Applied Ecology and Environmental Sciences, 2021, Vol. 9, No. 7, 707-714
Available online at http://pubs.sciepub.com/aees/9/7/10
Published by Science and Education Publishing
DOI:10.12691/aees-9-7-10

Forecasting the Electricity Demand with Increasing Population by Using System Dynamic Approach - A Case Study of Karnal City (India)

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Received June 09, 2021; Revised July 11, 2021; Accepted July 30, 2021

Abstract Electricity has become an important source of energy in human society. The enormous use of electricity necessitates a mechanism to predict future demand. Modelling and simulation of electricity markets have increasingly involved the use of a System Dynamics (SD) approach. The basis for population growth and policy option scenario is the variation in birth, death and migration rates. Accordingly, the resulting dynamic hypothesis and the stock-flow structures are represented and simulated using software such as Stella. The present study has been undertaken to assess the future electricity demand and the population dynamics in Karnal city (Haryana), India, covering an area of 90.4 km^2 with a population of 0.28 million. The System Dynamic Approach (Stella version 9.1) was successfully used to predict the future energy demands versus population growth dynamics in five modified scenarios (MS-I, MS-II, MS-III, MS-IV and MS-V) apart from the baseline scenario. The MS – IV was found to be the best scenario, as this scenario projects the stabilized population in the Karnal city, giving an edge over the other four modified scenarios policies. In this case, the population would rise to 0.46 million (2041) from 0.28 million (2011), while the energy demand will rise to 559 Gwh (2041) from 346 Gwh showing an increase of 213 Gwh (38%) over 30 years. The MS – I was found to be very critical, as the maximum energy demand was found to be very high (668 Gwh) with a total raise of 322 Gwh (48%).

Keywords: *population growth, electricity demand, system dynamic approach, stock-flow, modelling*

Cite This Article: Meenakshi, Mothi Kumar K E, and Nisha Kumari, "Forecasting the Electricity Demand with Increasing Population by Using System Dynamic Approach - A Case Study of Karnal City (India)." *Applied Ecology and Environmental Sciences*, vol. 9, no. 7 (2021): 707-714. doi: 10.12691/aees-9-7-10.

1. Introduction

Demographic and rapid urbanization has been a key feature of intermediary societies. The level of urbanization in Asia is higher than in other parts of the world, and by 2050, almost 64% of the population will live in urban areas. India and China are projected to grow by 37% over the next 33 years, with urban populations projected at 2.5 billion [12]. India's urban population is expected to reach 800 million by 2050 [13]. In India, urbanization increased from 27.7% in 2001 to 31.1% in 2011, an increase of 3.3% between 2001 and 2011, compared with 2.1% in 1991-2001 [1,2]. Economic growth increased from 6% in the 1990s to more than 8% in 2011 [3].

With the outgrowing population, the demand for resources, electricity, and water supply along with a rise in waste generation is bound to increase [4,5,15]. In recent years, per capita electricity consumption has been growing steadily, from 914 kWh in 2012-13 to 1208 kWh in 2019-2020, recording an increase of 32%. When India became independent in 1947, the demand was only 16 kWh, while in 2018-2019, India's per capita energy consumption reached 1,181 kWh [6]. Strategic planning to meet the demands plays a key role in managing aspects. The forecasting approach to fulfill the increasing demand with increasing population provides input to management activities and has been applied in this paper to increasing electricity demand using System Dynamic Approach (SDA). The simplicity and flexibility in mathematical calculations have attracted the simulation models for forecasting purposes in urban population growth policy and electricity demand [7,8]. Also, the behavioral construct of systems is employed by the simulation model which establishes the relationship between various variables to predict the future directions reducing discrepancy [9].

In this paper, we analyze the population growth of a city to develop different policy options scenarios to attain population stabilization options. A system dynamic approach was used and the birth, death and migration factors were taken as monitoring factors and highlight the

increasing electricity demand of Karnal, and forecasts the electricity demand of growing population for the year 2041.The significance of the selected time period (2011-2041) is for the long term planning implementation energy demand which can be focused on for a holistic management.

2. Study Area

The selected study area, Karnal city is located between 29°36'30.636" to 29°45'31.21"N and 76°56'26.674 to 77°2'27.409"E with a population of 286826 (Census, 2011), and occupies a geographical area of 90.4 sq. km (Figure 1). The average recorded rainfall for the study area is 642mm. The Karnal city is one of the fast-developing cities in the state of Haryana, and is expected to reach the status of the smart city by the end of the year 2025.

