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Electricity Generation Expansion Planning for Tamil Nadu Considering Greenhouse Gassesemission

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Abstract

Global climate change is the biggest challenge to energy and environmental policy. New approaches in energy policy are required due to an increasing indication on global warming. The application of Long-Range Energy Alternative Planning (LEAP) and EnergyPLAN software to forecast and plan a range of various technologies for expanding electricity generation with low GHG emission for Tamil Nadu is presented in this paper. The cost of generating electricity includes the capital, fuel, operation and maintenance costs are considered. Detailed analyses are performed with and without the inclusion of externality costs of local air pollution in order to examine the cheapest option of electricity generation. The impact of imposing GHG emission limit on the change in generating technologies was analyzed, considering least cost of electricity generation. Moreover, the corresponding overall cost of electricity generation was found for each case. The electricity generation is planned for future years until 2025, keeping 2016 as base year. This model can be further used for predictive electricity generation after 2025 also. The output from LEAP is fed into the energy modeling tool EnergyPLAN, to plan the same in monthly and hourly basis. This paper results with a good plan for electricity generation expansion, which would be the right path towards a low carbon emission in future.

Keywords: Electricity Generation Expansion Planning, EnergyPLAN, GHG Emissions, Tamil Nadu and LEAP.

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1 Introduction

Electricity plays an important role for the development of any country. It was reported that southern region of India had the highest peak demand and electrical energy shortage in 2013. Tamil Nadu, one of the states in southern region of India, had an average electrical energy shortage of 10.5 % in 2013. In the last few years Tamil Nadu is facing huge electrical energy shortage due to several reasons (Rallapalli and Ghosh, 2012). This problem of electrical energy shortage is being felt mainly by the industries, leading to a loss in production efficiency and heavy loss of income. This electrical energy shortage should be removed, because electrical energy is most important for socioeconomic development, particularly in the developing countries. In this era of globalization, a quick increase in urbanization, population and the energy demand show that electrical energy shortage will be the major problem in the developing countries as well as in the world in the coming years. Therefore, the electrical energy generation forecasting should be done effectively and economically. The first developed energy supply models were established on only one feature of the problem namely costs, environmental impacts, or energy supply security. The old energy supply models only reflect one energy sector or even one energy carrier. They were developed based on econometric methods and they relate energy demand with some macroeconomic indicators such as Gross Domestic Product (GDP). Because those models were not able to take into consideration two differing goals of using low-cost electrical energy production and environment conservation, they did not have sufficient efficiency in facing the recent energy concerns (Moradi et al, 2015).

In recent years, a great number of wide-ranging energy models have been developed which consider not only all energy consumption sectors and energy carriers, but also environmental aspects and the trend of energy utility's efficiency. LEAP has a significant impact in shaping energy and environmental polices worldwide. It had been successfully used in more than 150 countries worldwide for different purposes. For example in California, LEAP was used for energy forecasting and identifying alternative fuels (Ghanadan and Koomey, 2005). In Mexico, it was used to determine the feasibility of future scenarios based on moderate and high use of biofuels in the transportation and electricity generation sectors (Islasa et al, 2007). In Lebanon, mitigation options were assessed to reduce emissions from electricity generation with emphasis on the usage of renewable energy resources (El-Fadel et al, 2001). The energy consumption and various types of emissions in consumption sectors in Iran were analysed by using LEAP model (Awami and Farahmandpour, 2008). So far, for Tamil Nadu, an energy model of electricity is proposed using Energy and Power Evaluation Program (ENPEP-BALANCE) tool, with consideration of different Renewable Energy Technologies (RETs) for 30 years from 2013 to 2042. The various factors such as average capacity, Energy Not Served (ENS), energy consumption by demand sectors, ratio of supply and demand, average cost of energy generation, pollutants CO2, SO2 and Particulate Matter (PM) emitted by thermal plants are evaluated (Prabakar et al, 2015). It is necessary to plan an economic future electricity generation methods with low emission of GHG, by concentrating the renewable energy sources (RES). Hence, in this paper, the application of LEAP software to investigate a range of various technologies for generating electricity in Tamil Nadu for two different cases namely single-technology simulation scenarios and optimization scenario is presented. And this paper also aims to extract the range of various technologies for expanding power generation with low GHG emission specifically for the year 2025 from the optimization scenario using LEAP and feed the values into the energy modelling tool EnergyPLAN, for obtaining the monthly and hourly basis plan.

2 Literature Review

Generation Expansion Planning (GEP) determines WHAT generation plants should be constructed, WHERE and WHEN they should be committed over a long-range planning horizon (Wang and McDonald 1994) and (Khokhar 1997). The fundamental objective of the GEP is to determine the least-cost investment and operating plans to meet the load. In earlier for finding the solution of the GEP problem, methods like (Dynamic Programming) DP (Meier, 1990), Branch and bound method (Khodr et al, 2002), and Benders decomposition (Bloom, 1982) were applied. Some of the emerging techniques for GEP problem are reviewed in (Zhu and Chow, 1997). Genetic Algorithm (GA) and its variants had been implemented to the GEP problem in (Park et al, 1999) and (Park et al, 2000). Hybrid approaches like GA with Immune algorithm (Sung-Ling Chen, 2006) and DP (Park et al, 1998) were also applied. Eight meta-heuristic techniques were used, and the results were compared with DP in (Kannan et al, 2005). The authors concluded that Differential Evolution (DE) performed well compared to the other meta-heuristic techniques. In order to avoid extensive computational time Self-adaptive Differential Evolution (SaDE) was proposed to solve GEP problem (Karthikeyan et al, 2013a). In order to achieve better results, Opposition-based Differential Evolution (ODE) had been applied to solve the GEP problem (Karthikeyan et al, 2013b). The GEP problem was solved for Tamil Nadu for long term horizon using a state-of-the-art computer package, Wien Automatic System Planning IV (WASP-IV) (Karunanithi et al, 2014).

In GEP, escalation in the cost of energy derived from fossil fuels has shifted the attention to the improvement and use of Renewable Energy Sources (RES) (Farghal and Roehdy Abdel Aziz, 1988). The use of RES for electricity generation has many advantages over conventional generation technologies such as reduction of GHG, risk of fossil-fuel price fluctuations and the dependency on the regional power sector. The modeling studies carried out to demonstrate the impact of bringing in solar plants into the generating system as a technology alternative power plant are presented in (Rajesh et al, 2016a). In (Rajesh et al, 2016b), GEP modeling studies are conceded for a candidate power system, to investigate the impact of the introduction of solar power plant with storage facility. In (Rajesh et al, 2016c), least cost generation expansion DE is presented. A mathematical model for GEP of restructured power systems under uncertainty for a multi-period horizon is shown in (JaberValinejad and TaghiBarforoushi, 2015). It is modeled as a bi-level optimization problem, where the first level problem consists of decisions associated with investment to increase the total profit in the planning horizon and the second level problem consists of improving the social welfare where the power market is cleared.

