

A Comparative Evaluation of Renewable Energy Capacity Development in North-Eastern States of India

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Abstract

This study proposes a quantitative evaluation model for comparative analysis of installed renewable energy (RE) capacity development in seven north-eastern states of India. The north-eastern states of India have a hilly terrain and have high potential for renewable energy sources. Hence, they receive special attention as far as renewable energy capacity development is concerned. Performance indicators (PIs) are constructed to capture RE development status. Then a combination of modified CRITIC and VIKOR methods is used for getting the rankings for the selected states based on data collected for the PIs. The yearly trends of performance scores for five PIs of RE capacity development included in the evaluation index are compared with yearly trend of performance rank for all the selected states. This is critical for obtaining meaningful insights to identify weaker performance areas among state(s) considering relative performance ranks. Model helps in planning the expansion of RE projects by identifying the development trends in areas that are performing better than others and pinpointing concern for the areas that are lagging behind on a relative scale.

Keywords

Renewable energy capacity development, Evaluation model, CRITIC, VIKOR, North-eastern states of India

1. Introduction

The focus on clean source of energy is the need of the hour so that CO₂ emission is reduced and extreme climate alterations are avoided. India aims to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 and renewable energy (RE) will play a critical role in this context (Khariesaxena et al. 2020). India has achieved a cumulative installed RE capacity of 175 Gigawatts (GW) by adding 20 GW in 2021 (highest 12-month capacity addition till date) and has set an ambitious target of meeting 40% of its total energy demand through RE by 2030 (MNRE, 2020). The north-eastern states of India have a hilly terrain and have high potential for renewable energy sources. Hence, they receive special attention as far as renewable energy capacity development is concerned. A separate budgetary allocation of 10% is reserved for the these states under various Renewable Energy programmes for deployment of grid and off-grid Solar Energy Systems, Wind Energy Systems, Small Hydro Projects and Bio-gas Plants among others, in the region. A total of estimated potential for renewable energy in the north-eastern region from solar, small hydro and bio-energy is around 65,837 MW, a substantial part of which is suitable for grid connected applications (ENVIS, 2022). A comparative evaluation of the development of RE capacity in north-eastern Indian states must be done for establishing proper understanding of development trends and thereby enabling proper planning for the same. Hence, a quantitative evaluation model for the same is proposed in this paper.

Firstly, based on the RE development data in the reports published on Ministry of New and Renewable Energy (MNRE) Website (<https://mnre.gov.in/knowledge-center/publication>) for India, this paper constructs a set of five performance indicators (PIs) for evaluating the RE development status in a state. These PIs are explained in **Table 1**. Then an integrated quantitative approach is developed to evaluate and analyse the relative RE capacity development for a state on a year-to-year basis for three years. Modified CRITIC (criteria importance through inter-criteria correlation) method is adopted to assign weights to the various PIs and then VIKOR method is used to obtain the state ranks based on the state-wise data collected against the constructed PIs. The reasons behind an improvement or deterioration in rank of a state over three years are identified by comparing the trend of performance score under all the PIs for that state with the trend of compromised ranks for that state. The rational behind using CRITIC and VIKOR in the proposed framework is explained in subsequent paragraph.

Weights can be assigned to various criteria during a decision making process using the two commonly used methods viz. ENTROPY and CRITIC. Inconsistency among the criteria and the internal correlation between them is overlooked while weight determination using the ENTROPY method (Huang et al. 2018). On the other hand, the variations observed for a criteria considering various alternatives and conflict of a criterion with other criteria are both taken into account by the modified version of the CRITIC method, improving its relevance and objectivity in determining criteria weights (Joosep et al. 2020). Hence, CRITIC method was adopted in our evaluation model for assigning weights to various PIs.

The weights of PIs determined by applying the CRITIC method is then used to rank the states. TOPSIS and VIKOR are widely used method for ranking the alternatives (Faith 2021). Yoon (1987), pointed out that although the TOPSIS method considers two 'reference' points (the positive and the negative ideal solution), it fails to consider the relative distances from these points. Hence, the best alternative based on the ranking index used in TOPSIS might not be the closest to the ideal solution. Opricovic (1988), proposed the VIKOR method based on L_p-metric to overcome the flaws of TOPSIS. The ranking index used in VIKOR is based on absolute closeness to the ideal solution and gives rational and compromise solutions. Hence, VIKOR method was adopted in our evaluation model for ranking the states.