3. Materials and Methodology

To forecast the electricity demand with a growing population, a model was developed with the help of System Dynamics Approach using population, growth rate (birth rate, death rate and net migration), per capita demand of electricity as variables. These variables were introduced in software package (Stella 9.1) and are summarized in Table 1.

The SDA follows stock and flow process of modelling which is based on construction of Casual Loop Diagram (CLD) and further addition of dynamo equations to CLD [10]. The casual relationships among the variables are identified through CLD with the simulation process taking several steps along the time axis. The population dynamics as established by growth rate is given by equation 1 while, the per capita rate of increase of population indicates exponential growth represented by equation 2.

$$dN(t)/\,dT = kN(t) \tag{1}$$

$$N(t) = N_0 exp(kT) \tag{2}$$

where, dN/dT = Growth rate of population at any instance of time
k = rate constant
N = population at any time (t)
N_o = initial population.

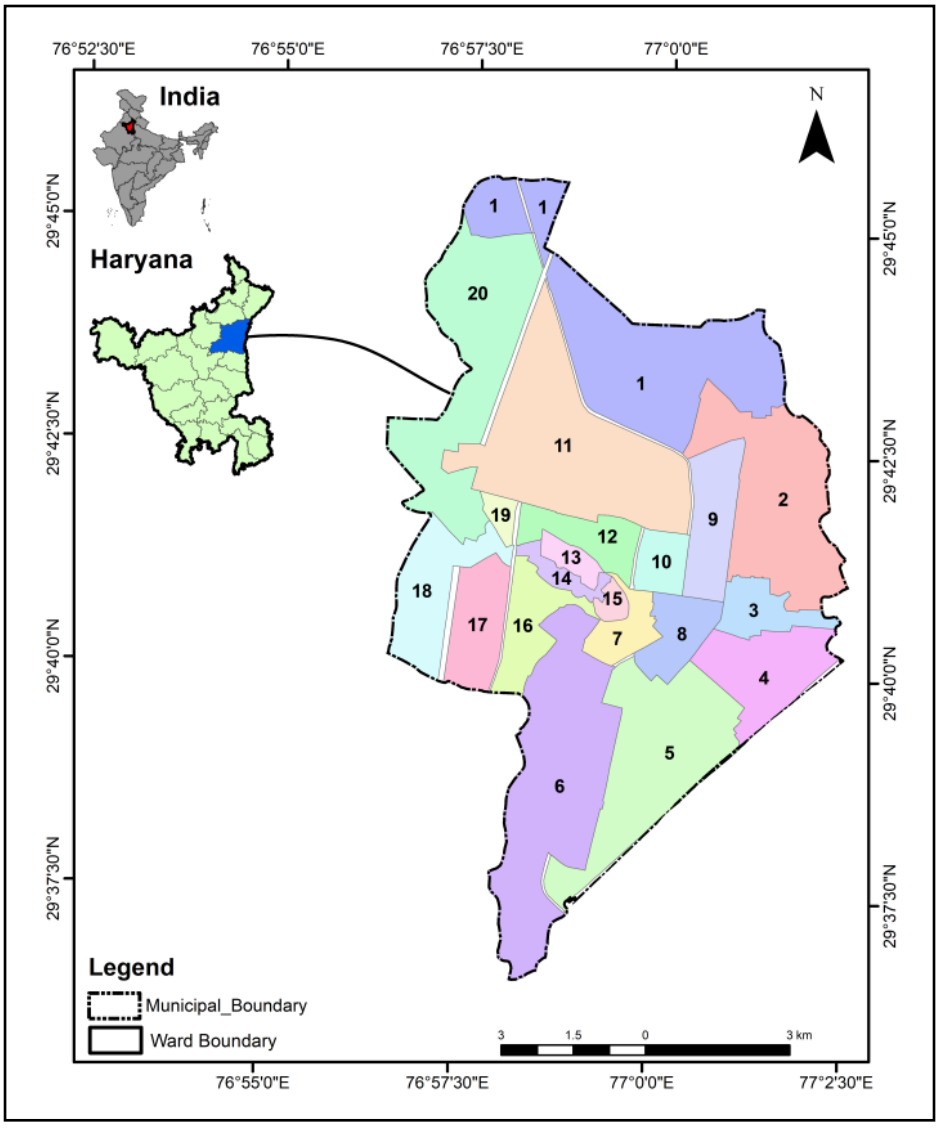

Figure 1. Study area location map

A system dynamic model developed to project population growth till 2041 used Crude Birth Rate (CBR) and Crude Death Rate (CDR) as variables provided by the Census of India. A causal loop diagram representing the relationship between population, birth rate, death rate and net migration rate (immigration minus emigration) and per capita energy consumption was constructed in the first stage. The birth rate and net migration (especially from immigration from rural areas) had a positive impact on population growth in the city while the death rate shows a negative impact. These input parameters are represented in Table 1.