In (HaticeTekiner-Mogulkoc et al, 2015), the GEP problems are solved where there are uncertainties related to the electricity demand forecasts. The mathematical models are developed to incorporate the risk aversion into the GEP problems. The authors use the conditional-value-at-risk and maximum regret as risk measures and the results exhibit that the investment strategies are affected when the risk is considered. In (Yonghan Feng and Sarah M. Ryan, 2013), the authors have created two different groups of scenarios for predicting the future electricity needs and fuel prices by statistical extrapolation of long-term historical trends. The cardinality of the first group is controlled by employing increasing time periods in a tree structure and the second group is controlled by its lattice structure with periods of equal length. A mixed-integer linear programming model for the solution of the centralized GEP problem is presented in (Grigorios et al, 2012). The objective is to minimize the total present value of the investment, operating and unserved energy costs at the end of the planning horizon. Moreover, the problem is modeled with environmental considerations through the integration of the cost of purchasing emission allowances in the units' operating costs and the insertion of annual renewable quota constraints and penalties. To solve the GEP problem for a hydro-thermal power producer, a novel decomposition algorithm, based on Benders decomposition is proposed in (Steffen Rebennack, 2014), where the uncertainty in hydro inflows is also considered.

In (Mustafa et al, 2014), a solution of GEP problem, which covers the 2012–2027 planning horizon, is optimized by using GA. It aims to examine the situation of RES, considering the Turkey's generation planning and determine its influence on overall generation, together with the electrical and economic consequences. In (Salvador Pineda and Andreas Bock, 2016), GEP models that contain both electricity and certificate markets to examine the degree to which a given quota obligation and non-compliance penalty incentivize the capacity expansion of RES are presented. Two market players are considered, namely, a RES company with null operating cost as well as a weather-dependent capacity factor; and a fossil-based generating company with a fixed capacity along with a known fuel cost function. In (HaticeTekiner et al, 2010), a new approach to solve the GEP problem is proposed to minimize simultaneously multiple objectives, such as cost and environmental pollutants, such as CO_2 and NOx, over a long term planning horizon. The GEP problem is solved to select the type of power generation, such as coal, nuclear, wind, etc., the location of new generation, and at which time period expansion should take place. Monte-Carlo simulation is applied to create various scenarios based on the component availabilities and anticipated demand for energy. A Multi-Period Multi-Objective Generation Expansion Planning (MMGEP) model including sustainable energy sources is presented in (JamshidAghaei et al, 2013). The problem is formulated to solve three objectives which are costs as well as environmental impact minimization and reliability maximization. A computationally efficient unit commitment, maintenance and capacity planning formulation with critical operating constraints are presented in (Bryan et al, 2015). In (Bhuvanesh et al, 2016a), the reasons behind the power shortages in Tamil Nadu and the initiatives to be taken to solve the problem have been proposed. Least cost GEP incorporating GHG emission for Tamil Nadu for the year 2025 using single technology scenario and optimization scenario in LEAP has been presented in (Bhuvanesh et al, 2016b).

3 LEAP and Energy PLAN

The LEAP model is a fixed energy-economy-environment model developed by the Stockholm Environment Institute since the early 1980s (Wei, 2006). This model predicts the energy demand, energy consumption and environmental impact and investigates the economic benefits of each energy scenario in detail. The model is based on simulation of the energy system and is called an end-use energy consumption model (Siteur, 2004). Numerous studies have been conducted using the LEAP model so far in different countries in the world. The various scenarios developed to meet future energy demand in China, using the LEAP model have been presented in (Guo et al, 2003). The GHG emission effects and potential of biomass energy technologies in Vietnam's energy system under alternative scenarios were evaluated in (Kumar et al, 2003). The influences of the expansion of landfill gas electricity generation capacity on the energy market, the cost of generating electricity and greenhouse gas emissions in Korea were analyzed in (Shin et al, 2005). The factors influencing energy consumption patterns and emission levels in the transport sector of New Delhi, extrapolated total energy demand, as well as the vehicular emissions using both LEAP and the associated Environmental Data Base (EDB) were analyzed in (Bose and Srinivasachary, 1997). The rural energy supply, as well as demand with LEAP and the global warming issues in Bangladesh caused by the traditional uses of biomass fuels in rural areas, have been studied in (Bala, 1997).

LEAP has the ability to calculate the optimal expansion of power plants for the electricity system at least cost over the whole period of calculation (from the base year to the end year). A least cost system can be planned subject to a number of user-specified constraints including maximum annual levels of emissions of pollutants such as CO_2, N_2O, CH_4, etc. and minimum or maximum capacities for individual plant types. An expansion pathway for an energy system that met a minimum renewable portfolio standard with a target for reducing GHG emissions was also explained in (Heaps, 2002). The primary objective of energy planning is not to identify a single optimal solution, but rather to identify strong energy policies that work well under a range of reasonable input assumptions.

EnergyPLAN, a software tool has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark (Lund and Munster, 2003). The purpose of the tool is to promote the design of national or regional energy plan strategies by simulating the entire energy system, which includes heat and electricity supplies as well as the transport and industrial sectors. It is a deterministic input-output tool and the general inputs to be given are demands, RES, energy station capacities, costs, and a number of different regulation strategies for import/export and excess electricity production. Outputs are energy balances with resulting annual productions, fuel consumption, import/export of electricity, and total costs including income from the exchange of electric power. In its programming, any procedures, which would increase the calculation time have been avoided, and the computation for 1 year requires only a few seconds on an average computer. Finally, EnergyPLAN optimizes the operation of a given system as opposed to tools, which optimize investments in the system (Connolly et al, 2010).

Previously, EnergyPLAN has been used to explore the large scale integration of wind (Lund, 2005) along with optimal combinations of RES (Lund, 2006), management of excess electricity (Lund and Munster, 2003), the integration of wind power using Vehicle-to-Grid electric vehicles (Lund and Kempton, 2005) the application of small-scale Combined Heat and Power

(CHP) (Lund and Andersen, 2005), integrated systems and local energy markets (Lund and Munster, 2006), renewable energy strategies for sustainable development (Lund, 2007), the use of waste for energy purposes (Munster and Lund, 2009), the potential of fuel cells and electrolysers in future energy systems (Mathiesen, 2008) and (Mathiesen and Lund, 2009) the potential of thermoelectric generation (TEG) in thermal energy systems (Chen et al, 2010), the effect of energy storage (Blarke and Lund, 2008) with particular work on compressed-air energy storage (Lund and Salgi, 2009) and (Lund et al, 2009) and thermal energy storage (Lund and Clark, 2002). Moreover, EnergyPLAN was used to analyze the potential of CHP and renewable energy in Estonia, Germany, Poland, Spain, and UK (DESIRE). It has been used to simulate a 100% renewable energy system for the island of Mljet in Croatia (Lund et al, 2007) as well as the countries of Ireland (Connolly et al, 2009) and Denmark (Mathiesen, 2009).

