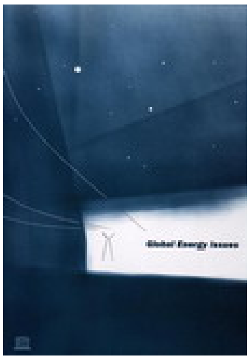

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Prioritisation for electric utility expansion scenarios in Maharashtra, India, using analytical hierarchical approach

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Abstract: Maharashtra is the second-largest and prominent state in India with an industrial and service sector economy consuming 12% of India's electricity. This paper forecasts electricity demand for 2030 using Long Range Energy Alternatives Planning (LEAP) and generates seven electricity scenarios. The study utilises the Analytical Hierarchy Process (AHP) algorithm for priority setting, employing a three-level hierarchical structure. Scenarios are ranked based on four main criteria and 25 sub-criteria, incorporating inputs from three stakeholder groups: electricity planners, utility officers and end users. The preferred scenario is Business as Usual (BAU), followed by the Energy Conservation (EC) scenario. Sensitivity analysis studies explore future implications for the identified scenarios. While the Least Cost Scenario (LCS) and Zero Emission Scenario (ZES) are highly desirable, the addition of significant infrastructure remains a concern for these scenarios.

Keywords: analytical hierarchy process; electricity scenarios; prioritisation; electric utility expansion.

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1 Introduction

Maharashtra stands as India's second-largest state in terms of population and industrial and service sector economy. Accounting for 12% of India's electricity consumption, the state has experienced an economic growth of 8.4% since 2002, propelling an increased demand for electricity (MAHADES ESM, 2018). However, Maharashtra has witnessed a steady deterioration in the power sector, with no significant additions to the installed capacity and delays in critical fast-track projects. Further, demand–supply mismatch was also found, attributed to insufficient capacity augmentation and high Transmission and Distribution (T&D) losses. As per Maharashtra Electricity Regulatory Commission (MERC), load shedding is an imprudent response to rationing a scarce resource, and the Commission has been trying to implement alternative measures to avoid load shedding (MERC, 2005) to develop a suitable strategy to bridge the demand–supply gap as compared to unregulated and unplanned shutdown in case of a shortfall (Kale and Pohekar, 2012).

Therefore, an energy policy needs to be framed which emphasises on using alternative energy sources and EC (both demand and supply management). This necessitates a thorough analysis of the current electricity situation, forecasting future demand and prioritising interventions. To meet the electricity demand projected for 2030, this study employs Long Range Energy Alternatives Planning (LEAP), generating seven distinct electricity scenarios: Business as Usual (BAU), Energy Conservation (EC), Renewable Energy (REN), Reliability Scenario (RS), Zero Emission Scenario (ZES), Least Cost Scenario (LCS) and Sustainable Society (SS) Scenario. The base year for forecasting was taken as 2012. These scenarios are aimed at giving futuristic solutions using different criteria which may be conflicting with each other (Kale and Pohekar, 2014). These scenarios need to be weighed by applying a suitable group decision-making method to reach a consensus decision.

The Analytic Hierarchy Process (AHP), devised by Saaty (1977), is an effective tool to deal with complex decision-making processes, aiding decision-makers in setting priorities and making informed choices. AHP has been prominently used for electric utility expansion planning worldwide. Among the prominent ones, Xiaohua and Zhenmin (2002) discussed China's Sustainable Development of Rural Energy (SDRE) using AHP.

Amer and Daim (2011) used AHP to prioritise renewable energy technologies for Pakistan. Bas (2012) used AHP to formulate an integrated framework for analysing electricity supply in Turkey. Lee et al. (2009) utilised Multi-Criteria Decision-Making (MCDM) analysis based on AHP, associated with Benefits, Opportunities, Costs and Risks (BOCR), to investigate and select a suitable wind farm in China. Henrich et al. (2007) employed a Multi-Criteria Decision Analysis (MCDA) model to prioritise energy expansion alternatives based on objectives and uncertainties and demonstrate its use in South Africa's electric supply industry. Aminloei and Ghderi (2010) applied AHP and Fuzzy Aggregate Power Planning (FAPP) to plan electricity generation for Iran. Uyan (2013) used AHP for micro-siting solar farms in Karapinar. Chatzimouraditis and Pilavachi (2008) used AHP to study the impact of power plants on living standards. Li and Zhang (2023) applied a short-term forecasting method for lighting energy consumption in large buildings based on time series analysis. Jebaraj et al. (2007) used an artificial neural network to forecast commercial energy consumption in India.

This paper introduces a hierarchical decision-making framework based on AHP to prioritise electricity scenarios for Maharashtra, India. Emphasising the significance of effective decision-making, the study uses four main criteria and 25 sub-criteria, decided based on prominent literature on electricity utility expansion planning (Rovere et al., 2010; Stein, 2013; Ahmed and Tahar, 2014; Zangeneh et al., 2009; Heo et al., 2010; Algarin et al., 2017; Kurka, 2013). Inputs from three decision-making groups – electricity planning, state electricity board, and end users – are considered.

