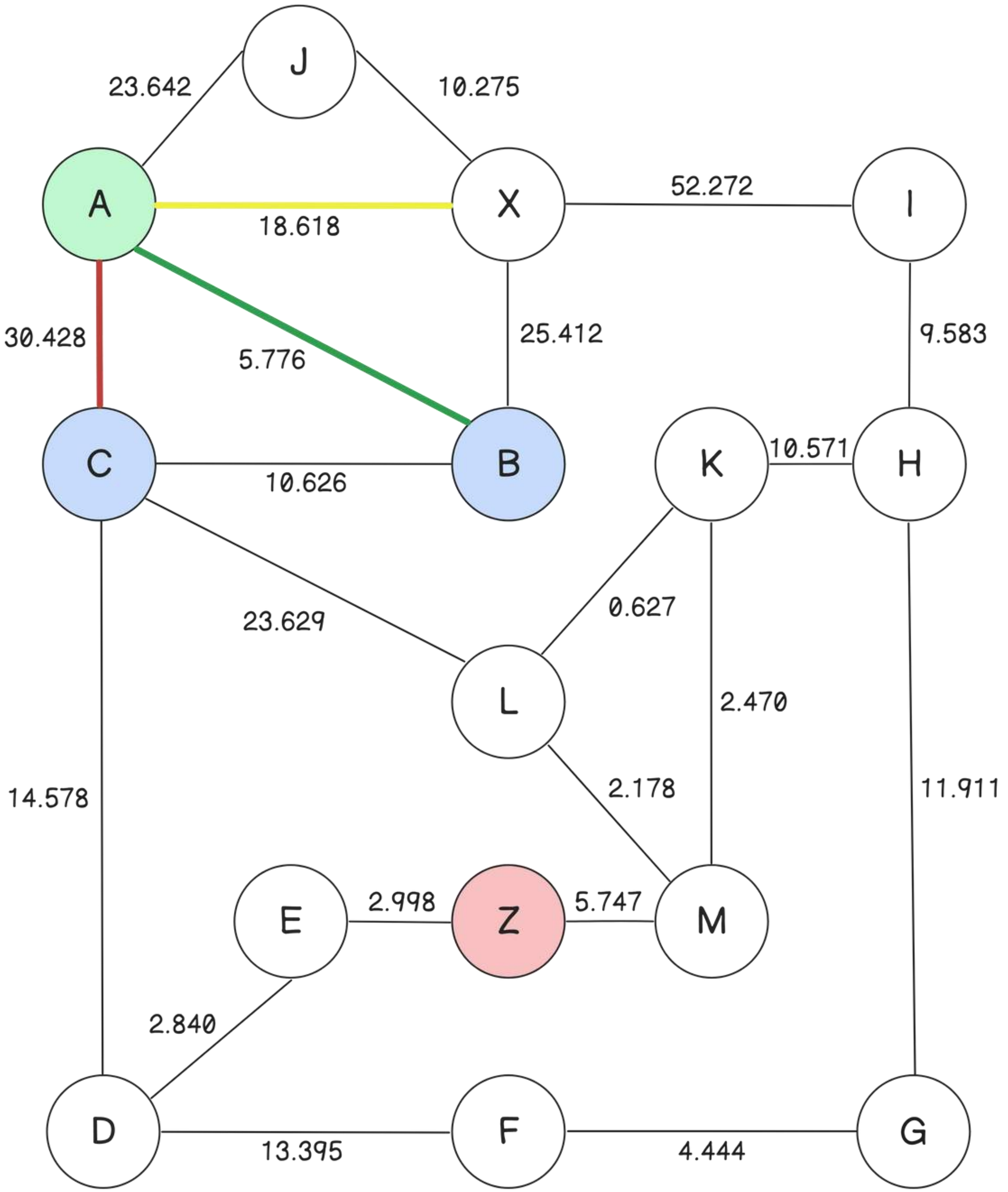
Node	Distance	Previous Node
X	0	
A	∞	
B	∞	
C	∞	
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	∞	
J	∞	
K	∞	
L	∞	
M	∞	
Z	∞	