So, LEAP is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute (Heaps, 2012). LEAP has been utilized by thousands of organizations in more than 190 countries worldwide. Its users include government agencies, academic institutions, non-governmental organizations, consulting companies, and energy utilities. LEAP is an uprising de facto standard for countries undertaking integrated resource planning, GHG mitigation assessments and Low Emission Development Strategies (LEDS) specifically in a developing country like India. Many countries have also chosen to use LEAP as part of their commitment to report to U.N. Framework Convention on Climate Change (UNFCCC).

4 LEAP Model for Tamil Nadu

The developed LEAP model for Tamil Nadu is shown Figure 1. In the developed LEAP model, the electricity is set as the only demand. The electricity can be generated by the plants namely Natural Gas (NGCC), RES, Coal, Hydro, Nuclear and Diesel. In addition, they are entered into the Process branch of LEAP model. The Carbon emitting substances to the environment are entered into the Effects branch of LEAP model.

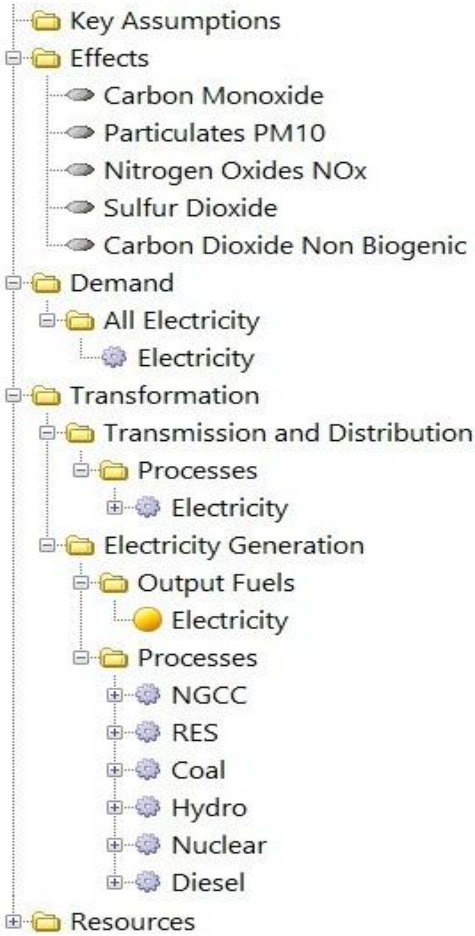

Fig. 1.Developed LEAP Model for Tamil Nadu

The LEAP model for Tamil Nadu has been developed by setting the base values shown in Table 1. The model has been developed for the base year 2016 and extrapolated until 2025. The electricity demand for the year 2025 will be 200 TWh and it is one of the inputs for LEAP (Prabakar et al, 2015). The electricity losses are taken as 18% for developing the model (Power Sector in Tamil Nadu, 2011).

Table 1. Base Values of LEAP for the Year 2016 Including Various Electricity Generation Technologies

Plant Type	Capacity (MW)	Efficiency (%)	Maximum availability (%)	Capacity credit (%)	Capital cost ($\times 10^3$ \$/MW)	Fixed OM Cost (\$/MW)	Variable OM Cost (\$/MW)	Life Time (years)
Coal	9688.10	35	90	90	2934	31.18	4.47	40
Gas	1026.30	38	90	90	917	13.17	3.60	40
Diesel	411.66	40	90	90	950	30	3.10	40
Nuclear	986.50	35	80	90	5530	93.28	2.14	50
Hydro	2182.20	90	90	50	2936	14.13	0	50
RES	8075.38	25	100	25	3000	52.00	0	50
Coal	9688.10	35	90	90	2934	31.18	4.47	40
Gas	1026.30	38	90	90	917	13.17	3.60	40

This data for various electricity generation technologies is taken from (Executive Summary Power Sector, 2016), (Annual Energy Outlook, 2015) and (Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants, 2013). These data are entered into the Transformation module called Electricity Generation in the LEAP model, which include various electricity generation plants namely Coal, Gas, Diesel, Nuclear, Hydro and Renewable Energy Sources (RES) and its properties are fixed to Capital cost, Fixed Operation and Maintenance (OM) Cost, Variable OM Cost, Fuel cost, Capacity, Efficiency, Maximum availability, Capacity credit, Life time, system load curve and a planning reserve margin. The discount rate is set as 5% while entering the cost data.

5 Results and Discussions

The fossil fuels are expected to unavailable in 50 more years if the consumption rate remains to grow at high rate. With the unstable nature of international crude prices, it is important to reduce this dependence and look for alternatives. Therefore, the renewable energy technologies also be expanded to supply secure electrical energy at least cost and low GHG emission. The developed LEAP model for Tamil Nadu having two different cases namely Single-technology simulation scenario and Optimization scenario. In Single-technology simulation scenario the LEAP having various electricity generation technologies namely Coal Only, Diesel Only, Hydro Only, Natural Gas Only, RES Only and Nuclear Only. LEAP decides the types of power plants to be added and when to be added to meet out the demand by giving more preference to a single generation technology, based on its availability and fuel cost. The Optimization scenario is simulated to explore least cost electricity generation by considering GHG emission limit also.

5.1 Case 1: Single-Technology Simulation Scenario

In this case, a simple scenario using each of single generation technology have been simulated. They are namely, Coal only, Diesel only, Hydro only, Natural Gas only, RES only and Nuclear only. In the Coal only technology, LEAP automatically gives more preference to coal plant for generating electricity to meet out the electricity demand based on its availability. If the coal is not sufficient to generate the required electrical energy, then other sources for generating electrical energy are considered based on its fuel cost. Based on standard simulation calculations, LEAP decides the types of power plants to be added and when to be added to meet out electrical energy demand. This simulation is also carried out for all the other single generation technologies such as Diesel only, Hydro only, Natural Gas only, RES only and Nuclear only. The predicted values of capacity, Electrical energy output and Social cost in the year 2025 for various single technologies are shown in figures 2, 3 and 4 respectively.

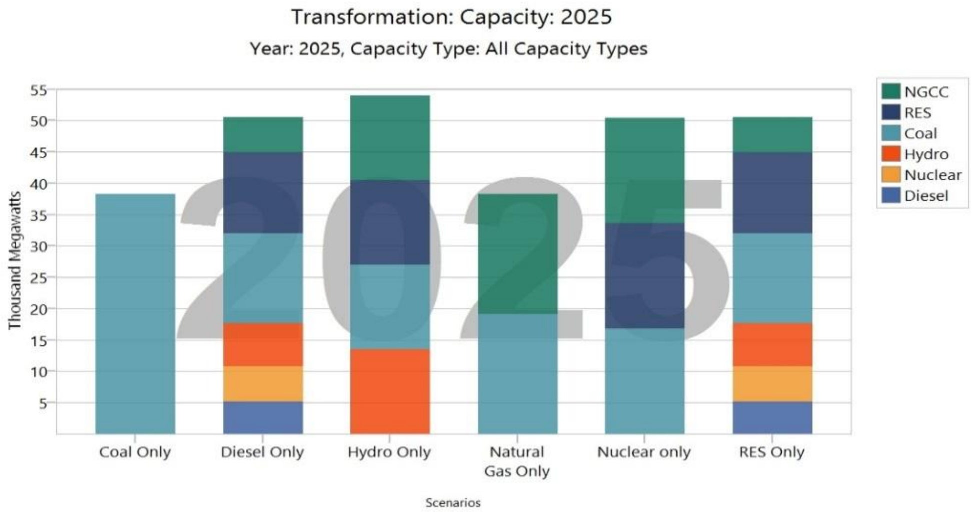

Fig. 2. Capacity values predicted by LEAP by single-technology simulation scenarios for the year 2025