Table 1.

Input parameters	Values
Population	286827 person
Birth rate	21.4 births per 1000 people
Death Rate	6.3 deaths per 1000 people
Net Migration	6 person per 1000 people
Annual per capita energy consumption	1208 kWh

*Source: Central Electricity Authority, 2020 and Census 2011.

The stock and flow diagram was further formulated as represented in Figure 2. The CBR multiplied by population gives the birth rate while CDR multiplied by population represents the death rate. The net migration rate is obtained by multiplying net migration factor to population. The per capita demand of electricity in multiplication with the population represents total electricity demand. The population growth (P_{t+1}) over a given time (t) is given by equation 3 which is a summation of the population at time t (P_t), increase in population at the time, t ($P_{in(t)}$) as represented by equation 4, and migration rate over time, t ($P_{m(t)}$) represented by equation 5.

$$P_{t+1} = P_t + P_{in(t)} + P_{m(t)\,m} \quad (3)$$

$$P_{in(t)} = B_t - D_t \quad (4)$$

$$P_{m(t)} = I_{m(t)} - E_{m(t)} \quad (5)$$

The total electricity demand projected in the study is evaluated by using equation 6.

$$TED = PCD \times P_{(t)} \quad (6)$$

Where TED and PCD are Total Electricity Demand and Per Capita Demand of electricity respectively.
The forecast of increasing population overtime associated with increasing electricity demand is calculated following various policy option scenarios i.e.Baseline Scenario (BS) and Modified Scenario (MS) which are sub-categorized into MS-I, MS-II, MS-III, MS-IV and MS-V. This baseline and modified scenarios combined with electricity per capita demand forecast the electricity demand projected till the year 2041.