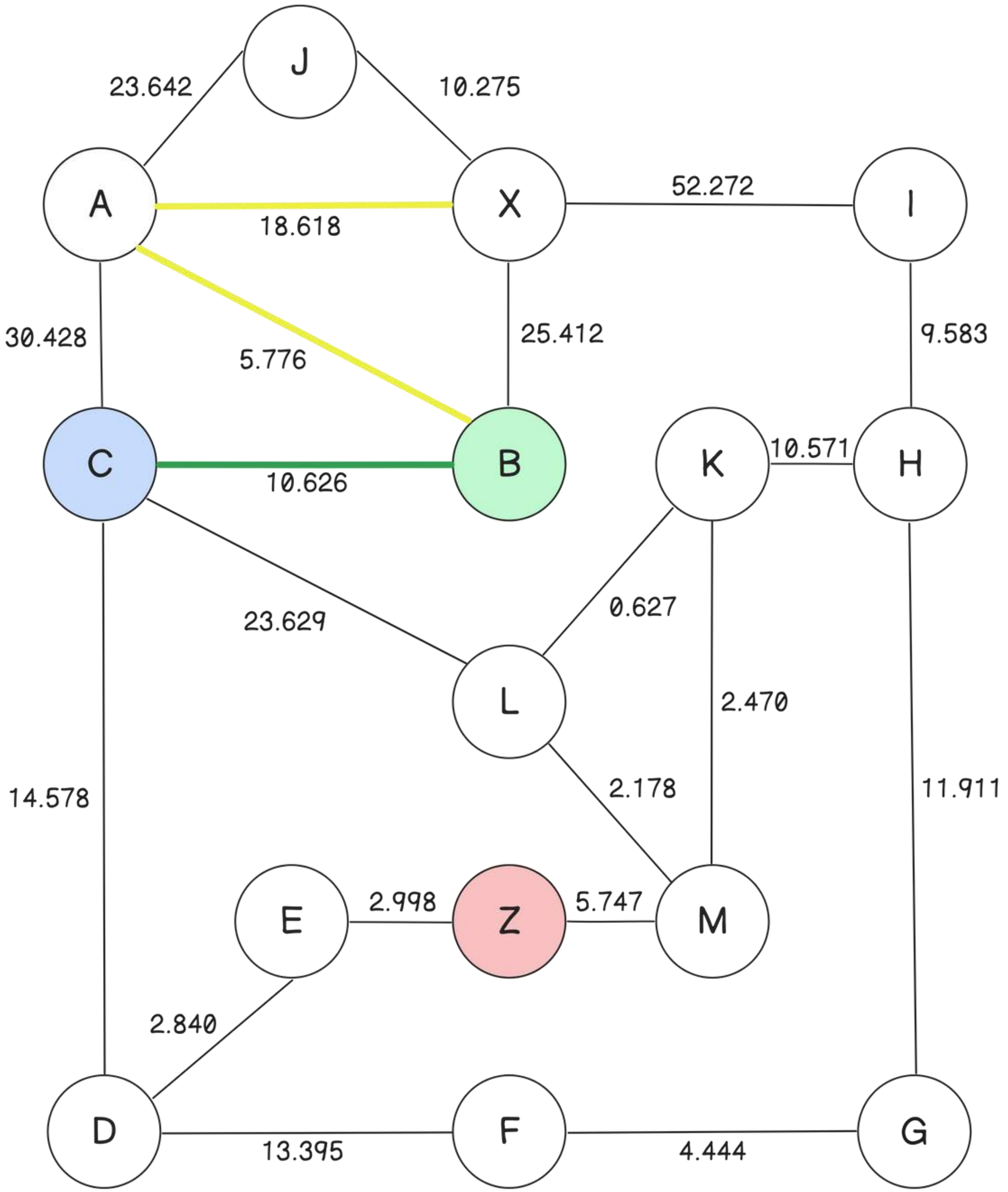
Node	Distance	Previous Node
X	0	
A	18.618	X
B	25.412	X
C	∞	
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	