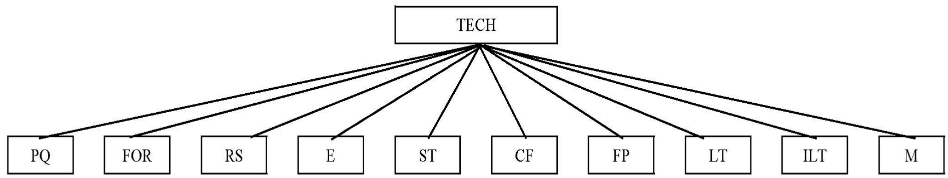
2 Selection of criteria

Criteria selection has been undertaken to check and compare all the features of the scenarios under consideration for prioritisation in this study. The selected criteria and their corresponding sub-criteria are discussed below.

2.1 Technical criteria (TECH)

The technical sub-criteria illustrated in Figure 1 are grouped into three categories: operational, technological and structural requirements. Various regulatory bodies that oversee supply quality have established a range of operating criteria (Strbac and Mutale, 2005). The operational characteristics of electric supply can impact both the grid and consumers. The grid network's capability is assessed to ensure it can effectively handle the power plant's entire output under various loading scenarios. Six sub-criteria fall under the operational category of technical criteria: power quality, Forced Outage Rate (FOR), Response Speed (RS), Efficiency (E), Startup Time (ST)and Capacity Factor (CF). The attribute power quality represents the voltage and harmonic characteristics of the supply. Within an electricity system, issues such as power surges, sags, poor voltage regulation, frequency fluctuations, harmonics, electrical noise and electromagnetic interference can lead to damage, safety concerns, reliability loss and significant economic losses.

Figure 1 Technical sub-criteria

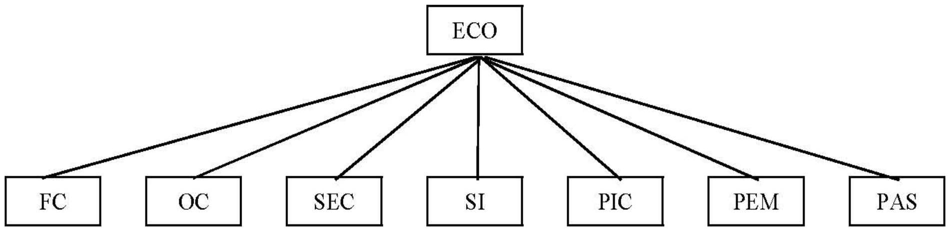


Forced Outage Rate (FOR) is defined as the expected hours of power outage over a given period. Minimising FOR is crucial, as it reflects the probability that a power plant unit will not be available when needed. Response speed assesses the ability of generation technology to regulate frequency and handle load fluctuations. An electric utility should have quick response speed in order to counter load fluctuations effectively. Efficiency gauges the performance of electricity generation technology, representing the saleable energy produced as a percentage of the heating value of the fuel consumed. Efficiency of a generation technology should be the maximum possible. The ST of generation technology is important for determining the ability to provide a spinning reserve for the grid. A shorter ST is desirable. Spinning reserve, the extra generating capacity that is available by increasing the power output of generators, is crucial for handling uncertainties due to unforeseen load variations. CF, a ratio of total energy produced over a period to its output if operated at full capacity, should be maximised. The structural and constructional attributes are further divided into four sub-attributes: footprint, lifetime, installation lead time and maintenance. Footprint (FP) represents the area needed per unit generation capacity and is crucial in densely populated areas where space is limited. Lifetime (LT) signifies the operational lifespan of generation technology. Distribution network has large physical assets with long operational lifetime (Collinson et al. 2003). Therefore, any fundamental change in the network should be undertaken over an extended period of time. Installation Lead Time (ILT) is vital for comparing generation technologies and should be minimised. To increase the performance and lifetime of a generation plant, regular Maintenance (M) is required, but excessive maintenance costs should be avoided.

2.2 Economic criteria (ECO)

Figure 2 displays the sub-criteria falling under economic criteria. Fixed Cost (FC) stands as a crucial parameter in the evaluation of electricity generation plants, wherein the investment cost per MW of electricity should be minimised. Conventional and fossil fuel technologies generally exhibit lower investment costs than renewable technologies. This investment cost is a significant metric for assessing power plants under construction (Peppermans et al., 2005).