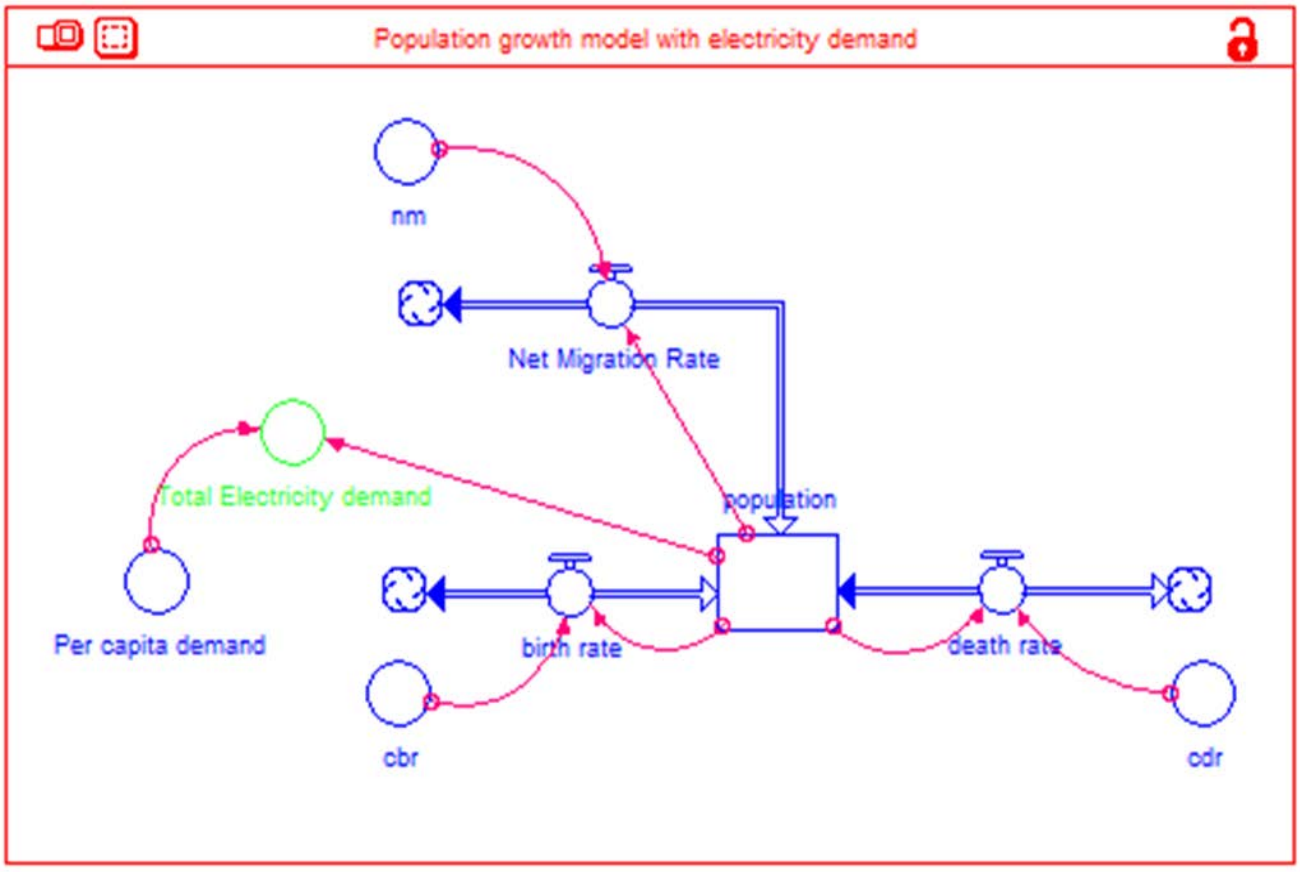

Figure 2. The stock flow diagram of the model representing the electricity demand coupled with population growth

4. Results and Discussion

4.1. Forecasting of Population Growth

In India, many efforts are being made to control population growth and to name oneamong them is the National Population Commission (National Health mission) of the Government of India, with the guidelines for rapid progress towards population sustainability and sustainable development. Population forecasting is basic requirement of the government for making best policy to control degradation of natural resources.

4.2. Baseline Scenario

Baseline scenario shows the significant growth rate in the population at the same rate up to 2041 considering birth rate, death rate and migration rate similar to 2011. Figure 3 shows the transient increases in total population, births, deaths, and migration estimated from the BS model. The total population is expected to reach 536,622 in the year 2041 considering 21.4, 6.3 and 6 (per thousand) as birth rate, death rate and net migration rate respectively. This rapid population growth is due to high birth rates, low mortality, and increasing rural-urban migration. The impact of eliminating mortality on population growth will diminish in the coming years as urban health services and infrastructure improvements. The rapid growth of the population owing to the input parameters of the base scenario as shown in Table 1 is worrying as it reduces the impact on economic growth.

4.2.1. Modified Policy Scenario 1 (MPS1)

Figure 4 shows the temporal increase in total population, births, deaths, and migration as estimated by the model. Births, deaths and migration rates of the total population are plotted in 21.4, 5.3 and 6, respectively for the entire period and the population is expected to reach 552,614 in 2041. This scenario will decrease the mortality rate by 1% compared to the baseline scenario by 2041.

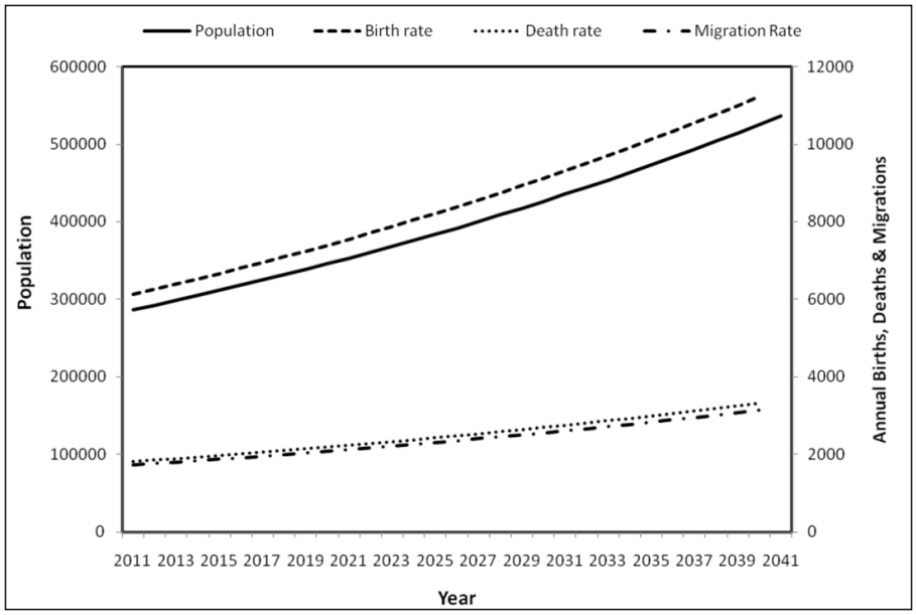

Figure 3. Projections of births, deaths, migrations and population (baseline scenario)