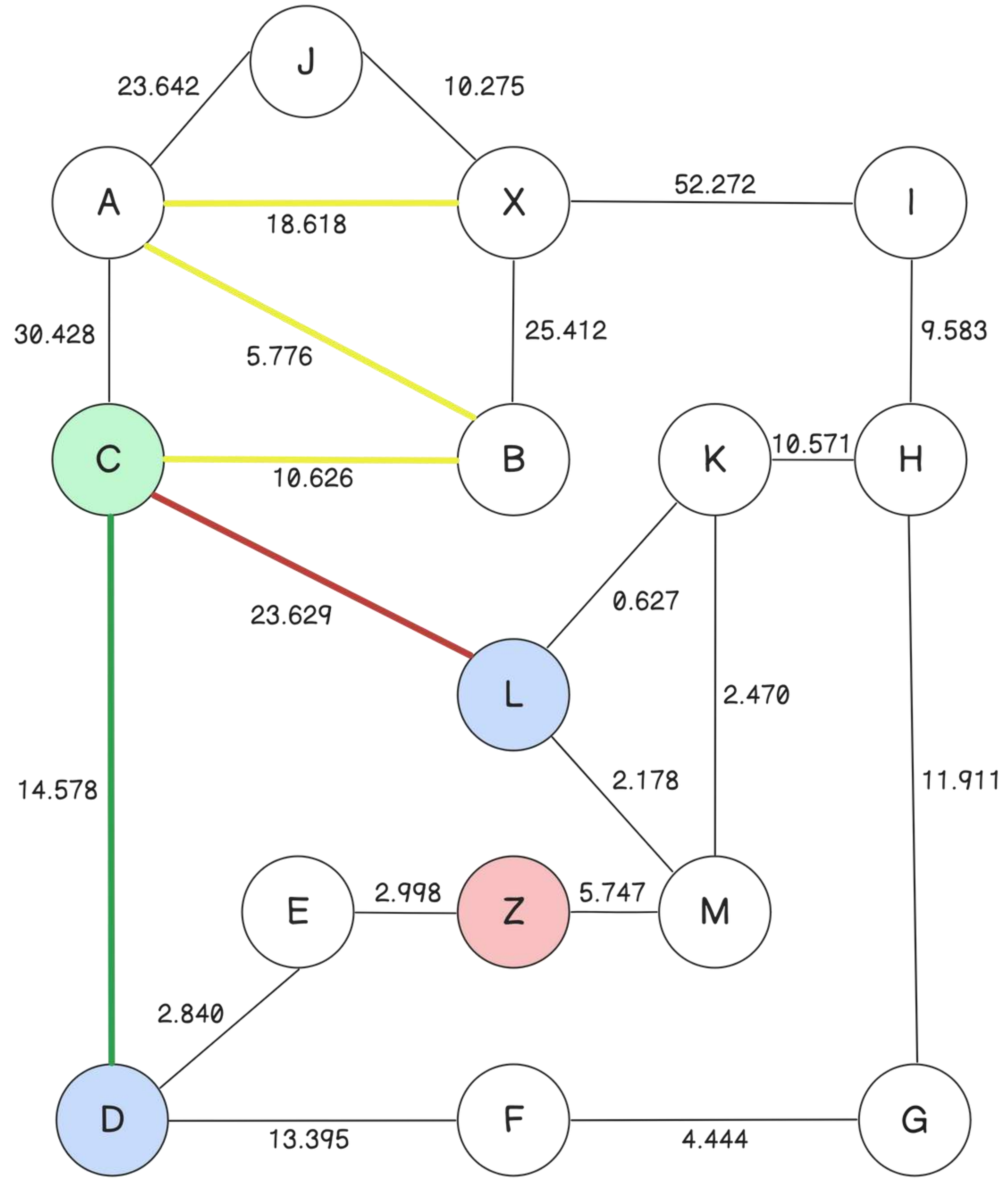
Node	Distance	Previous Node
X	0	
A	18.618	X
B	25.412	X
C	∞	
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	