Figure 2 Economic sub-criteria

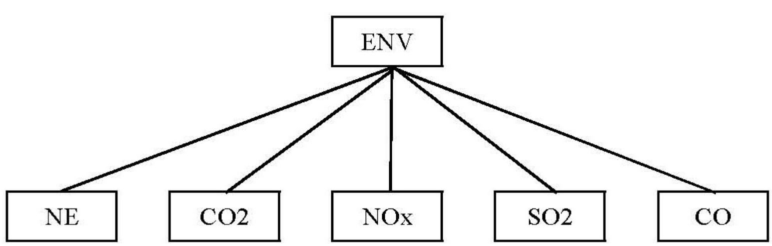


Operating Cost (OC), a variable term, encompasses the cost of primary energy resources and generation technology and should be minimised. Specific Electricity Cost (SEC), expressed in Rs/kWh, represents the cost of generating electricity at the point of connection to a load or electricity grid. SEC includes initial capital, discount rates and the costs of continuous operation, fuel and maintenance, and should be minimised. Specific Investment (SI) cost, representing the unit cost of the installed capacity of a power plant, should be minimised. Some equipment, materials and services may need to be imported, and the Potential of Imported Costs (PIC) gauges the percentage cost of acquiring such items, aiming for minimisation. The potential to attract investments from private companies, indicative of a project's capability to enter the electricity market, is termed Potential to Enter Electricity Market (PEM). This economic attribute can significantly influence the rate of return for the project and should be high. A power station's ability to provide ancillary services, denoted as Potential of Ancillary Services Supply (PAS), should be maximised.

2.3 Environmental criteria (ENV)

In Figure 3, the hierarchy of environmental criteria is presented, encompassing three sub-attributes: noise pollution, air pollution and aesthetics. Generation technologies are evaluated based on the emission of four Greenhouse Gases (GHGs), namely, CO_2, NOx, SO_2 and CO. Given the significant impact of GHG emissions on global climate change, maintaining low emissions is imperative, as it poses a threat to both present and future generations. Noise Emission (NE) stands as a crucial sub-criterion for generation technologies. Elevated noise levels can pose serious health hazards, making it essential to minimise noise emissions.

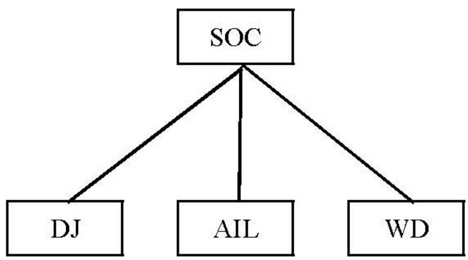
Figure 3 Environmental sub-criteria



2.4 Societal criteria (SOC)

In Figure 4, various sub-criteria listed under societal criteria are presented. During the construction phase of a power plant, the number of Direct Jobs (DJ) created per MW, and during the operational phase, direct jobs based on activity (per MWh) are considered. The average job income level serves as a crucial indicator of the income generated by a power plant and should be on the higher side. It also reflects the required job skills for different roles (Rovere et al., 2010). Waste Disposal (WD) is another significant sub-criterion. The chemical wastes generated in the process of electricity generation pose environmental and, ultimately, human risks. The substantial amount of ash produced in coal plants and the need for underground depositories for nuclear wastes burden the environment. Hence, WD is a critical criterion to be considered while prioritising energy technologies and should be minimised.

Figure 4 Social sub-criteria



3 Scenarios considered for analysis

The study considers seven possible electricity scenarios for priority setting as described below.

3.1 BAU scenario

In the BAU scenario, it is anticipated that no modifications will be made to the policies, and future development patterns will align with precedents set by previous trends. All parameters and variables within the electric system in the BAU scenario adhere to historical patterns. This includes the methods of electricity generation, their efficiency, T&D losses, the percentage of electricity generated, installed plant capacity, fuel usage, the rate of growth in electricity consumption, economic growth rate, greenhouse gas emissions and more.

3.2 EC scenario

The EC scenario proposes a reduction in energy consumption through EC measures and the use of energy-efficient appliances. The state government of Maharashtra has implemented EC measures following guidelines established by the Bureau of Energy

Efficiency (BEE, 2018). Considering that every unit of energy saved at the user's end reduces the need for new capacity additions by 2 to 2.5 times, efficient energy use and conservation become crucial.

3.3 Renewable energy scenario (REN)

The Renewable Energy Scenario (REN) involves the generation of electricity from renewable energies, which are inexhaustible and harnessed without the generation of harmful pollutants. Substantial efforts are underway to promote renewable energy (Ahamer, 2021; Okonkwo et al., 2018). In this scenario, renewable energy technologies are recommended to generate power in lieu of fossil fuel-based power plants. Approximately 60% of all power generation in the base year 2012 came from coal-based power plants (MAHADES ESM, 2018), a significant contributor to greenhouse gas emissions. The focus on environmental protection in renewable energy prioritises the installation of renewable energy plants as coal-based and natural gas facilities approach the end of their useful lives and are phased out, aiming to maintain GHG emission levels from 2012.

3.4 RS

The RS entails the efficient supply of electricity to customers with reasonable assurance of continuity. The infrastructure for coal plants is already in place in the state. Modernisation and expansion of existing plants are considered an easy and economical option compared with adopting new technologies. Coal-based generation is identified as a reliable source globally. With an abundance of coal in and around Maharashtra and a proper transportation system, coal-based plants are considered the most reliable in the state. The present electricity scenario is built around coal plants, contributing over 60% of the total generation. Supercritical and ultra-critical technologies would improve the efficiency of power plants. Therefore, a futuristic electricity scenario for the target year 2030, where all electricity demand is met by coal plants, can be considered as RS.

