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Solar Energy Generation Based Urban Development: A Case of Jodhpur City

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Abstract**—**India has the most year-round favorable sunny conditions along with the second-highest solar irradiation in the world, the country holds the potential to become the global solar hub. The solar and wind-based generation capacity has skyrocketed in India with the successful effort of the Ministry of Renewable Energy, whereas the potential of rooftop based solar power generation has yet to be explored for proposed solar cities in India. The research aims to analyze the gap in the energy scenario in Jodhpur City and proposes interventions of solar energy generation systems as a catalyst for urban development. The research is based on the system concept which deals with simulation between the city system as a whole and its interactions between different subsystems. A system-dynamics based mathematical model is developed by identifying the control parameters using regression and correlation analysis to assess the gap in energy sector. The base model validation is done using the past 10 years timeline data collected from secondary sources. Further, energy consumption and solar energy generation-based projection are made for testing different scenarios to conclude the feasibility for maintaining the city level energy independence till 2031.

Keywords**—**City, consumption, energy, generation.

I. Introduction

INDIA being the third-largest economy in the world, a greater number of the population (more than two-thirds of the total population) lives in villages and started to consume more quantity of energy in the recent years. Developed countries have developed a well-designed information and communication system to integrate Solar Energy Generation infrastructure at the city level. Germany was adding around 400 MW every month in 2010, whereas Germany receives only half of the solar radiation compared to India but has a generation capacity of 3400 MW in 2015 [5]. The reason behind such a growing success is their GIS-based application and efficient solar energy planning as per a report published by TERI, New Delhi in 2019 [8]. The urge to fulfill the gap in demand and supply has led us to a catastrophic challenge of global warming caused by deforestation and greenhouse gas emissions. When it became a concern of the future of mankind, developed and developing nations came together with a national action plan on climate change. It requires proper resource mobilization to harness energy from these naturally available sources. Solar energy is universally available around the country and has a huge demand due to the maximum favorable condition. The Western part of India has large unused land and has maximum sunny days around the year. India receives the second-highest solar irradiation of 4-7 kWh/M^2 in the world as per the report published in 2015 by the Ministry of Renewable Energy, India [3], [4]. There is no doubt about manifold growth from 2014 to 2017 in solar energy generation, but this entire capacity has very little contribution from the urban system, which is proposed under the national program of solar city and smart city. As per the power generation capacity of India, the country is ranked among the top six nations. India has recorded a thermal-power- generation of 158496 MW (70%) and a renewable power generation of 31696 MW, which is only 12% of the total power generation of 261006 MW during the year 2015 [3]. The Indian power sector is majorly dependable on thermal-based power generation whereas coal-based power generation alone contributes to 86.77% of total thermal power generation capacity (158496 MW). Population exposition and comparatively slow growth of power generation capacity of secondary sources resulted in the demand-supply gap of 3.8% (4.6% peak) in Feb 2014 and 2.5% (2.8% peak) in Feb 2015. Per capita power consumption in India is 957 kWh (as in 2014) with the cost of supply is 3.74 Rs./kWh [3].

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II. Study Area at a Glance

Jodhpur city is also known as Sun City and Blue City of Rajasthan state, India. Jodhpur city lies between 26 00' and 27 37' North latitudes and 72° 55' to 73°52' East longitudes. Population wise, Jodhpur district holds the second rank out of 33 districts in the state, after Jaipur. Jodhpur district is centrally located in the Western part of the State. It is a divisional headquarter of Western districts of the State, and shares boundary with Pali, Jodhpur, Sirohi, Barmer, Jalore, and Jaisalmer district. The District is spread over 22850 km^2 which is 6.59% of the total area of the State, and shares 11.6% of the area under the arid zone of Rajasthan [7]. Jodhpur is majorly habituated by the Hindu religion, which consists of cast Brahmin, Rebari, Choudhari, Jangid, etc., and the remaining 13%, 3.7 0% and 1.3% are respectively Muslim, Jain and Christian (including Sikh and others). The city is the origin of Maarwad's social and cultural values. In 1901, the population of the city was 79,109, and it has increased to 1,033,918 in 2011. Its Urban/Metropolitan population is 1,137,815 of which 599,332 are males and 538,483 are females. Higher-level population growth of an average of 30% is expected in the next two decades. It consumed 13813 lakh units of electrical energy in 2015 [6], [7]. Domestic energy consumption in Jodhpur city has increased 61.15% from 2010 to 2015, i.e in 2010 it was 2950 lakh units, and in 2015, it was

4754 lakh units [5].