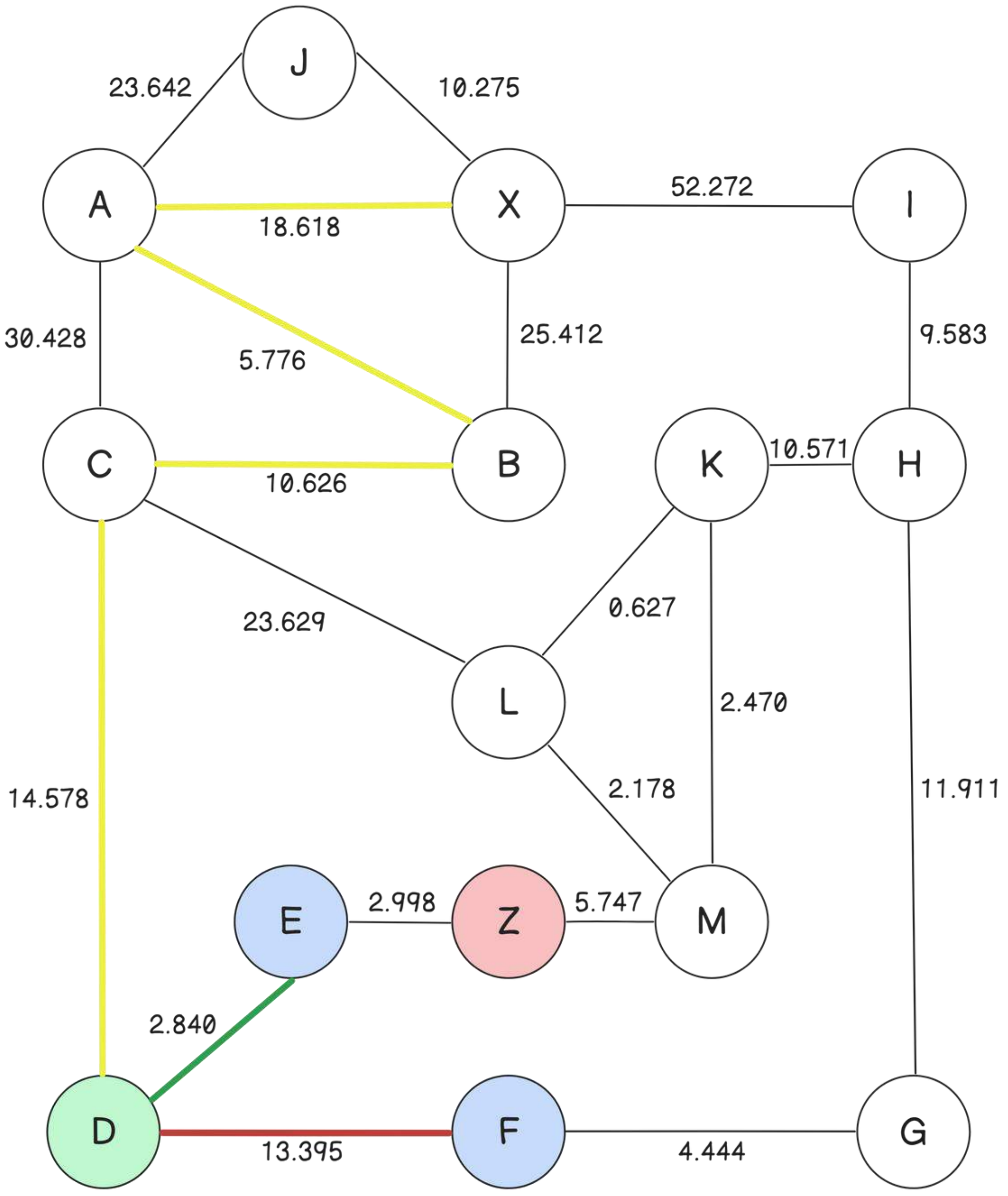
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	49.046	A
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	