3.5 ZES

Energy systems with zero emissions are possible with modern energy technologies (Tokimatsu et al., 2014). The ZES assumes zero emissions from the energy system, considering carbon dioxide as the primary greenhouse gas emission from the state's electric utilities in the baseline year 2012, totalling 65.7 million metric tonnes. The GHG emission levels of specific plants during the base year 2012 form the basis for this estimation. Research indicates a 244.6% rise in estimated CO_2 emissions for BAU by 2030 (Kale and Pohekar, 2014). Owing to coal being the primary fuel for new power plants, there has been a sharp increase in CO_2 emissions. The increasing CO_2 concentration is the primary reason behind global warming. Therefore, a global campaign has been ongoing to curb emission levels from power plants (Barin et al., 2006; Polatidis and Haralambopolous, 2006; Kaya and Kaharaman, 2010). Power generation based on hydro and renewables has been considered in this scenario.

3.6 LCS

The LCS aims to find the most cost-effective solutions for electricity supply. Capital cost, fuel cost and O&M cost collectively contribute to the total cost of a generation plant. Renewable energy and hydraulic plants are relatively economical compared to coal and natural gas, primarily due to their high fuel costs. Thus, an LCS can be developed by combining hydraulic and renewable technologies to meet the projected demand.

3.7 Sustainable society scenario (SS)

The Sustainable Society Scenario (SS) assumes that the electricity system should cater to present energy needs without compromising the energy needs of future generations. GHG emissions from the electricity supply sector pose a challenging issue for energy planners, with mounting pressure from environmentalists. Energy planners must strike a balance between the reliability of electric supply (through fossil fuels) and pollution mitigation (renewable energy). The SS scenario considers a reduction in GHG emissions while giving weightage to fossil fuels. It adopts a backcasting approach, setting a future target and working backward to the present to achieve it. The SS scenario aims for an 80% reduction in GHG emissions compared to the base year 2012 level, considering the expansion of renewable energy.

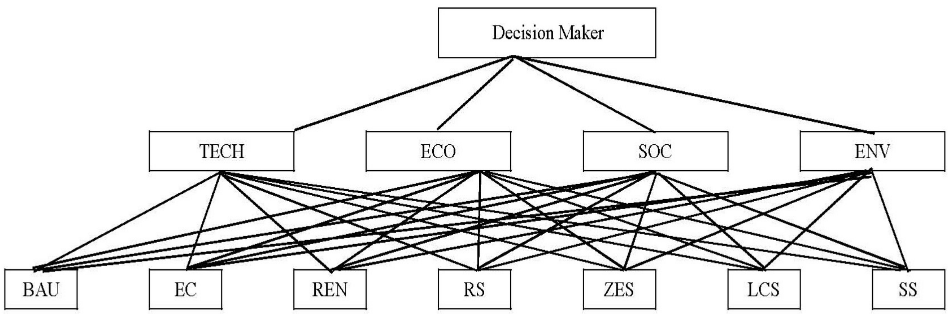
4 Framing hierarchical structure

Multi-criteria evaluation techniques are increasingly employed in the electricity field due to the growing role of decision-making groups in energy planning. This approach has proven applicable to evaluating electricity scenarios in the state, providing solutions for problems involving conflicting and multiple objectives (Brownie et al., 2010; Cinelli et al., 2014). It is noteworthy that single-criteria-based planning has become obsolete, and the multi-criteria framework is gaining popularity for arriving at suitable decisions (Pohekar and Ramachandran, 2004; Bernow and Greening, 2004). These methods enhance the understanding of the inherent features of decision problems, promote the role of participants in the decision-making process, facilitate compromise and collective decisions, and provide a good platform to comprehend the perception of models and analysts in a realistic scenario (Beltran et al., 2014). They also contribute to improving the quality of decisions by making them more explicit, rational and efficient (Cherni et al., 2007). Negotiating, quantifying, and communicating priorities are also facilitated through the use of these methods.

The theory of AHP is based on three stages of problem-solving. AHP decomposes a complex problem into a hierarchy with the goal (objective) at the top, criteria and sub-criteria at various levels and decision alternatives at the bottom (Saaty, 1977; Saaty and Katz, 1990).

The present problem was decomposed into a hierarchical structure, as shown in Figure 5. The figure comprises two levels of hierarchy, with the objective at the top level and main criteria – technical (TECH), economic (ECO), societal (SOC) and environmental (ENV) – at the second level. The criteria and sub-criteria are explained in the following section. The alternatives, i.e., scenarios, are indicated at the end of the structure according to the fundamentals of the AHP methodology. Elements at each hierarchy level were compared in pairs to assess their relative preference concerning each of the elements at the next higher level.

Figure 5 Hierarchical structure



5 Application of AHP

In choosing between scenarios, the decision-maker must weigh and prioritise different criteria; this means assigning preferences to scenarios and providing weightages to identified criteria for assessment.