Table 1. Performance indicators for evaluating RE capacity development status

PI	Definition
Total renewable energy potential harnessed by a state (X1):	It is the ratio of cumulative RE capacity of a state at the end of a year to its total RE potential. (Unit : %)
Solar energy potential harnessed by a state (X2):	It is the ratio of cumulative solar energy capacity of a state at the end of a year to its total Solar energy potential. The RE potential for a state is estimated based on land availability and solar radiation received. (Unit : %)
Small hydro power potential harnessed by a state (X3):	It is the ratio of cumulative Small hydro power capacity of a state at the end of a year to its total Small hydro power potential. The Small hydro power potential for a state is estimated based on apt water source availability and the height of the source. (Unit : %)
Annual off-grid solar lamp addition per capita (X4):	It is the number of off-grid solar lamp per capita, at the end of a year. It reflects the social implications of RE power development. (Unit : No.s/lakh people)
Annual off-grid street solar light addition per capita (X5):	It is the number of off-grid street solar lights per capita, at the end of a year. It reflects the social implications of RE power development. (Unit : No.s/lakh people)

1.1 Objective

We aim to achieve the following objectives with our proposed evaluation model for the identified state: -

1. To define an evaluation index by constructing suitable PIs for assessing RE power capacity development
2. To determine year-wise rank of northe-eastern Indian states based on their relative performance in the RE capacity development.
3. To identify the reasons that confirm improvement or deterioration in trend of rank for a given state over the three year span.

Section 2 elaborates the literature on RE power capacity development assessment. Section 3.1 talks about the methodology with the mathematical formulation. Subsection 3.2 highlights the critical information of our case studies that includes assessment of RE capacity development in north-eastern Indian states. Section 4 discusses the result of application of proposed framework to the data of our case. Finally, the conclusion of the research article is mentioned in section 5.

2. Literature Review

In context to countering climate change while securing sufficient energy for all, the development of global energy capacity emphasises on low carbon emission (Peng et al. 2018). For the sustainable development of modern energy industry (Rashid et al. 2019; Schroeder et al. 2019), it is necessary to objectively understand the development situation of the electric power based on renewable energy. The timely understanding of the development trends in renewable

energy sector and advanced experience from different administered regions can help frame the policies for future planning of the same (Kucukvar et al., 2018). The main research focus for RE power development or electric power development has been on risk assessment (Lin et al. 2018), wind power projects assesment (Wang and Niu 2019), renewable energy projects performance and its comparative assesment (Zhang et al., 2019). Studies on comparative evaluation of RE power development status from a geographical region perspective are rarely seen. By comprehensively assessing the current status of RE power development in a region, it is possible to find the weaknesses of RE power development and provide information support for leaders and decision makers in the power industry (Rashid et al. 2019; Liu et al. 2019). In the field of comprehensive electric power evaluation, there are many evaluation methods applied, such as principal component analysis (He et al. 2018; Tan et al. 2019), data envelopment analysis (Pourhabib et al. 2018; Xian et al. 2018), fuzzy comprehensive evaluation (Li et al. 2019; Seddiki and Bennadji 2019), etc. Therefore, it is necessary to conduct comprehensive evaluation and analysis of the state wise sustainable electric power development. There are many factors affecting the development of the state sustainable electric power development. It mainly includes the electricity supply through sustainable energy sources (Banaei et al., 2019; Ioannidis et al., 2019), carbon emissions (Kim, 2019) and intentions of sustainable growth in the field of electricity production.

The application of multi criteria decision making techniques to propose a framework for comparative evaluation of regions based on objective data is easy to implement and shall provide meaningful insights to managers without performing complex mathematical operations. A lot of recent works focused on RE development in one or more countries has been done and is mentioned in the Table 2 along with the recent work done on the similar topic in the context of Indian states, some of which include application of MCDM techniques.