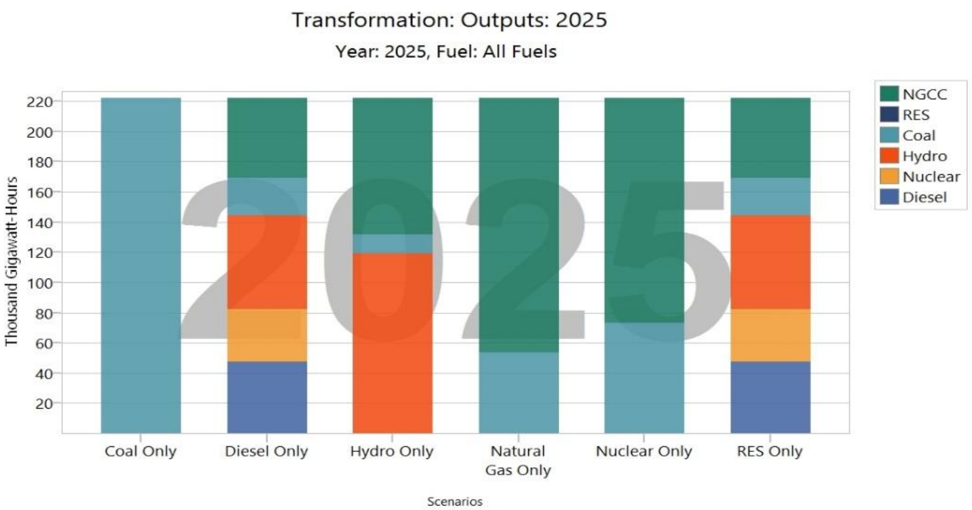

Fig. 3. Electrical Energy Output predicted by LEAP by single-technology simulation scenarios for the year 2025

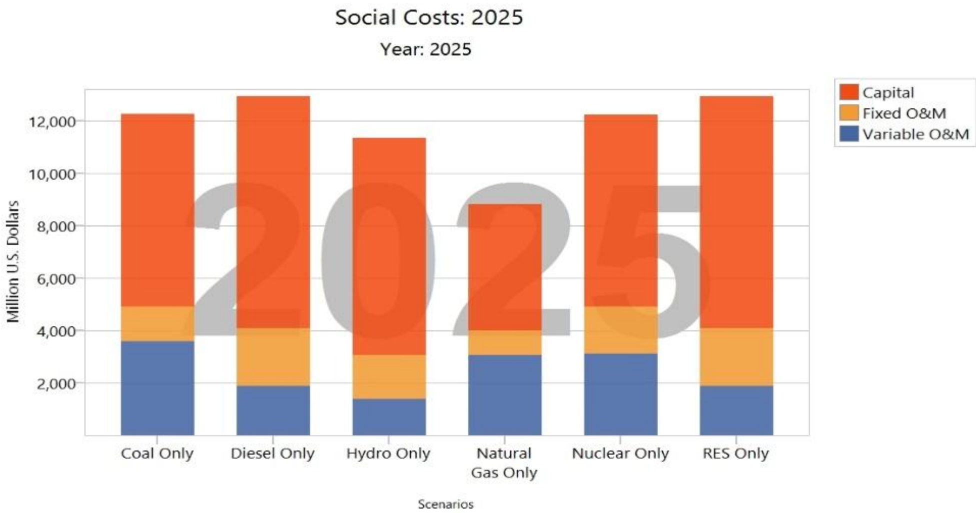

Fig. 4. Social Cost predicted by LEAP by single-technology simulation scenarios for the year 2025

The results from LEAP model show that for most of the single-technology simulation scenarios, Natural Gas technology is used to generate more amount of electrical energy and is shown in Figure 3. Figure 4 shows that the Natural Gas only generation technology will be the cheapest option for power generation in the year 2025, due to their low fuel cost.

5.2 Case 2: Optimization Scenario

The Optimization scenario allows LEAP to decide the combination of power plants which will meet demand at the lowest cost and lowest emission of GHG.

5.2.1 Evaluation of Least Cost Electricity Generation

The LEAP model runs the OSeMOSYS optimization model, which is used to simulate the optimization scenario. The comparison of capacity, electrical energy output and social cost in the year 2025 using single-technology simulation scenarios and Optimization Scenario are shown in figures 5, 6 and 7 respectively.

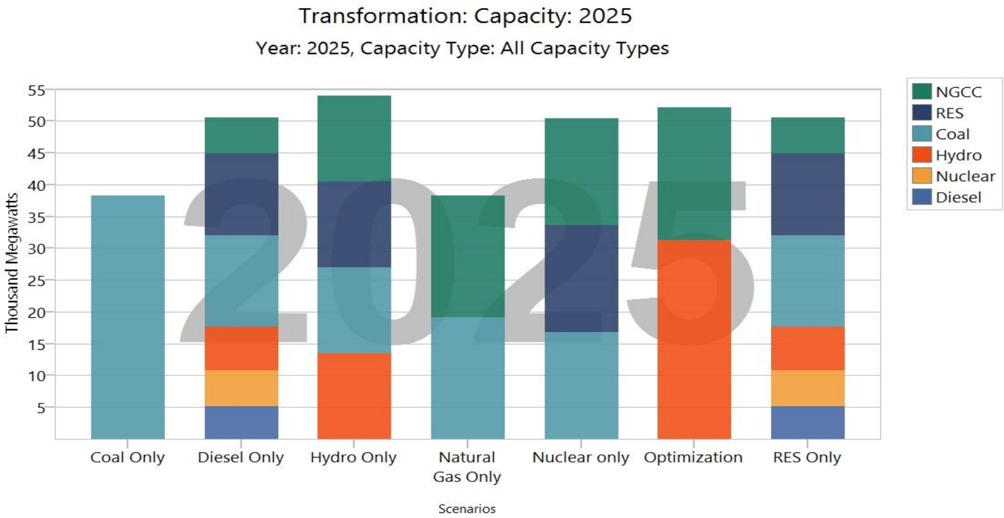

Fig. 5. Comparison of Capacity by single-technology simulation scenarios and Optimization Scenario predicted by LEAP for the year 2025