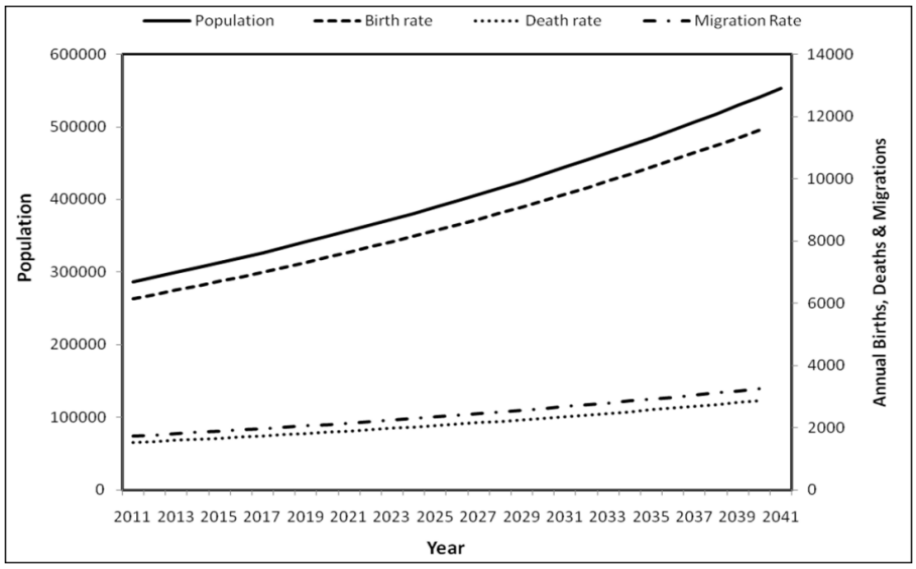

Figure 4. Projections of births, deaths, migrations and population (Modified Scenario-I)

4.2.2. Modified Policy Scenario 2 (MPS2)

In this scenario, the birth rate was 21.4 per year from 2011 to 2016, but since 2016, the birth rate has decreased by 0.2 per million. This reduction is considered to have been developed and studied in the context of the mid-range version of this strategy. Annual mortality rates of 5.3 per thousand and net migration rates of 6 per thousand are assumed to be constant over time. To emphasize the need for birth control, these indicators have not been modified to show the effect of only one indicator at a time. Figure 5 shows the results of this scenario expecting the population to reach 521,059 by the year 2041 when compared with the baseline scenario of 2041 (536,622).

4.2.3. Modified Policy Scenario 3 (MPS3)

In this scenario, the net migration for 2011-2016 and the CBR will be maintained at 6 and 21.4 (per thousand) respectively. Since 2016, net migration and CBR have declined by 0.2 per thousand per year. The CDR is constant at 5.3 per thousand at all times. As an alternative to this policy, Karnal's births, deaths, migration, and total population projections are shown in Figure 6. According to this scenario the population is expected to reach 491,213 by the year 2041 when compared with the baseline scenario of 2041 (536,622).

4.2.4. Modified Policy Scenario 4 (MPS4)

This scenario is based on an annual birth, death, and migration rate of 21.4, 5.3, and 6 per thousand from 2011 to 2016, followed by an annual decrease in births, deaths, and migration of 0.5, 0.1 and 0.2 per thousand, respectively (Figure 7). According to this scenario the urban population growth is stabilized but the effects of stabilization are not being felt. The migration rate though appeared to be increased up to 2016 but after that it is steadily decreased to the year 2041. The birth rate has also followed the same trend that is a slight increase up to 2016 after that it was observed that gradually decreased up to 2041.