5.1 Pairwise comparison

Following the initial step of developing a hierarchy, as discussed in the previous section, pairwise comparisons of main criteria and sub-criteria were carried out using a qualitative scale. Once qualitative judgements were made, they were translated into numbers using the fundamental scale. Saaty and Katz (1990) suggested a scale of 1–9, as indicated in Table 1.

Table 1 Scale of preference between two elements

Preferences	*Definition*
1	Equal importance
2	Weak importance of one over another
5	Essential or strong importance
7	Very strong importance.
9	Absolute importance.
2, 4, 6, 8	Intermediate values

The degree of importance of the criteria (criterion weightages) was computed based on a survey of literature available on the topic. The preference of scenarios at a particular level over those at the succeeding level was measured by conducting pairwise comparisons between the assigned values. This procedure was repeated for elements at each level in an upward direction.

5.2 Computation of eigenvectors

After performing the step-by-step procedure and creating comparison matrices at different hierarchical levels, aggregate eigenvectors were computed until the composite final vectors of weight coefficients for the scenarios were determined.

Figure 6 General matrix

$$\begin{bmatrix} a_{11} & a_{12} & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & a_{2n} \\ a_{n1} & a_{n2} & \cdot & a_{nn} \end{bmatrix}$$

To elicit pairwise comparisons performed at a given level, *a* matrix *A*, as shown in Figure 6, was created by putting the result of pairwise comparisons of element *i* with element *j* into the position a_{ji}.

The reciprocal value of the comparison was placed in a position a_{ji}. The result of pairwise comparisons was the weight coefficient for each element at a given level with respect to the element of a higher level. The entries of the final weight coefficients vector reflected the relative importance (value) of each scenario with respect to the usefulness stated at the top of the hierarchy.

The second step, after defining the criteria and sub-criteria, was the elicitation of pairwise comparison judgements. The criteria, namely, Technical (TECH), Economic (ECO), Environmental (ENV) and Social (SOC), were arranged into a matrix, and then pairwise comparisons of these criteria were done, as shown in Figure 7. When comparing two criteria, the question to ask was of the following kind: of the two criteria being compared, which criteria are considered more important with respect to the scenarios? The scale for comparison used was based on extensive literature on the similar topic.

Figure 7 Pairwise comparison of criteria

$$\begin{bmatrix} & ECO & TECH & ENV & SOC \\ ECO & 1 & 1 & 5 & 6 \\ TECH & 1 & 1 & 5 & 6 \\ ENV & 1/5 & 1/5 & 1 & 1 \\ SOC & 1/6 & 1/6 & 1 & 1 \end{bmatrix}$$

Once the values of the pairwise comparison matrix were entered, the consistency index was calculated using the eigenvector method. Additionally, the consistency ratio was computed, which is the ratio of the consistency index to that available in the random index table. If this consistency ratio was <10%, the matrix was accepted; otherwise, the values had to be adjusted until consistency was achieved. The column of numbers was normalised by dividing each entry by the sum of all entries. The sum of each row of normalised values was computed, and the average was taken. This provided the principal eigenvector (PRIN VEC). For the above matrix, the value of the consistency index is 0.0014, and the consistency ratio is 0.0015.

Normalisation of the matrix contains information on the total dominance of the elements being compared, making it possible to divide the priority of the criteria to each element according to the relative dominance of the element. The matrix of criteria was normalised for further computation, as shown in Figure 8. The PRIN VEC of the matrix is the vector of priorities, giving the relative priority of the criteria measured on a ratio scale. In this case, technical and economic criteria have the highest priority with 42.26%, followed by environmental with 8.09% and social with 7.34%.

Figure 8 Normalised matrix of criteria

	ECO	*TECH*	*ENV*	*SOC*	*PRIN VEC*
ECO	0.4225	0.4225	0.4167	0.4286	0.4226
TECH	0.4225	0.4225	0.4137	0.4286	0.4226
ENV	0.0845	0.0845	0.0833	0.0714	0.0809
SOC	0.704	0.0704	0.0833	0.0714	0.0739

Following this, in the second level, to carry out pairwise comparison of sub-criteria listed under 'Economic criteria', a matrix of 7×7 was created, and pairwise comparison was done, as shown in Figure 9. For this matrix, the consistency index is 0.1223, and the consistency ratio is 0.0927. The principal vector values indicate that, in the case of economic criteria, FC and OC have the highest priority with 23.36%, followed by SI with 21.17% and SEC with 17.61%.