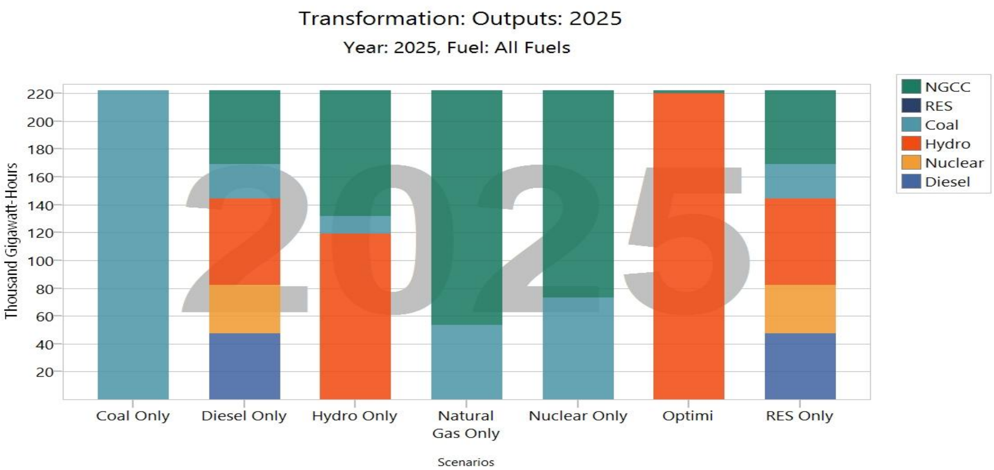

Fig. 6. Comparison of Electrical Energy Output by single-technology simulation scenarios and Optimization Scenario predicted by LEAP for the year 2025

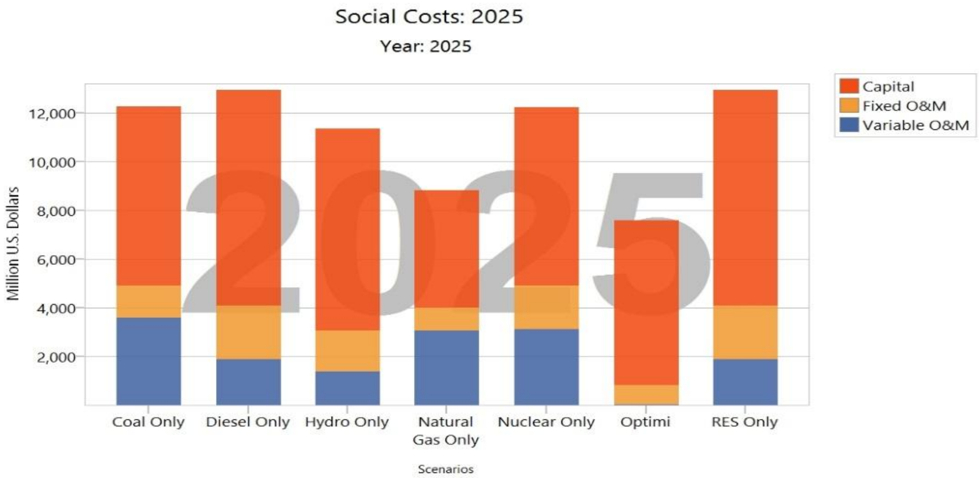

Fig. 7. Comparison of Social Cost by single-technology simulation scenarios and Optimization Scenario predicted by LEAP for the year 2025

Figure 6 shows that the LEAP has chosen a mix of power plants in the Optimization scenario, unlike the other single-technology simulation scenarios. The results show that peak load periods favor Natural Gas power plants that are relatively cheap to build but expensive to operate. Base load periods favor Hydro power plants that have higher capital cost but with low running costs. Figure 7 shows that, because of the low variable and fixed O&M cost, the total social costs of Optimization Scenario are slightly cheaper than even the cheapest of the other single-technology simulation scenarios which were created previously. Table 2 compares the cost of all single-technology simulation scenarios with the Optimization Scenario.

Table 2. Comparison of the Cost of All Single-Technology Simulation Scenarios with the Optimization Scenario

Cost of Various Scenarios (Million U.S $)							
Overall Cost Components	Coal Only	Diesel Only	Hydro Only	Natural Gas Only	Nuclear Only	Optimization	RES Only
Capital	7335	8863	8304	4808	7314	6767	8863
Fixed O&M	1338	2197	1670	950	1813	797	2197
Variable O&M	3576	1882	1377	3048	3109	27	1882
Overall Cost	12249	12942	11351	8806	12236	7591	12942

All the single-technology scenarios having maximum penetration of non-renewables in its fuel mix. So the fixed and variable O&M cost will be high. But the Optimization scenario penetrates renewables in more amount. So the fixed and variable O&M cost will be very low. So the overall cost will be minimum. The Optimization Scenario also shows a maximum level of GHG emissions is imposed on the system with least cost. The comparison of total GHG emission for generating electrical energy by single-technology simulation scenarios and Optimization Scenario predicted by LEAP for the year 2025 is shown in Figure 8.

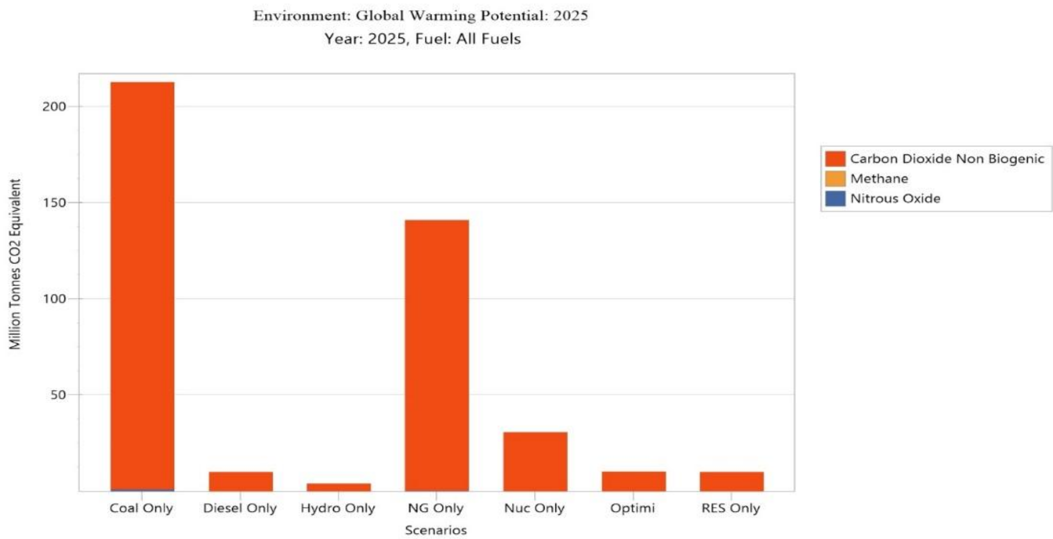

Fig. 8. Comparison of Total GHG Emission by single-technology simulation scenarios and Optimization Scenario predicted by LEAP for the year 2025

Figure 8 shows that the emission of GHG is less in Optimization Scenario next to Hydro Only single-technology simulation scenario, compared to other single-technology simulation scenarios. The values of all GHG emission in Million Tonnes CO_2 Equivalent by all single-technology simulation scenarios and the Optimization Scenario are shown in Table 3.