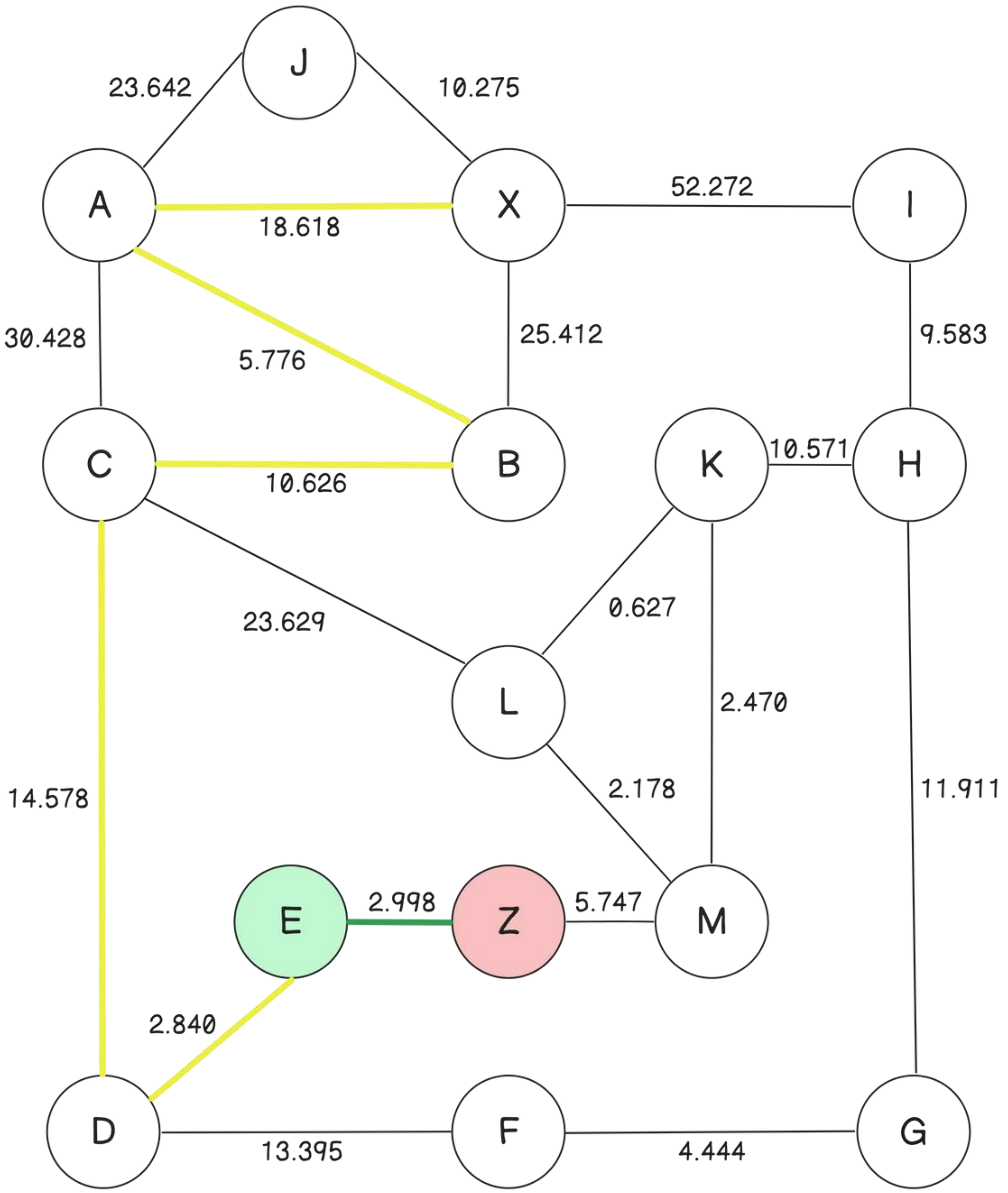
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	∞	
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	∞	
M	∞	
Z	∞	