Figure 9 Pairwise comparison of the sub-criteria of ECO criteria

	FC	*OC*	*SEC*	*SI*	*PIC*	*PEM*	*PAS*
FC	1	1	2	1	5	6	7
OC	1	1	2	1	5	6	7
SEC	1 / 2	1 / 2	1	1	5	6	7
SI	1	1	1	1	5	6	7
PIC	1 / 5	1 / 5	1 / 5	1 / 5	1	5	6
PEM	1 / 6	1 / 6	1 / 6	1 / 6	1 / 5	1	5
PAS	1 / 7	1 / 7	1 / 7	1 / 7	1 / 6	1 / 5	1

For 'technical criteria', a 10×10 matrix was created, and pairwise comparison was done for the sub-criteria. Similarly, for 'environmental criteria', a matrix of 5×5 was created and pairwise comparison was done. For 'society criteria', a 3×3 matrix was created, and comparison was done. Normalisation of sub-criteria of 'ECO criteria' was done, as shown in Figure 10. PRIN VEC values show that FC and OC are top on the priority list with 23.36%, followed by SI with 17.61%, SEC with 17.61%, PIC with 7.67%, PEM with 4.47% and PAS with 2.35%.

Figure 10 Normalisation of the sub-criteria of ECO criteria

	FC	*OC*	*SEC*	*SI*	*PIC*	*PEM*	*PAS*	*PRINVEC*
FC	0.2494	0.2494	0.3072	0.2218	0.234	0.1987	0.175	0.2336
OC	0.2494	0.2494	0.3072	0.2218	0.234	0.1987	0.175	0.2336
SEC	0.1247	0.1247	0.1536	0.2218	0.234	0.1987	0.175	0.1761
SI	0.2494	0.2494	0.1536	0.2218	0.234	0.1987	0.175	0.2117
PIC	0.0499	0.0499	0.0307	0.0444	0.0468	0.1656	0.150	0.0767
PEM	0.0416	0.0416	0.0256	0.0378	0.0094	0.0033	0.125	0.0447
PAS	0.0356	0.0356	0.0219	0,0317	0.0078	0.0066	0.025	0.0235

After this, in the third level, pairwise comparisons of the alternatives (which are seven in number) were done for all the sub-criteria (N=25). Thus, 25 matrices of 7×7 were formed, and pairwise comparison was done. A sample matrix is shown in Figure 11, comparing the alternatives for the sub-criteria ‘FC’. For this matrix, the consistency index is 0.0377 and the consistency ratio is 0.0286.

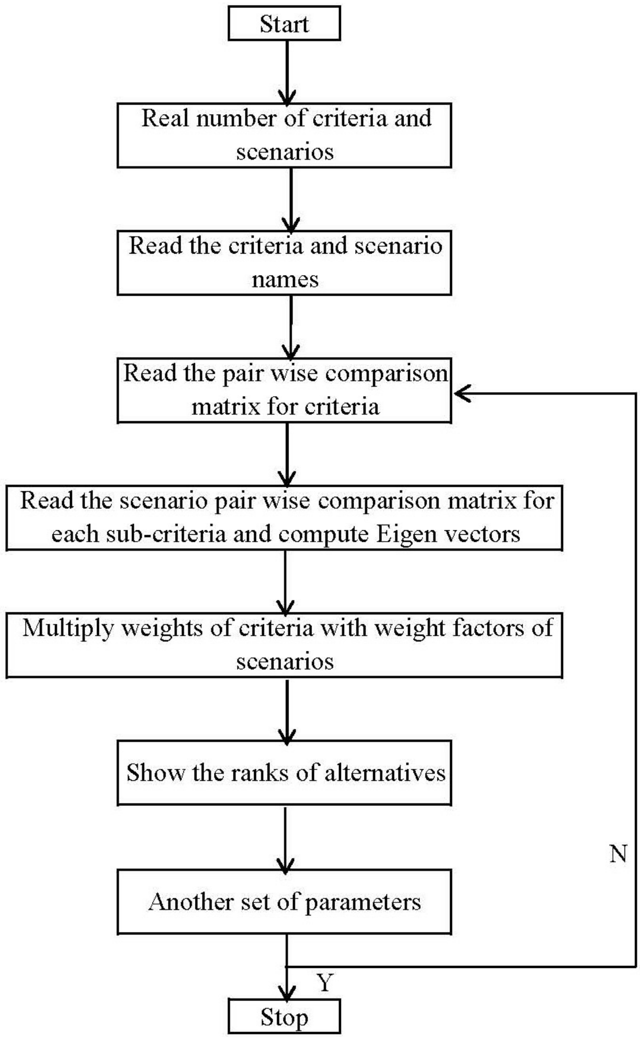
Figure 11 Pair wise comparison of scenarios with respect to FC

	BAU	*EC*	*REN*	*RS*	*ZES*	*LCS*	*SS*	*PRINVEC*
BAU	1	3	1	2	6	8	5	0.2436
EC	1 / 3	1	1	2	6	7	5	0.2391
REN	1	1	1	2	6	7	5	0.2391
RS	1 / 2	1 / 2	1 / 2	1	6	7	5	0.1666
ZES	1 / 6	1 / 6	1 / 6	1 / 6	1	1	1	0.037
LCS	1 / 8	1 / 7	1 / 7	1 / 7	1	1	1	0.0333
SS	1 / 5	1 / 5	1 / 5	1 / 5	1	1	1	0.0412

Normalisation of the matrix of scenarios with respect to FC was performed for further calculations. The PRIN VEC values indicate that for the criterion FC, BAU tops the priority list with 24.36%, followed by EC and REN with 23.91%, RS with 16.66%, SS with 4.12%, ZES with 3.7% and LCS with 3.33%.