III. System Dynamics Technique

A. System and Its Subsystems

A system and its subsystem are defined as "A system functions as a whole with the interaction of several subsystems. All the subsystems of the system are interlinked and interdependent to each other and forming a system. If one of the subsystems defunct, or partly functions or functions with a higher degree (taking a lead role) during its function, its effects can be visualized in the entire system over a period. In some cases, the system would not function at all, while in some cases the system may function with a lot of disturbances or the smooth functioning of the system may be paralyzed"[1].

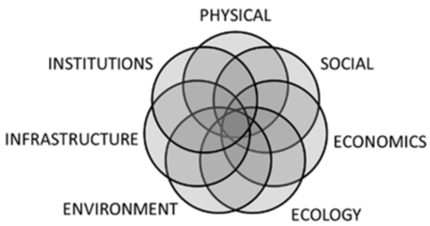

Fig. 1 Urban Dynamics System with its Subsystems

System concept enables us to assess the functions of multiple variables of all the subsystems and interrelations. They are then connected to citizen information systems (distinguished from management information systems) and to mixed, adaptive, conditional models for urban planning. The system concept permits dynamic action and reaction within multiple variables to allow stakeholders and experts to make conditional inputs, allowing them to change values and objectives, at each stage, and it makes the system's consequences apparent. The approach provides better control to study causal relationships, uncertainty, linear and non-linear dynamic relationships within variables of each subsystem. Dynamic functions of the urban system and the city with its subsystems are presented in Figs. 1-3.

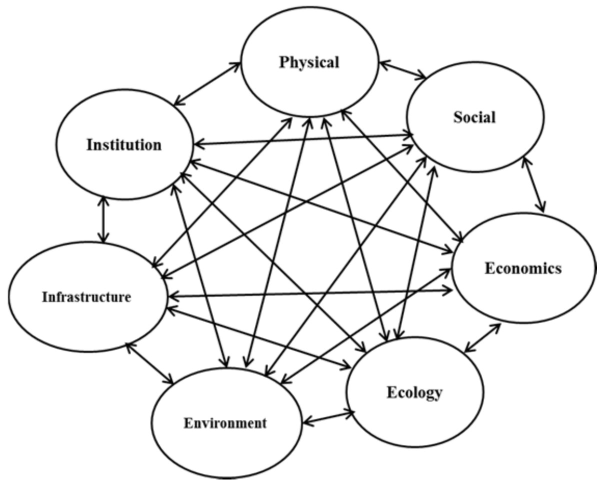

Fig. 2 Urban System with its Subsystems

IV. Urban Dynamic Model for Jodhpur City

In the present study, Jodhpur City is considered as an urban system and using system concepts a population model is developed.

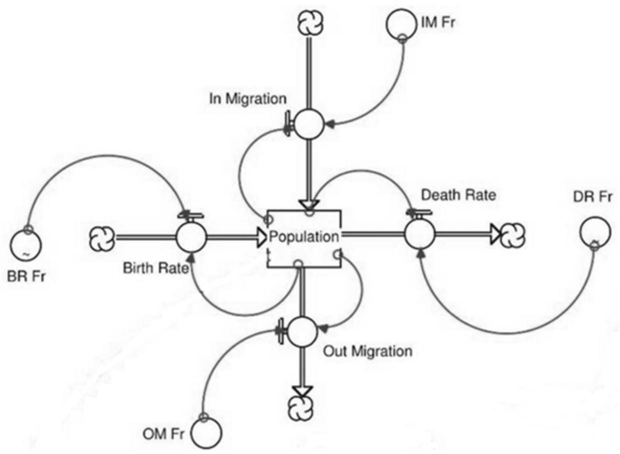

Fig. 3 Population Model of Urban System Concept

In this model, the population is considered as a function of in-migration, out-migration, birth rate, and death rate. An increase in birth rate and in-migration results in growth in the city population and similarly increase in out-migration and death rate results in a population reduction. Based on the available secondary data a model is tested and further used in population projection to calculate the number of consumers till 2031.