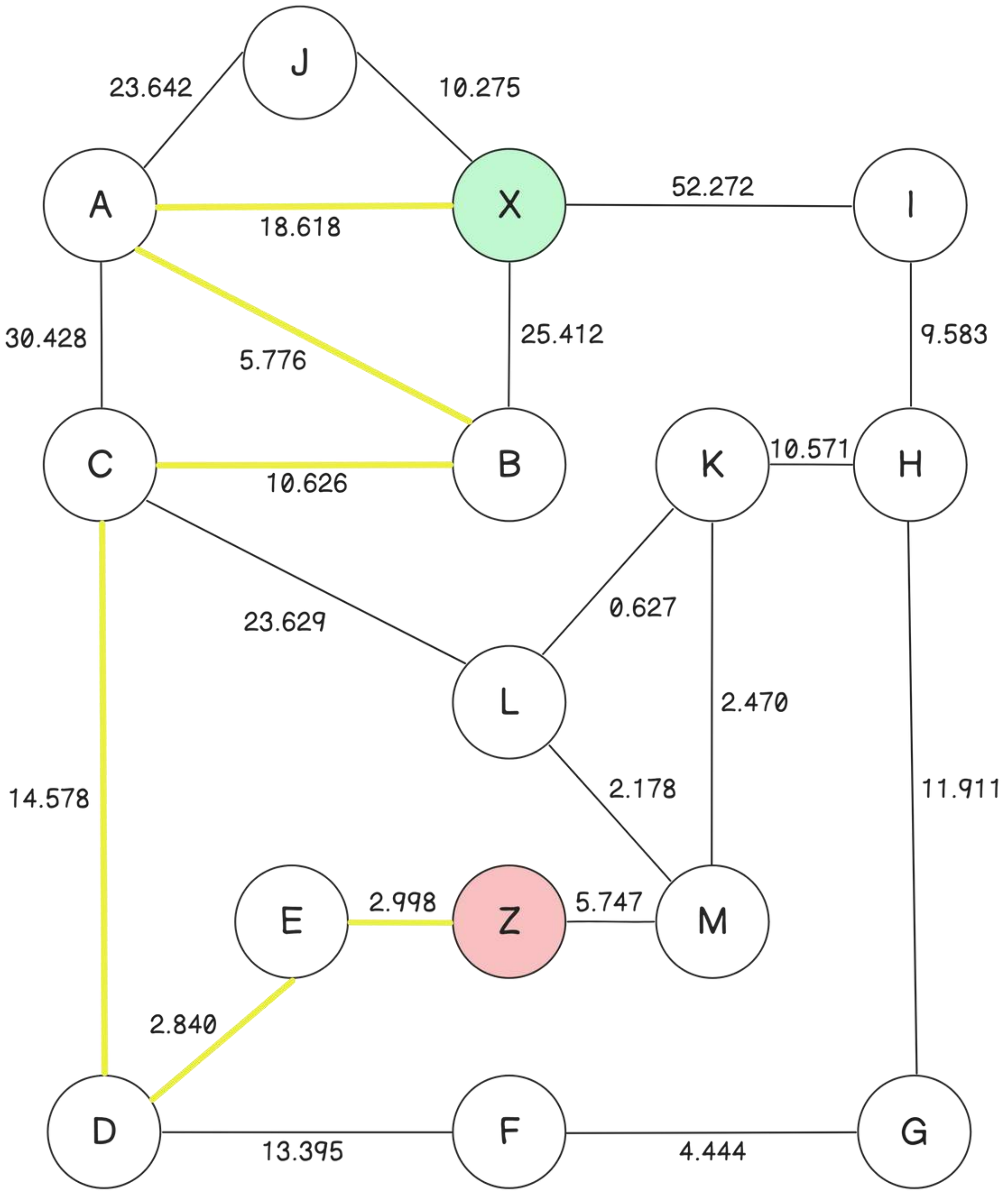
Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	49.598	C
E	∞	
F	∞	
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	58.649	C
M	∞	
Z	∞	