Table 3. Comparison of GHG Emission by All Single-Technology Simulation Scenarios with the Optimization Scenario

Global Warming Potential of Various Scenarios (Million Tonnes CO_2 Equivalent)							
GHG Types	Coal Only	Diesel Only	Hydro Only	Natural Gas Only	Nuclear Only	Optimization	RES Only
Carbon Dioxide Non Biogenic	211.75	9.88	3.91	140.45	30.51	10.00	9.88
Methane	0.052	0.0161	0.0016	0.0494	0.0125	0.0041	0.0160
Nitrous Oxide	0.9472	0.0324	0.0020	0.2782	0.0161	0.0053	0.0324
Total	212.74	9.9285	3.9136	140.77	30.538	10.009	9.9284

5.3 Monthly and Hourly Basis GEP Using EnergyPLAN

EnergyPLAN relies on analytical programming, with the same input, it will always come to the same results. This model performs the calculation on the basis of RES data of stochastic and intermittent in nature. It is an hour-simulation model as opposed to a model based on aggregated annual demands and generation. Consequently, the model can examine the influence of fluctuating RES on the system as well as weekly and seasonal alterations in electricity. The results obtained by RES only scenario in LEAP are given as input to EnergyPlan. The predicted value of electrical energy demand for the year 2025 is 200 TWh, which is provided as the input in EnergyPLAN.

In the EnergyPLAN model, electricity is considered as the only demand. The available capacity of various power plants in the year 2025 are given as input in the supply branch of the EnergyPLAN model. The input data are given to the EnergyPLAN in two branches. The first branch has the central power plants such as Coal, Natural Gas, Diesel, Nuclear and Hydro, where Coal, Natural Gas and Diesel are combined together. The second branch has the RES. The hourly distribution values (8784 hours) for Tamil Nadu, of different power plants are considered depending on their electricity generating capability and seasonal conditions and given as input to the EnergyPLAN. The EnergyPLAN model is shown in Figure 9.

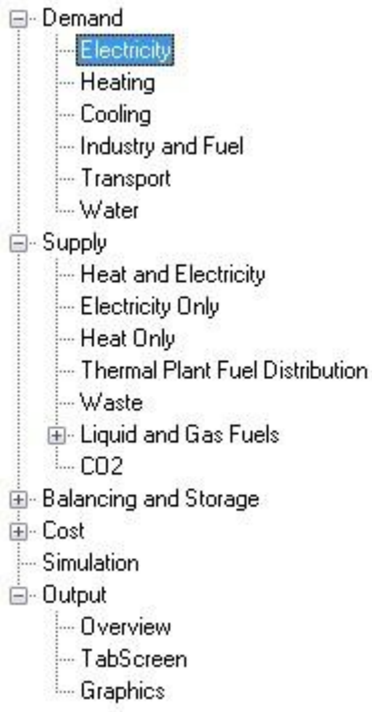

Fig. 9. The EnergyPLAN model for Tamil Nadu

EnergyPLAN model calculates the monthly and hour by hour electricity demand as well as the contribution of different power plants including RES to satisfy the demand. The output from the EnergyPLAN shows the Electricity demand in MW, contribution of different power plants to meet the demand and total electricity production which are given in Table 4.

Table 4. Monthly electricity production to satisfy the demand using different power plants during the year 2025 for Tamil Nadu

Months	Electricity Demand (MW)	Production of different power plants (MW)				Total Production (MW)
		RES	Nuclear	Hydro	Coal+ Natural Gas+ Diesel	
January	25734	5176	5935	5500	9438	26049
February	25457	4090	5217	5500	10696	25503
March	24505	4281	5021	5500	10148	24950
April	21594	3707	4827	5500	8213	22247
May	21069	4442	5413	5500	6465	21820
June	20477	2874	5413	5500	7420	21207
July	18671	2001	5739	5500	6174	19414
August	21481	2015	5739	5500	8867	22121
September	22045	4272	4892	5500	8068	22732
October	22866	3622	5217	5500	9098	23437
November	24709	6402	5739	5500	7577	25218
December	24717	7050	6000	5500	6768	25318
Average Values	22777.08	4161	5429.333	5500	8244.333	23334.67

The results from the EnergyPLAN show that Nuclear and Hydro plants contribute consistently to satisfy the electricity demand. RES plants generate more electricity during the months January, November and December. The hourly basis electricity production of randomly chosen two days (February 21 and September 26) during two different seasons of the year 2030 are given in Table 5 and Table 6.

Table 5. Hourly Electricity Production To Satisfy The Demand Using Different Power Plants On February 21, 2025 For Tamil Nadu

Hours	**Electricity Demand (MW)**	**Production of different power plants (MW)**				**Total Production (MW)**
		RES	**Nuclear**	**Hydro**	**Coal+ Natural Gas+ Diesel**	
1	21411	1260	5217	5500	9434	21411
2	19672	1697	5217	5500	7258	19672
3	18700	2700	5217	5500	5283	18700
4	18591	1971	5217	5500	6002	18690
5	18705	1837	5217	5500	6151	18705
6	19145	1400	5217	5500	7028	19145
7	20343	3697	5217	5500	5929	20343
8	23937	6787	5217	5500	6442	23946
9	29019	7785	5217	5500	10517	29019
10	31289	9130	5217	5500	11442	31289
11	31783	7769	5217	5500	13297	31783
12	32141	7377	5217	5500	14047	32141
13	30709	7287	5217	5500	13740	31744
14	30671	7057	5217	5500	12934	30708
15	29970	6413	5217	5500	13541	30671
16	28739	5231	5217	5500	14021	29969
17	28258	6867	5217	5500	11155	28739
18	30128	8693	5217	5500	10847	30257
19	31767	8508	5217	5500	12902	32127
20	31315	7774	5217	5500	13275	31766
21	29116	7623	5217	5500	10975	29315
22	27391	7127	5217	5500	10272	28116
23	25459	5234	5217	5500	10439	26390
24	22952	1433	5217	5500	11308	23458
Average value	26300.46	5527.375	5217	5500	10343.29	26587.67

The results show that a maximum demand of 32141 MW occurs during the 12th hour. The demand is also high during the hours 9-14 hours and 18-21 hours. The results also show that the conventional plants (Coal, Natural Gas and Diesel) are to be operated in more amounts during the peak demand hours. Nuclear and Hydro plants generate consistent power throughout the day. The RES plants are also utilized during their availability.