A detailed urban dynamics model is developed for the Jodhpur City system using the variables such as land-use, built-up area, rooftop area of buildings, consumer, electricity consumption, solar energy generation, and demand-supply gap of the city (Fig. 4). Further, the simulation is done by considering the utilized Roof-Top area in scenarios of 7%, 12%, and 15% of the total built-up area in the Jodhpur city for solar energy generation [5].

V. Results and Discussion

The urban dynamics model simulation was done considering 7% (scenario 1), 12% (scenario 2), and 15% (scenario 3), area of the total rooftop area of the city, which is to be utilized for installation of roof-top based solar energy generation systems. The simulation results are presented in Tables I and II. The combination of scenario no. 2 (12%) and scenario no. 3 (15%) is recommended based on the suitable city sector for policy and project proposal. The desired condition of achieving long-term energy self-sufficiency for Jodhpur city is observed based on the analysis of population growth, demand-supply gap modal, solar energy generation capacity, land coverage, land use, suitable roof-top area and solar roof area fraction up-to-the year 2031 [1].

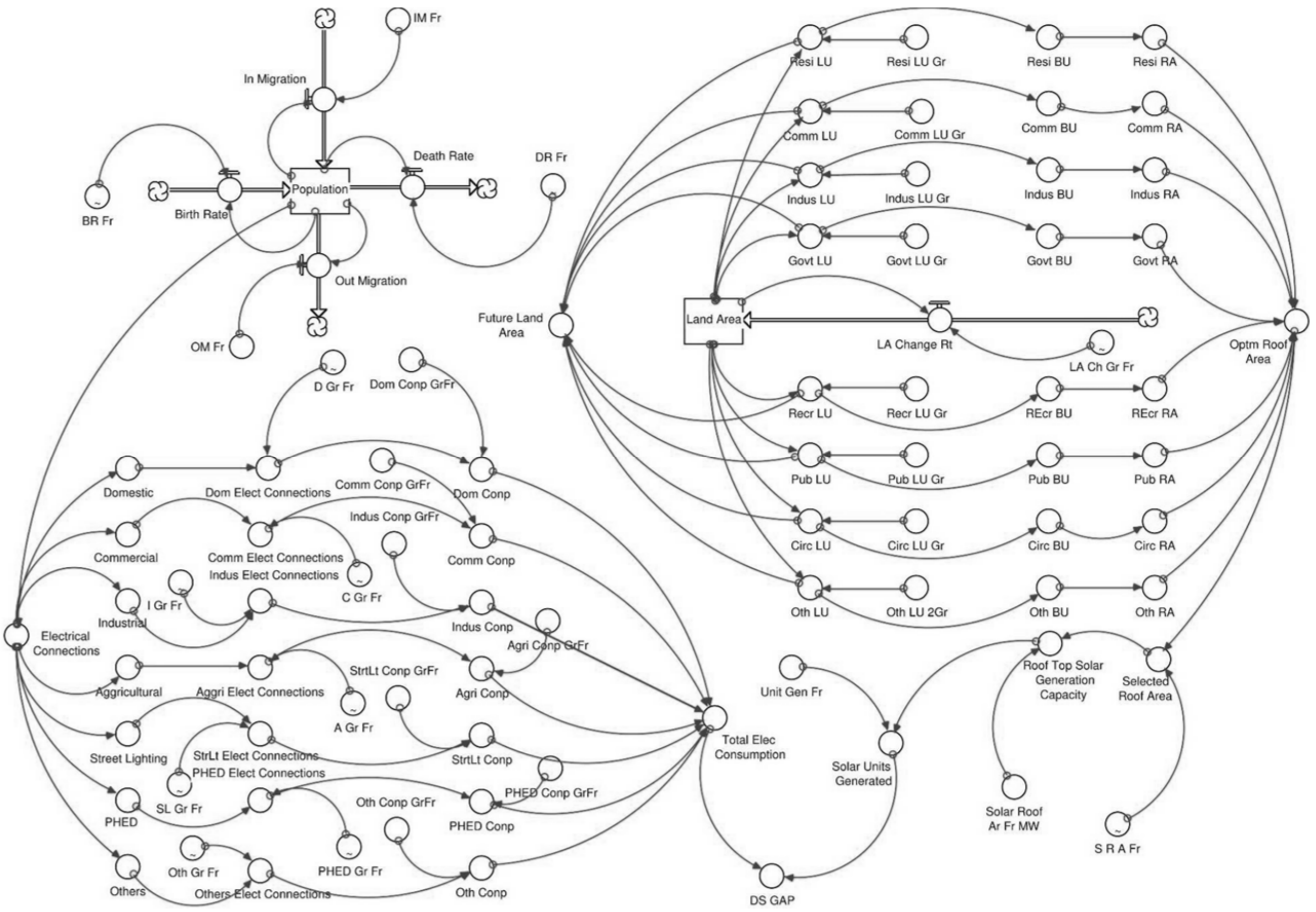

Fig. 4 Energy Demand-Supply gap and land use Model

TABLE I
PROJECTED AREA SIMULATION WITH URBAN DYNAMICS MODEL -JODHPUR CITY (AREA UNIT IN HECTARE)