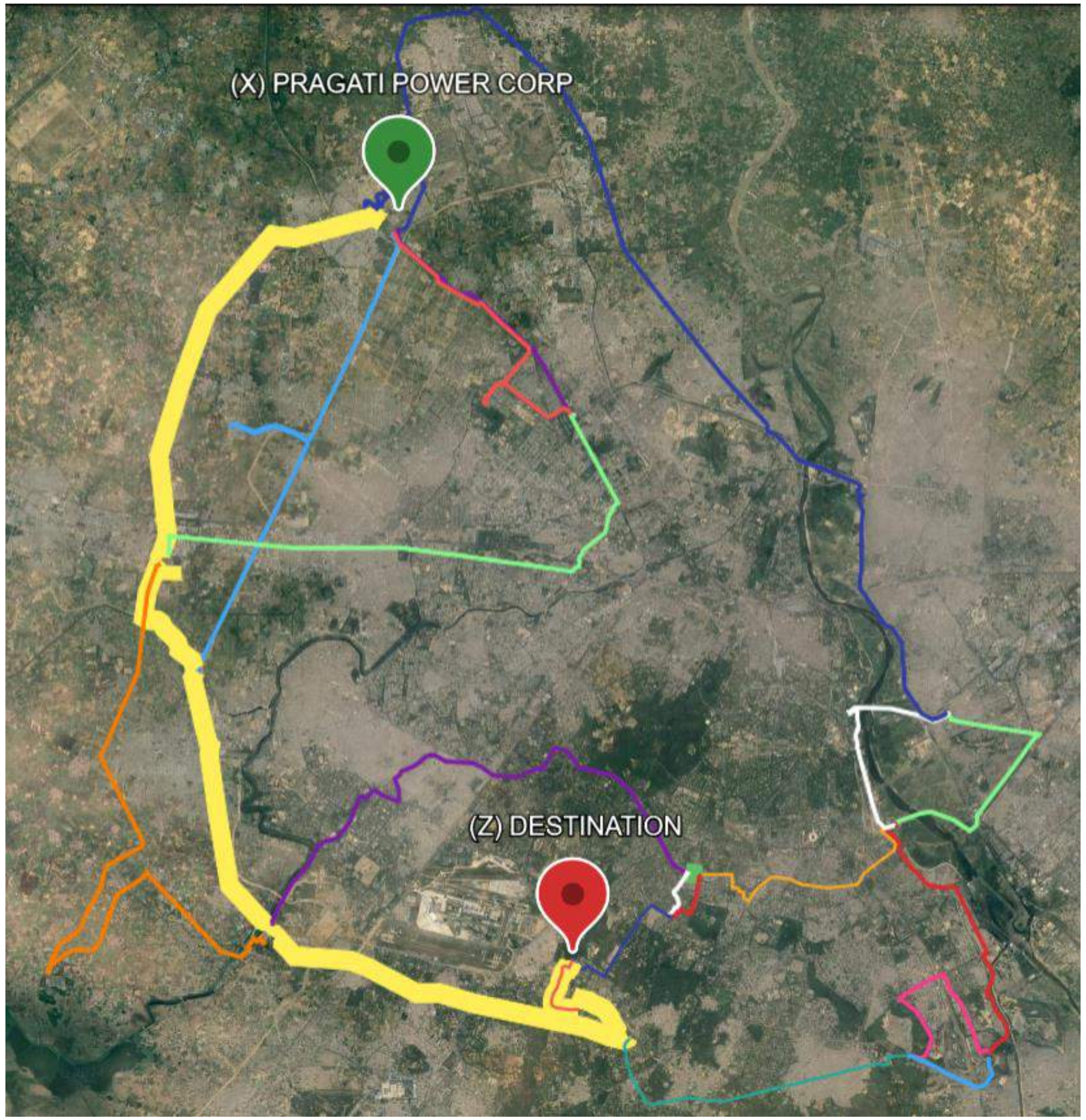


Node	Distance	Previous Node
X	0	
A	18.618	X
B	24.394	A
C	35.02	B
D	49.598	C
E	52.438	D
F	62.993	D
G	∞	
H	∞	
I	52.272	X
J	10.275	X
K	∞	
L	58.649	C
M	∞	
Z	∞	



