Electricity usage planning is a main concern for electricity stakeholders in a country. To meet the compelling demand for electricity and to deal with different uncertainties involved in this process, development of sustainable policies through proper planning is becoming increasingly challenging. We propose development of a macro-level, multi-scale, multi-resolution, hierarchical simulation model of nationwide energy generation and consumption using System Dynamics approach. The SD based simulation will provide a conceptual modeling framework and a tool for simulation, visualization and analysis of the future demand and supply of electricity energy in Pakistan. Furthermore various influencing factors including prices, tariffs, policies, regulations, available resources and the environment will be coupled with the simulation model to study their sensitivity. Our simulation framework will be used by analysts to answer different energy related research questions, which further will lead the decision makers to adopt optimal choices for future electricity energy planning in the country.

**Background**

System Dynamics Modeling & Simulation

System Dynamics (SD), is a simulation-based approach to understanding the nonlinear behavior of complex systems over time using stocks and flows, internal feedback loops and time delays. Because of the complexity of energy systems with a huge number of variables, SD is being considered as an appropriate approach to make a simulation model with the consideration of specific characteristics of Pakistan. SD modeling makes use of two basic elements: Stocks and Flows. Stocks are the accumulations of quantities, influenced by the flows over a period of time and with a specified rate. Proposed Approach and Architecture

We propose development of a hierarchical, multi-scale, multi-resolution SD model based on composition of sub-models in a hierarchical order. The proposed SD model will consist of five modules.

The Energy Generation Module is composed of different sub-modules, each representing different source of electricity. The data collection activity for each power generation methods was started in July 2016. Energy generation data from various power plants in Pakistan was collected and used for developing the simulation models. Similarly we collected one year consumption data for the consumers of LESCO.

**Methodology**

**Results & Impact**

Model Development and Results

Pakistan generates power from different sources like water, solar, wind, thermal etc. Pakistan produces 29% of power from hydro resources installed at various locations. Pakistan is blessed with hydropower potential of above 40,000 MW but only 15% has joined the national grid. Based on our literature survey and data collection we have identified the following elements in the conceptual model of a hydro power plant. We also identified the key parameters and factors that influence the power generation.

**Parameters**

1. Inflow - cubic feet /second
2. Rainfall - mm.
3. Evaporation - mm.
4. Head - feet.
5. Full capacity of reservoir - feet.
6. Dead capacity of reservoir - feet.
7. No. of operating units (turbines)
8. Efficiency %

**Equations**

- The volume of water in reservoir at any time can be calculated as
  \[
  \frac{dV}{dt} = Q_{\text{inflow}} - Q_{\text{outflow}} + \text{Precipitation} - \text{Evaporation}
  \]
  where Evaporation = evaporation rate \times \text{surface area} and Precipitation = precipitation rate \times \text{surface area}

- The power generated can be calculated as
  \[
  \text{power} = N \times \text{units} \times \frac{\text{g} \times \text{H} \times \text{e} \times \text{d}}{\Delta t}
  \]
  where \(d\) is discharge through turbine in cubic meters per second and \(g\) is gravitational constant = 9.81 m/s², \(H\) is the head height, \(d\) is discharge across turbine \((Q_{\text{outflow}})\) and \(e\) is the efficiency (assumed to be 0.85)

- Energy over the period of month is calculated as
  \[
  \text{energy} = \text{power} \times \Delta t
  \]
  Where \(\Delta t\) is time duration

**Location of Power Stations in Pakistan**

**Conclusion**

The System Dynamics based simulation will provide as a framework and a tool for conceptual modeling, simulation and visualization of the future demand and supply of electricity energy in Pakistan. Our System Dynamics based simulation framework for electricity demand and supply will be useful in forecasting future energy demand and therefore will play a very significant role in electricity energy planning. Once the model is configured and calibrated with the national infrastructure, the results generated from the model will be used by analysts to answer different research questions, which further will lead the decision makers to adopt optimal choices for future electricity energy planning in the country.

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**Project Duration:** June 2016 – December 2017

**Related Industry:** Power Sector (Tarbela Power Plant, LESCO), Planning Commission