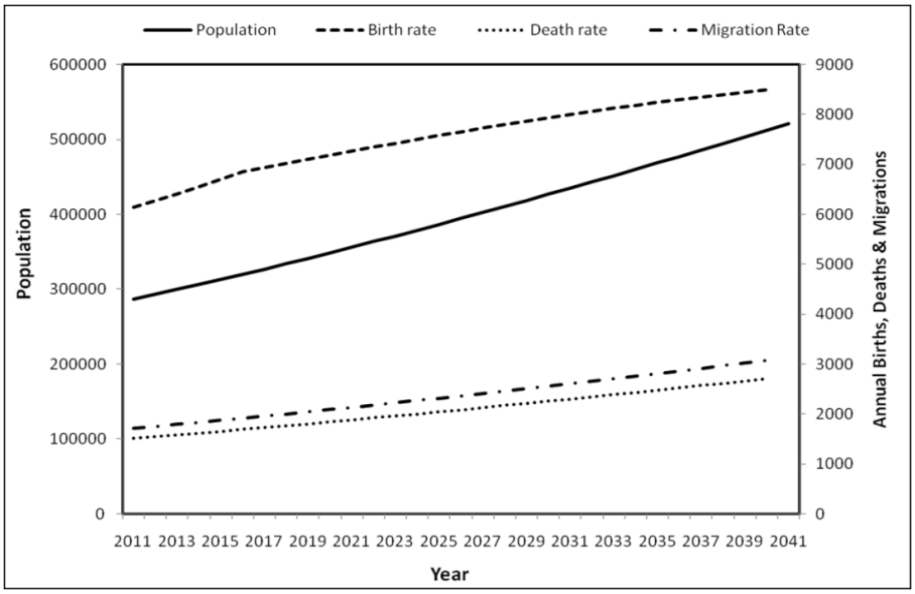

Figure 5. Projections of births, deaths, migrations and population (Modified Scenario-II)

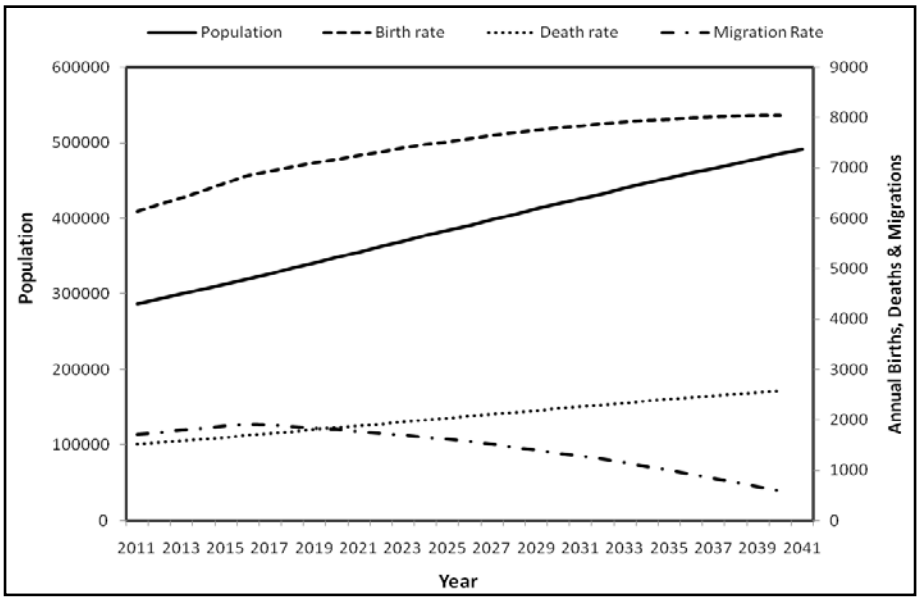

Figure 6. Projections of births, deaths, migrations and population (Modified Scenario-III)

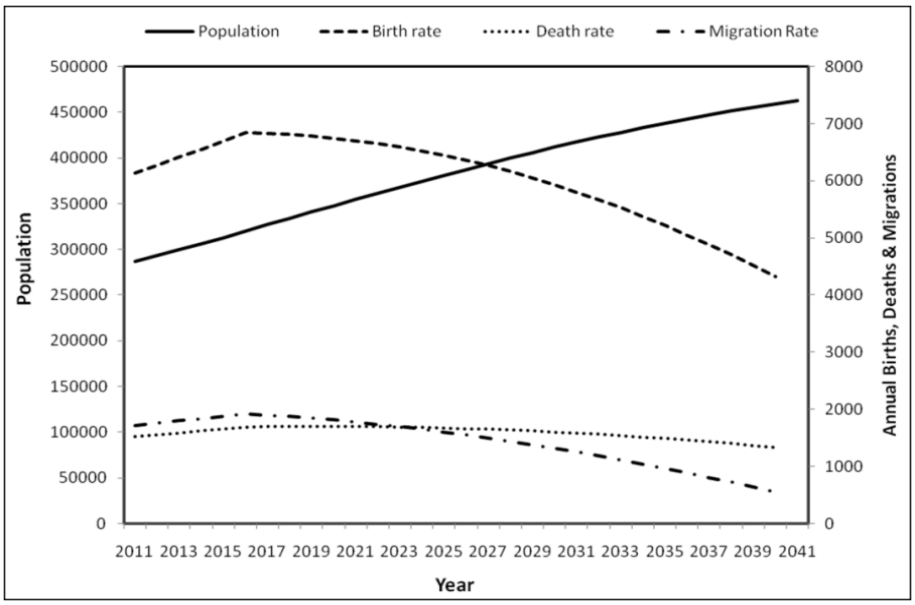

Figure 7. Projections of births, deaths, migrations and population (Modified Scenario-IV)