Table 6. Hourly Electricity Production To Satisfy The Demand Using Different Power Plants On September 26, 2025 For Tamil Nadu

Hours	Electricity Demand (MW)	Production of different power plants (MW)				Total Production (MW)
		RES	Nuclear	Hydro	Coal+ Natural Gas+ Diesel	
1	16627	6334	4891	5500	249	16974
2	15933	5715	4891	5500	374	16480
3	15566	4881	4891	5500	706	15978
4	15472	2442	4891	5500	2639	15472
5	15756	1742	4891	5500	3632	15765
6	17037	1221	4891	5500	5425	17037
7	20303	734	4891	5500	9178	20303
8	25004	1686	4891	5500	12927	25004
9	27561	1989	4891	5500	15220	27600
10	28098	2572	4891	5500	15634	28597
11	28589	2509	4891	5500	15689	28589
12	28748	2817	4891	5500	15540	28748
13	28030	2148	4891	5500	15493	28032
14	28154	2112	4891	5500	15652	28155
15	27770	2302	4891	5500	15077	27770
16	26452	2515	4891	5500	13546	26452
17	25303	2156	4891	5500	12756	25303
18	26094	1656	4891	5500	14064	26111
19	26168	1003	4891	5500	14774	26168
20	25851	1703	4891	5500	13775	25869
21	25402	234	4891	5500	14861	25486
22	24166	70	4891	5500	14029	24490
23	22286	34	4891	5500	12326	22751
24	19854	34	4891	5500	9952	20377
Average value	23342.67	2108.708	4891	5500	10979.92	23479.63

Table 6 shows that a maximum demand of 28748 MW occurs during the 12th hour on September 26, 2025. The demand is high during 9-14 hours and 18-21 hours. Nuclear plants and Hydro plants generate consistent power throughout the day, and the conventional plants produce more electricity during the peak demand hours. The RES are also utilized during their availability.

5 Conclusion

In this paper, the LEAP model, including two scenarios to plan the electricity generation, and EnergyPLAN model to plan the electricity generation expansion for Tamil Nadu for the year 2025 are proposed. The results of optimization scenario in LEAP provides the least cost electricity generation plan. And the RES only scenario in LEAP results with 9.9284 Million Tonnes CO_2 Equivalent of GHG while generating electricity, which is lower than other scenarios. So, with the results of RES only scenario, the monthly and hourly basis electricity generation planning have been done successfully using EnergyPLAN model. So, the implementation of RES in the power sector will give Tamil Nadu more energy independence in the future and will reduce the GHG emissions.

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References

Annual Energy Outlook, (2015), U.S. Energy Information Administration.

Awami, A. and B. Farahmandpour, (2008), Analysis of environmental emissions and greenhouse gases in Islamic Republic of Iran, International Institute for Energy Studies.

Bala B.K., (1997), Computer modeling of the rural energy system and of CO2 emissions for Bangladesh, Energy, 22, 999-1003.

Bhuvanesh A., S.T.Jaya Christa and S.Kannan, (2016a), Generation Expansion Planning in Tamil Nadu with High Penetration of Renewables to Limit GHG Emission, In: International Conference on Civil, Mechanical and Environmental Engineering Technologies.

Bhuvanesh A., S.T.Jaya Christa and S.Kannan, (2016b), Electricity Generation Planning for Tamil Nadu by Considering GHG Emission Using LEAP, In: International Conference on Soft Computing Systems.

Blarke MB and Lund H, (2008), The effectiveness of storage and relocation options in renewable energy systems, Renewable Energy, 33, 1499–507.

Bloom J. A., (1982), Long-range generation planning using decomposition and probabilistic simulation, IEEE Trans. Power App. Syst., 101, 797-802.

Bose R.K., Srinivasachary V., (1997), Policies to reduce energy use and environmental emissions in the transport sector: a case of Delhi city, Energy Policy, 25, 1137–1150.

Bryan S. Palmintier and Mort D. Webster, (2015), Impact of Operational Flexibility on Electricity Generation Planning with Renewable and Carbon Targets, IEEE Transactions on Sustainable Energy.

Chen M, Lund H, Rosendahl LA and Condra TJ, (2010), Energy efficiency analysis and impact evaluation of the applications of thermoelectric power cycle to today's CHP systems, Applied Energy, 87, 1231–8.

Connolly D, Lund H, Mathiesen BV and Leahy M, (2009), Ireland's pathway towards a 100% renewable energy-system: the first step, In: Proceedings of the 5 th Dubrovnik conference for sustainable development of energy, water and environment systems. Dubrovnik, Croatia.

Connolly D., H. Lund, B.V. Mathiesen and M. Leahy, (2010), A review of computer tools for analyzing the integration of renewable energy into various energy systems, Elsevier Applied Energy, 87, 1059–1082.

DESIRE. Dissemination strategy on electricity balancing for large scale integration of renewable energy, Available at: http://www.project-desire.org/

El-Fadel, M., M. Zeinati, N. Ghaddar and T. Mezher, (2001), Mitigating energy-related GHG emissions through renewable energy, Energy Policy, 29:1031-1043.

Executive Summary Power Sector; Government of India Ministry of Power Central Electricity Authority New Delhi, January 2016.

Farghal S. A. and M. Roehdy Abdel Aziz, (1988), Generation Expansion Planning Including the Renewable Energy Sources, IEEE Transactions on Power Systems, 3, 816-822.

Ghanadan, R. and J.G. Koomey, (2005), Using energy scenarios to explore alternative energy pathways in California, Energy Policy, 33, 1117-1142.

Grigorios A., Bakirtzis, Pandelis N. Biskas and VasilisChatziathanasiou, (2012), Generation Expansion Planning by MILP considering mid-term scheduling decisions, Electric Power Systems Research, 86, 86-112.

Guo B., Wang Y. and Zhang A., (2003), China's Energy Future: Leap Tool Application in China, East Asia Energy Futures (EAEF)/Asia Energy Security Project Energy Paths Analysis/Methods Training Workshop.

HaticeTekiner, David W. Coit and Frank A. Felder, (2010), Multi-period multi-objective electricity generation expansion planning problem with Monte-Carlo simulation, Electric Power Systems Research, 80, 1394-1405.

HaticeTekiner-Mogulkoc, David W. Coit and Frank A. Felder, (2015), Mean-risk stochastic electricity generation expansion planning problems with demand uncertainties considering conditional-value-at risk and maximum regret as risk measures, Electrical Power and Energy Systems, 73, 309-317.

Heaps C.G., (2012), Long –range Energy Alternative Planning (LEAP) system, Stockholm Environment Institute, Somerville, MA, USA.

Heaps, C.G., (2012), Long-range Energy Alternatives Planning (LEAP) system. [Software version 2015.0.16] Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org

HeloisaTeixeiraFirmo, and Luiz Fernando LoureiroLegey, (2002), Generation Expansion Planning: An Iterative Genetic Algorithm Approach, IEEE Transactions on Power systems, 17, 901-906.

Islasa, J., F. Manzini and O. Masera, (2007), A prospective study of bioenergy use in Mexico, Energy, 32, 2306-2320.

JaberValinejad and TaghiBarforoushi, (2015), Generation expansion planning in electricity markets: A novel framework based on dynamic stochastic MPEC, Electrical Power and Energy Systems, 70, 108-117.

JamshidAghaei, Mohammad Amin Akbari, AlirezaRoosta and Amir Baharvandi, (2013), Multiobjective generation expansion planning considering power system adequacy, Electric Power Systems Research, 102, 8–19.

Kannan S, Mary Raja Slochanal S, Narayana Prasad Padhy, (2005), Application and comparison of meta-heuristic techniques to generation expansion planning problem, IEEE Trans. Power Syst. 20, 466-475.

Karthikeyan K., S. Kannan, S. Baskar and C. Thangaraj, (2013a), Application of Self-adaptive Differential Evolution Algorithm to Generation Expansion Planning Problem, Journal of Electrical Systems, 2, 203-211.