The same procedure was applied to form all the matrices. The results obtained provide the priorities for criteria and sub-criteria. The decision indices give the preference for the scenarios. The steps involved in the prioritisation of scenarios are explained in Figure 12.

Figure 12 Flow chart for AHP



6 Results and discussion

The prioritisation of scenarios by AHP indicates that BAU is the most suitable scenario by the target year 2030. The study recommends a sustainable energy option along with the reliability of supply as the best policy for the state. Sizing of the energy technologies for BAU was conducted. The obtained results are presented, analysed, and discussed in the following section.

AHP was applied to the present problem of ranking suitable electricity scenarios for the state by the target year 2030. Criteria and sub-criteria relevant to the study were selected from a literature survey.

The weighing of criteria was determined through a survey of literature available on the topic and by referring to some evaluation problems of a similar type. The present problem was decomposed into a hierarchical structure, comprising four levels, with usefulness at the top level (objective), main criteria at the next level, sub-criteria at the succeeding level and the alternatives (i.e., scenarios) indicated at the end of the structure, following the fundamentals of the AHP methodology. In the first level, the criteria, namely, TECH, ECO, ENV and SOC, were arranged into a matrix, and then pairwise comparisons of these criteria were done. In the second level, pairwise comparisons were performed for the sub-criteria under the four criteria, and the consistency index was calculated using the eigenvector method. Furthermore, the consistency ratio was computed; if this consistency ratio was <10%, the matrix was accepted; otherwise, the values had to be adjusted until consistency was achieved. The above-discussed procedure was followed to formulate all the matrices in AHP. The data summary table provides the priorities for all the criteria. Next, in the second level, the summary Table 2 shows the weights of sub-criteria for all four criteria. In the third level, it also gives the weights of each alternative for all 25 sub-criteria.

Table 2 Weightages of sub-criteria for the identified alternatives

Sub-criteria	*Level 3-Sub-Wt*	*Level -2-Sub-Wt*	*BAU*	*EC*	*REN*	*RS*	*ZES*	*LCS*	*SS*
FC	0.2336	0.4226	0.4226	0.2058	0.2345	0.1643	0.0362	0.0325	0.0402
OC	0.2336	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
SEC	0.1761	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
SI	0.2117	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
PIC	0.0767	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
PEM	0.0447	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
PAS	0.0235	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
PQ	0.1477	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
FOR	0.1447	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
RS	0.1477	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
E	0.1956	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
ST	0.1253	0.4226	0.4226	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
CF	0.1253	0.4226	0.2865	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
FP	0.0334	0.4226	0.2916	0.2045	0.2348	0.1631	0.351	0.0333	0.0386
LT	0.0328	0.4226	0.2865	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
ILT	0.0217	0.4226	0.2865	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
M	0.0228	0.4226	0.2865	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
NE	0.3789	0.0809	0.2865	0.2057	0.2348	0.1641	0.0353	0.0333	0.0402
CO_2	0.3477	0.0809	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
NO_X	0.1141	0.0809	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
SO_2	0.0947	0.0809	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
CO	0.0646	0.0809	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
DJ	0.7189	0.0739	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
AIL	0.1684	0.0739	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377
WD	0.1127	0.0739	0.2837	0.2065	0.2353	0.1649	0.0367	0.0351	0.0377

These weights were multiplied by the priorities of all parent sub-criteria in the hierarchy, and the cumulative sum of them was stored in the decision index of each alternative. The final decision was based on this index.

The data summary Table 3 provides the priorities for each criterion and sub-criterion below the second level. It also gives the weights of each alternative under the last level of sub-criteria. These weights were multiplied by the priorities of all present sub-criteria in the hierarchy, and a cumulative sum of them was stored in the decision index of each alternative. The final decision was made based on this index.