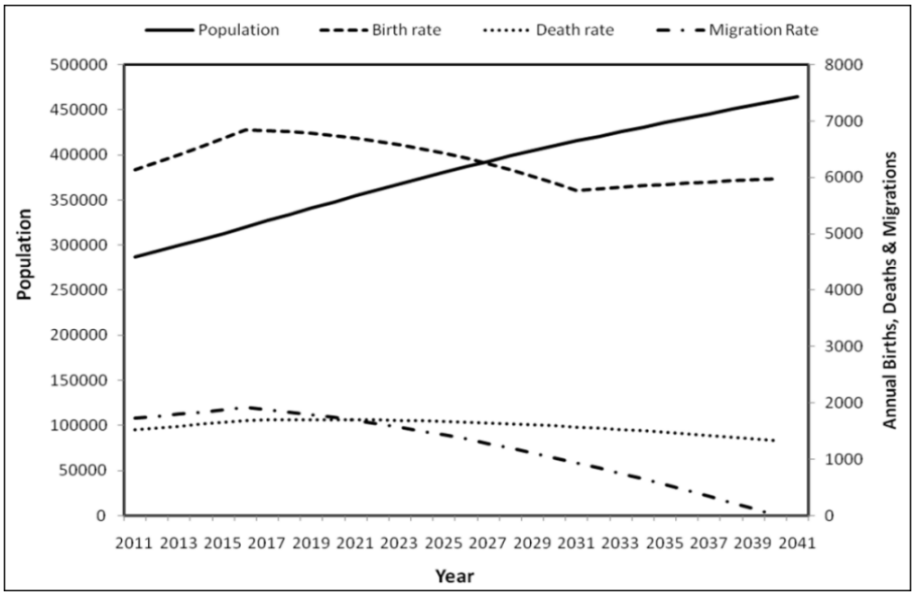

Figure 8. Projections of births, deaths, migrations and population (Modified Scenario-V)

4.2.5. Modified Policy Scenario 5 (MPS5)

This scenario is designed to develop a policy option to keep Karnal's population stable until the year 2041. As in the previous versions, the annual births, deaths and migration rates from 2011 to 2016 were 21.4, 5.3 and 6 per thousand respectively while, an annual decrease in mortality and migration was considered after 2016 as 0.1 and 0.25 per thousand. Births per thousand decreased by 0.5 per year between 2017 and 2030 and decreased by 0.1 per year between 2031 and 2041. A gradual decline is planned each year to implement policies aimed at achieving sustainable population growth. The results of this scenario are shown in Figure 8 indicating Karnal's population to stabilize at around 464,382 in case, if drastic measures are could not follow, in this scenario, the birth rates decline sharply. As mentioned above, the decline in the birth rate in different time scales ranging from 2011 - 2041. As Karnal city has the advantage of having high rate of literacy, this could be achieved.

4.3. Forecasting of Electricity Demand

We have attempted to calculate the energy demand versus population growth rate in the study area (Table 2), and observed that MS-4 opts to be the best among all the five applied scenarios. The population in the case of MS-4 would show a rise to 462988 (2041) from 286827 (2011), while the energy demand will rise to 559 Gwh (2041) from 346 Gwh showing an increase of 213 Gwh (38%) over 30 years. In the case of MS-5, we found that there will be an increase in energy demand from 346 GWh to 561Gwh showing an increase of 215 Gwh (38%) over 30 years. The main reason being attributed for this was found to be that the birth rate scenario was found to be decreased to 0.5 per year from 2016 to 2030, and decreased by 0.1 per year between 2031 and 2041, while the death rate and migration rate was found to be same with that of modified scenario number 4. We observed that MS-1 was found to be very critical, as in this case the maximum energy demand was predicted to be about 668 Gwh, with a total

rise of 322 Gwh (48%). This is mainly because the death rate was found to be decreased to 5.3 from 6.3 (total of 1%), while the birth rate and migration rate were found to be the same as that of the baseline scenario.

The simulated results of total electric energy demand for the year 2041 are shown in Figure 9 which forecasts that the total electricity energy demand from 2011 will rise from 346 GWh to 648.24 GWh in 2041. This is an increase of around 46% per annum, if the population will show an increase as the current pattern (baseline scenario).