Year	Land Area (Hectare.)	O. Roof Area (Ha.)	Scenario 1 7% Roof Area	Scenario 2 12% Roof Area	Scenario 3 15%Roof Area
2015	25,394.61	110.05	770.35	1320.60	1650.75
2016	25,420.80	110.11	770.77	1321.32	1651.65
2021	25,628.18	110.94	776.58	1331.28	1664.10
2026	26,070.12	112.72	789.04	1352.64	1690.80
2030	26,721.41	115.38	807.66	1384.56	1730.70
2031	26,938.84	116.26	813.82	1395.12	1743.90

TABLE II
DEMAND SUPPLY GAP IN LAKH UNIT PER YEAR

Sn	Year	Scenario 1 7% Roof Area	Scenario 2 12% Roof Area	Scenario 3 15% Roof Area
1	2015	-33.47	-32.18	-35.61
2	2016	-29.38	-22.80	-23.69
3	2021	-2.32	14.97	41.94
4	2026	18.92	63.04	104.59
5	2031	4.38	81.33	126.86

A. Scenario 1

In this scenario, if 7% of total rooftop area is considered for electricity generation then after 8 years the Surplus will be achieved, however, due to the rise in consumption after 2032 the surplus will decrease as shown in Fig. 5.

Project capacity- 7 MW and Project cost- 606 Cr. Rs.

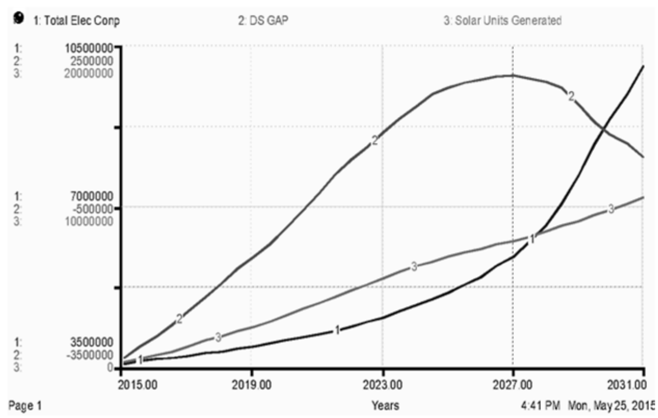

Fig. 5 Scenario: Solar Suitable Roof Area 7%

B. Scenario 2

In this scenario, if 10% of the total rooftop area is considered for electricity generation then after 6 years the Surplus will be achieved, however, due to the rise in consumption after 2035 the surplus would decrease as shown in Fig. 6.

Project capacity- 11.67 MW and Project cost- 1050 Cr. Rs.