Table 3 Data summary table

Sub-criteria	*BAU*	*EC*	*REN*	*RS*	*ZES*	*LCS*	*SS*
FC	0.0338	0.0231	0.0156	0.0159	0.0035	0.0031	0.0038
OC	0.0338	0.0230	0.0156	0.0159	0.0034	0.0031	0.0038
SEC	0.0249	0.0177	0.0120	0.0120	0.0026	0.0024	0.0029
SI	0.03	0.0213	0.0144	0.0144	0.0031	0.0028	0.0035
PIC	0.0109	0.0077	0.0052	0.0052	0.0011	0.001	0.0013
PEM	0.0063	0.0045	0.0030	0.0030	0.0007	0.0006	0.0007
PAS	0.0034	0.0023	0.0016	0.0016	0.0003	0.0003	0.0004
PQ	0.0214	0.0146	0.0099	0.0100	0.0022	0.0020	0.0024
FOR	0.0214	0.0146	0.0099	0.0100	0.0022	0.0020	0.0024
RS	0.0214	0.0146	0.0099	0.0100	0.0022	0.0020	0.0024
E	0.0283	0.0193	0.0131	0.0133	0.0029	0.0026	0.0032
ST	0.0181	0.0124	0.0084	0.0085	0.0018	0.0017	0.0021
CF	0.0181	0.0124	0.0084	0.0085	0.0018	0.0017	0.0021
FP	0.0049	0.0033	0.0022	0.0023	0.0005	0.0004	0.0005
LT	0.0047	0.0032	0.0022	0.0022	0.0005	0.0004	0.0005
ILT	0.0031	0.0021	0.0015	0.0015	0.0003	0.0003	0.0004
M	0.0033	0.0022	0.0015	0.0015	0.0003	0.0003	0.0004
NE	0.0105	0.0072	0.0049	0.0049	0.0011	0.0010	0.0012
CO_2	0.0095	0.0066	0.0045	0.0045	0.0010	0.0010	0.0010
NO_X	0.0031	0.0022	0.0015	0.0015	0.0003	0.0003	0.0003
SO_2	0.0026	0.0018	0.0012	0.0012	0.0003	0.0003	0.0003
CO	0.0018	0.0012	0.0008	0.0008	0.0002	0.0002	0.0002
DJ	0.018	0.0124	0.0085	0.0086	0.0019	0.0018	0.0019
AIL	0.0042	0.0029	0.0020	0.0020	0.0005	0.0004	0.0004
WD	0.0028	0.0019	0.0013	0.0013	0.0003	0.0003	0.0003

Analysis of weightages revealed that FC (0.4226), power quality (0.4226) and efficiency (0.4226) were given the same weightages. The average income level (0.0739) was allocated the least weightage. The respondents had neither given too much importance to any of the criteria nor out-rightly considered any criterion trivial in the analysis. The total differential in the weightage accounted for 0.3487.

Table 4 shows that BAU is the best option under the circumstances of the developed case situation, followed by EC and then RS.

Table 4 Result of AHP

Sr. No	*Scenario*	*Decision index*	*Rank*
1	BAU	0.3402	i
2	EC	0.2344	ii
3	RS	0.1609	iii
4	REN	0.1591	iv
5	SS	0.0384	v
6	ZES	0.0358	vi
7	LCS	0.0318	vii

Thus, BAU is the preferred scenario, followed by EC. Although RS and REN are buzzword in energy management, the group decision-making exercise using AHP indicated lower priorities to them. The indices computed for SS, ZES and LCS indicated that they may not be considered as feasible options by the stakeholders.

The weights assigned by the stakeholders, namely, electricity planners, utility officers and end users, were used to rank the electricity scenarios. Technical criteria [42.26%] and economic criteria [42.26%] had more weightage than environmental criteria [8.09%] and social criteria [7.34%]. The laws on industrial pollution were relatively lax in the state and did not attract severe penalties; thus, an overall increased sense of social obligation is needed in the energy sector. Slightly higher weightage assigned to sub-criteria FC, OC, SEC, SI, PIC, PEM, PAS, PQ, FOR, RS, E and ST to BAU scenario than EC and REN scenarios led to marginally better ranking for BAU relative to EC and REN.

BAU was ranked marginally higher on the notion of being superior in terms of reliability, quality of power, and to some extent being sustainable. EC is based on demand-side management, and the success of EC depends on awareness amongst end-users and participation at the customer end. Implementation of REN needs a total revamp of the existing system in terms of technical and infrastructure, which will incur huge costs, and hence it is slightly lower in the hierarchy.

7 Conclusion

This paper aims to prioritise futuristic electricity scenarios for Maharashtra, a prominent industrial and service sector state in India, using a hierarchical decision-making framework based on AHP. Seven electricity scenarios (BAU, EC, RS, REN, SS, ZES and LCS) were considered in this study. These scenarios were ranked based on four main criteria (TECH, ECO, ENV and SOC) and 25 sub-criteria. The problem comprised two levels of hierarchical structure, with the objective (preferred situation) at the top level and the main criteria at the second level. The alternatives, i.e. scenarios, were indicated at the end of the structure. The study incorporated inputs from three stakeholder groups: electricity planners, utility officers and end-users. Following a pairwise comparison algorithm, the weightages were computed to arrive at a preferred scenario. From the above prioritisation, it is evident that BAU is the preferred scenario, with a decision index of 0.3402, followed by EC with a decision index of 0.2344. The indices computed for SS, ZES and LCS indicated that they may not be considered as feasible options by the stakeholders. Sensitivity analyses studies revealed that BAU is preferred due to major weightages assigned to technical criteria. EC may supersede BAU if obvious interventions, such as educating customers, no need for capacity addition and lowering emissions, are practiced. LCS and ZES have a long way to become a reality due to the prevailing need for high energy demand and need for adding substantial infrastructure.

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