The increasing electricity will put great pressure on the requirement to fulfill the need but can be met by alternate energy sources such as solar energy is the goal to achieve sustainability and also aiding in reaching the target of the smart city by utilizing the available rooftops for the generation of additional energy demands by installing the solar panels on the roof-tops. In an earlier study, we have successfully digitized the available rooftops in Karnal city using the satellite data (Sentinel 2A and Worldview data sets) and the Digital Elevation Model (DEM) data derived from ALOS (Advanced Land Observing Satellite) PALSAR to calculate the Global Horizontal Irradiance (GHI). If solar panels are installed on the proposed rooftops additional amount of energy could be generated. The study also concluded that the work would also help reduce CO_2 production in the environment because coal-based power plants for electricity generation are the main source of CO_2 emission [14].

Table 2. Increasing population and electricity demand with different scenarios up to 2041

Scenarios	2021		2031		2041	
	Population	Electricity Demand (Gwh)	Population	Electricity Demand (Gwh)	Population	Electricity Demand (Gwh)
BS	353430	427	435497	526	536622	648
MS-I	356906	431	444107	536	552614	668
MS-II	356208	430	435067	526	521059	629
MS-III	355511	429	426195	515	491213	593
MS-IV	354815	429	417487	504	462988	559
MS-V	354641	428	415335	502	464382	561

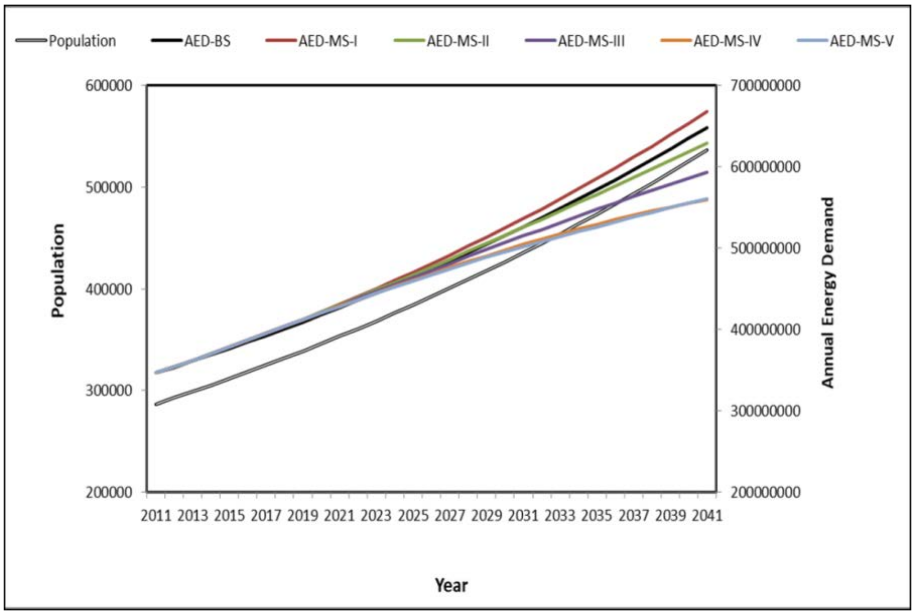

Figure 9. Annual Electricity demand forecasting with different scenarios

5. Conclusion

In the present study, we have attempted to study the energy demands for the year 2041, taking the year 2011 as the baseline year using the SDA (Stella software). The system dynamic approach was used to project population growth and its impact on the electricity demand of the smart city, Karnal. The study revealed that there will be an increase in the population from 2, 86,827 (2011) and is expected to reach 5, 36,622 (2041), while the total energy demand will rise from 346 GWh (2011) to 559 GWh (2041) as in case of MS – IV which happened to be the optimum scenario. Also, it was found that in the case of MS – I, which is one of the very critical in the scenario, the population would rise from 2, 86,827 (2011) to 5, 52,614 (2041), as the death rate is found to be creased from 6.3 to 5.3, while the other inputs such as CBR and NMR are found to be increasing as that of the baseline scenario.

Acknowledgments

The first author (Meenakshi) is thankful to the Chairperson, Centre of Excellence for Energy and Environmental Studies (CEEES), Deenbandhu Chhotu Ram University of Science and Technology (DCRUST), Murthal for allowing to undertake the Ph.D program at CEEES Department. The

author also would like to thank the Director, Haryana Space Applications Centre (HARSAC), CCS HAU Campus, Hisar for providing the infrastructure facilities to carry out the research program.

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