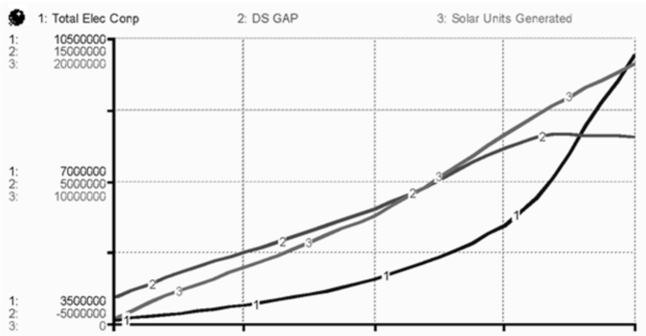

Fig. 6 Scenario: Solar Suitable Roof Area 12%

C. Scenario 3

In this scenario, if 15% of the total rooftop area is considered for electricity generation then after 3 years the Surplus will be achieved, however, due to the rise in consumption after 2038 the surplus would decrease as shown in Fig. 7.

Project capacity- 14.59 MW and Project cost- 1313 Cr. Rs.

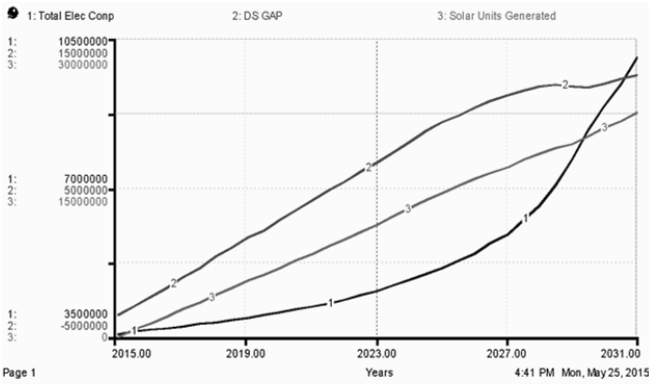

Fig. 7 Scenario: Solar Suitable Roof Area 15%

D. Energy Management Model in Jodhpur City

The present investigation, to evolve an optimum energy management plan for Jodhpur city, has opted for a bottom-up approach for energy generation and consumption calculation from various sectors within the city. Based on this present investigation the following addition is suggested to the existing system for energy management at Jodhpur City as in Fig. 8.

E. Urban Energy Database Management

At present, the authority requires an intensive and reliable information database to tackle the challenges bottlenecking the development of the city. Keeping this in mind and demand-supply oriented various database layers are proposed for integrated energy management [2]. The importance of this framed structure will enable the various sub authorities at the city level to establish interconnection, research and development, generation, conservation, and efficient energy consumption. The two-axis layer database proposed for Urban Energy Database is presented in Fig. 9.

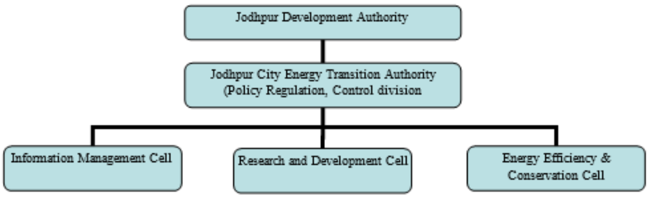

Fig. 8 Jodhpur City Level Energy Management

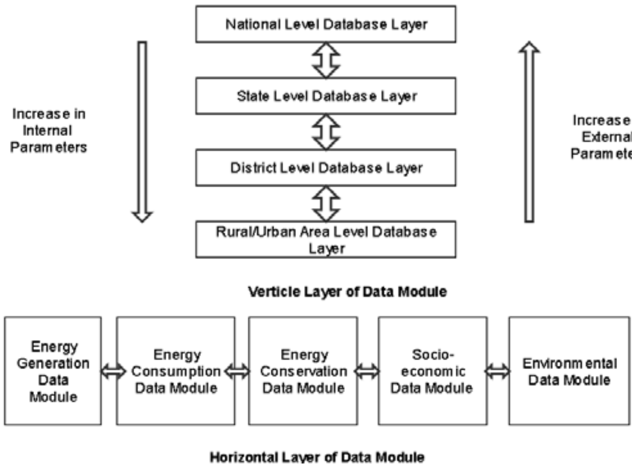

Fig. 9 Energy Database Management

VI. Conclusion

In this investigation, city-wide solar energy generation has been projected under alternative condition by employing the system dynamics technique. Further, the scenarios no. 2 and 3 are recommended to implement suitable area-based development. The energy management model along with the energy database framework is proposed to enable efficient energy management. The author feels that with the recommendation and flow models if implemented in time, optimal energy management is anticipated in the Jodhpur city system.

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