Karthikeyan K., S. Kannan, S. Baskar and C. Thangaraj, (2013b), Application of Opposition based DE to Generation Expansion Planning Problem, Journal of Electrical Engineering and Technology, 8, 686-693.

Karunanithi K., S.Kannan, C.Thangaraj, (2014), Generation Expansion Planning for Tamil Nadu- A case study, International Transactions on Electrical Energy Systems.

Khodr, H. M. , J.F. Gomez, L. Barnique, J. H. Vivas, P. Paiva, J. M. Yusta and A.J. Urdaneta, (2002), A linear programming methodology for the optimization of electric power generation schemes, IEEE Transactions on Power Systems. 17, 864¬869.

Khokhar JS, (1997), Programming Models for the Electricity Industry. New Delhi, Delhi: Commonwealth Publishers, 21–84.

Kumar A., Bhattacharya S.C., Pham H.L., (2003), Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model, Energy, 28, 627-654.

Lund H and Andersen AN, (2005), Optimal designs of small CHP plants in a market with fluctuating electricity prices, Energy Convers. Management, 46, 893–904.

Lund H and Clark WW, (2002), Management of fluctuations in wind power and CHP comparing two possible Danish strategies, Energy, 27, 471–83.

Lund H and Kempton W, (2005), Integration of renewable energy into the transport and electricity sectors through V2G, Energy Policy, 36, 3578–87.

Lund H and Munster E, (2003), Management of surplus electricity-production from a fluctuating renewable-energy source, Applied Energy, 76, 65–74.

Lund H and Munster E, (2003), Modelling of energy systems with a high percentage of CHP and wind power, Renewable Energy, 28, 2179–93.

Lund H and Munster E, (2006), Integrated energy systems and local energy markets, Energy Policy, 34, 1152–60.

Lund H and Salgi G, (2009), The role of compressed air energy storage (CAES) in future sustainable energy systems, Energy Conversion Management, 50, 1172–9.

Lund H, (2005), Large-scale integration of wind power into different energy systems, Energy, 30, 2402–12.

Lund H, (2006), Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply, Renewable Energy, 31, 503–15.

Lund H, (2007), Renewable energy strategies for sustainable development, Energy, 32, 912–9.

Lund H, Duic N, Krajacic G and GracaCarvalhoMd, (2007), Two energy system analysis models: a comparison of methodologies and results, Energy, 32, 948–54.

Lund H, Salgi G, Elmegaard B and Andersen AN, (2009), Optimal operation strategies of compressed air energy storage (CAES) on electricity spot markets with fluctuating prices, Applied Thermal Engineering, 29, 799–806.

Mathiesen BV and Lund H, (2009), Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources, IET Renewable Power Generation, 3, 190–204.

Mathiesen BV, (2008), Fuel cells and electrolysers in future energy systems, PhD thesis, Department of Development and Planning, Aalborg University, Aalborg, Denmark. <http://people.plan.aau.dk/~bvm/FinalWebVersion3.pdf>.

Mathiesen BV, (2009), 100% Renewable energy systems in project future climate – the case of Denmark, In: Proceedings of the 5th Dubrovnik conference for sustainable development of energy, water and environment systems. Dubrovnik, Croatia.

Meier, P., (1990), Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints, Annual Review of Power, 15, 277-306.

Moradi, M.A, H. Shakouri, and A.M. Aboutaleb, (2013), Developing the Electricity Demand Model for Iran's Residential Sector; Based on LEAP, In: International Power System Conference, Tehran, Iran.

Munster M and Lund H, (2009), Use of waste for heat, electricity and transport – challenges when performing energy system analysis, Energy, 34, 636–44.

Mustafa Ozcan, SemraOzturk and Mehmet Yildirim, (2014), Turkey's long-term generation expansion planning with the inclusion of renewable-energy sources, Computers and Electrical Engineering, 40, 2050-2061.

Park JB, Park YM, Won JR, Kim DG, (1999), Generation expansion planning based on an advanced evolutionary programming, IEEE Trans. Power Syst. 14, 299–305.

Park JB, Park YM, Won JR, Lee KY, (2000), An improved genetic algorithm for generation expansion planning, IEEE Trans. Power Syst., 15, 916–922.

Park, Y. M., J. B. Park, and J. R. Won, (1998), A hybrid genetic algorithm/dynamic programming approach to optimal long-term generation expansion planning, Electrical Power and Energy Systems, 20, 295-303.

Power Sector in Tamil Nadu: A Comparative Analysis; Athena Infonomics India Pvt. Ltd, 2011.

Prabakar B.R., K.Karunanithi, S.Kannan, C. Thangaraj, (2015), Energy Model of Electric Sector for Tamil Nadu, International Journal of Applied Engineering Research, 10, 5681-87.

Rajesh K., A. Bhuvanesh, S. Kannan, C. Thangaraj, (2016a), Least cost generation expansion planning with solar power plant using Differential Evolution algorithm, Elsevier Renewable Energy, 85, 677-686.

Rajesh K., K.Karthikeyan, S. Kannan, C. Thangaraj, (2016b), Generation expansion planning based on solar plants with storage, Elsevier Renewable and Sustainable Energy Reviews, 57, 953-964.

Rajesh K., S. Kannan, C. Thangaraj, (2016c), Least cost generation expansion planning with wind power plant incorporating emission using Differential Evolution algorithm, Electrical Power and Energy Systems, 80, 275–286.

Rallapalli S.R. and S. Ghosh, (2012), Forecasting monthly peak demand of electricity in India-A critique, Energy Policy, 45, 516-520.

Salvador Pineda and Andreas Bock, (2016), Renewable-based generation expansion under a green certificate Market, Renewable Energy, 91, 53-63.

Shin H.C., Park J.W., Kim H.S., Shin E.S., (2005), Environmental and economic assessment of landfill gas electricity generation in Korea using LEAP model, Energy Policy, 33, 1261-1270.

Siteur J., (2004), The Long-range Energy Alternatives Planning Model (LEAP) and Wood Energy Planning. Available at http://www.rwedp.org/p_leap.html.

Steffen Rebennack, (2014), Generation expansion planning under uncertainty with emissions quotas, Electric Power Systems Research, 114, 78–85.

Sung-Ling Chen, Tung-Sheng Zhan, and Ming-Tong Tsay, (2006), Generation expansion planning of the utility with refined immune algorithm, Electric Power Systems Research, 76, 251-258.

Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants, (2013); U.S. Energy Information Administration.

Wang X, McDonald JR, (1994), Modern Power System Planning. London: McGraw Hill; 208-229.

Wei Y.M., (2006), Progress in energy complex system modeling and analyses, Int. J. of Global Energy Issues, 25, 109-128.

Yonghan Feng and Sarah M. Ryan, (2013), Scenario construction and reduction applied to stochastic power generation expansion planning, Computers & Operations Research, 40, 9-23.

Zhu J, Chow MY, (1997), A review of emerging techniques on generation expansion planning, IEEE Trans. Power Syst. 12, 1722–1728.