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





The least possible connection distance is 55,436 meters

CONCLUSION

India's steps forward in transformation of its energy sector to a greener one have been incredibly ambitious with a lot of initiatives and schemes being introduced and hefty steps being taken to expand this sector. Our project aims to give a calculated representation of the vision that India aspires to reach and hopes to set a pertinent example for development in this sector with the aid of our efforts.

REFERENCES

M.M. Kamal, I. Ashraf, and E. Fernandez, "Energy Resource Allocation for Distributed Energy Resource Based Power Generation in a Rural Microgrid," in 2018 Third International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT), pp. 571, Dec. 2018.

CERC, "CERC RE Tariff Order for FY 2022-23," Central Electricity Regulatory Commission, Petition No. 14/SM/2022, New Delhi, November 7, 2022.

R.M. Elavarasan et al., "A Holistic Review of the Present and Future Drivers of the Renewable Energy Mix in Maharashtra, State of India," Energies, vol. 13, no. 16, Aug. 2020.

E. López, R.F. Domínguez-Cruz, and I. Salgado-Tránsito, "Optimization of Power Generation Grids: A Case of Study in Eastern Mexico," Math. Comput. Appl., vol. 26, p. 46, 2021.

K. G. K. NAIR and Prof. P. B. SUGATHA KUMAR, “A LINEAR PROGRAMMING APPROACH FOR THE INSTALLATION OF ENERGY SAVING DEVICES,” journal-article, 1996.

S. Jebaraj, S. Iniyan, and R. Goić, “An optimal electricity allocation model for sustainable resource use in India,” International Journal of Energy Research, vol. 37, no. 8, pp. 923–935, Feb. 2012, doi: 10.1002/er.2896. Available: https://doi.org/10.1002/er.2896

REFERENCES

S. Subramaniyan, M. Mathew, J. Hossain, and A. Kumar, “Capacity Value Estimation of Renewable Energy in Maharashtra using Peak Period Method,” TERI University, 2018.

DIRECTORATE OF ECONOMICS AND STATISTICS, PLANNING DEPARTMENT, GOVERNMENT OF MAHARASHTRA, MUMBAI and V. Aher, “Economic Survey of Maharashtra 2022-23,” Mar. 2023.

S. Kumar, I. M. Bohari, and M. Khullar, “MERC Mid-Term Review Order for MSEDCL for Truing-up of ARR for FY 2019-20, FY 2020-21 and FY 2021-22, Provisional Truing-up of ARR for FY 2022-23 and revised ARR for FY 2023-24 and FY 2024-25,” report, Mar. 2023.

J. K. Jethani, “Continuation of Off-grid and Decentralised Solar PV Applications Programme in Phase III for financial years 2018-19 and 2019-20,” Aug. 2018.

Government of India and I. Ahmad, “All India electricity statistics: General Review 2023 (Containing Data for the Year 2021-22),” Central Electricity Authority, report, Jun. 2023.

“Comparing CO2 emissions from different energy sources,” COWI. Available: https://www.cowi.com/about/news-and-press/comparing-co2-emissions-from-different-energy-sources

REFERENCES

The Tata Power Company Limited, “Integrated Annual Report 2022-23,” 2023.

Ministry of New and Renewable Energy, Government of India, “ANNUAL REPORT 2022-23,” 2023.

“Continuation of Off-grid and Decentralised Solar PY Applications Programme in Phase III for Financial Years 2018-19 and 2019-20,” Ministry of New and Renewable Energy. Available: https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/02/2023021085.pdf

Open City Urban Data Portal, “Delhi Power Grid Data”. Available: https://data.opencity.in/dataset/delhi-power-grid-data.

THANK YOU