Table 2. Relevant literature focusing on RE Scenario with a country based perspectives

S.No	Reference	Research topic discussed
1.	Chen et al. (2014)	Discussed the growth of renewable energy policies and roadmaps through SWOT analysis.
2.	Ghosh et al. (2020)	The evolution of Indian power sector is analysed by assessing its techno-commercial performance by employing the DEA model (that has been improved using Shanon's entropy) as a comparative tool.
3.	Kamran et al. (2020)	The feasibility and future road map to nurture the renewable energy region in Pakistan are analysed by employing SWOT analysis to individual renewable sources and policy implications are derived according to the results.
4.	Krishankumar et al. (2021)	Identifying sand selecting suitable RE sources using the double-hierarchy hesitant fuzzy linguistic term sets.
5.	Kucukvar et al. (2018)	An integrated hybrid model using SWOT, Analytic Network Processing (ANP), and weighted fuzzy TOPSIS is proposed to formulate energy strategies and alternatives in Turkey. The study gives necessary actions that can be taken to attain sustainable energy developments.
6.	Rani et al. (2019)	Various RE technologies are evaluated for feasibility and sustainability using the Pythagorean fuzzy set extension of VIKOR.
7.	Sarangi et al. (2019)	Sustainability of electricity sector is assessed using ten years data against 11 indicators for 12 Indian states through an empirical analysis.
8.	Saraswat et. al. (2021)	Investigating suitable sites for installation of solar and wind farms in India using the using technology of geographic information system (GIS) and MCDM.
9.	Sharvini et al. (2018)	Reviews the energy demand scenario of China, Malaysia, Japan and Indonesia along with the growth of non-fossil energy sources while pinpointing the demands in renewable energy development.
10.	Vallecha et al. (2020)	Community energy barriers and enablers are identified against RE sources and their capacity development and then evaluated using the fuzzy TOPSIS-IRP methodology.
11.	Wang et al. (2020)	The Fuzzy Analytical Hierarchy Process (AHP) is used in a multi-perspective (i.e., economic, environmental, technical, and socio-political criteria) approach to analyse the factors responsible for the growth of renewables.

After analysing the literature it can be observed no recent study has been done comparing the performance of Indian states with huge potential in field of sustainable electricity generation, especially after observing the significant growth in this sector over the last decade a comparative analysis would enable us to identify the best practices being taken up by the best performing states and the loop holes in the approach of poor performing states towards realising their full potential in this sector. The method used for objective weight allocation to the PI is adopted by critical literature review and the rationale behind is explained in the Introduction section. Likewise for the VIKOR method adopted for ranking the states. Mostly the evaluation of power development have been conducted based on geographical alternatives taking into account objective data for one year or cumulative objective till date. This paper takes into account objective data for constructed PIs over a span of three consecutive years and hence proposes an evaluation framework for time series analysis of RE power development.

3. Methodology

3.1 CRITIC and VIKOR method

After compiling the data for constructed PIs for all the identified states, following steps are followed to get the PI weight and rank for alternative states. Step 1 to 3 of this section are for CRITIC method and step 4 to 9 are for VIKOR method.

Step 1: Construct an evaluation matrix $X = (x_{ij})_{I \times J}$, where x_{ij} represents i^{th} evaluation alternative (identified state) and j^{th} PI. The total number of administered states is represented by I, and J indicates the number of PIs included in the evaluation index system. Find out z-score normalized values of PI columns using corresponding column average (\bar{x}_j) and standard deviation (σ_j) (eq (1)).

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{\sigma_j} \quad (1)$$

Step 2: Compute the independent coefficient of all PIs. The independence coefficient measures the degree of conflict between two PIs. For computing independent coefficient, first, find out Pearson correlation coefficients (r_{kl}) using eq (2) between PIs using normalized evaluation matrix from step 1. Next, use the following formula (eq (3)) to estimate the independent coefficient (η_j) of j^{th} PI.

$$r_{kj} = \frac{\sum_{i=1}^I (z_{ik} - \bar{z}_k)(z_{ij} - \bar{z}_j)}{\sqrt{\sum_{i=1}^I (z_{ik} - \bar{z}_k)^2} \sqrt{\sum_{i=1}^I (z_{ij} - \bar{z}_j)^2}} \quad (k = 1, 2, \dots, J; j = 1, 2, \dots, J) \quad (2)$$

$$\eta_j = \sum_{k=1}^J (1 - r_{kj}) \quad (3)$$

Step 3: Weight for the j^{th} PI is obtained as per eq (6) with the help of c_j obtained as per eq (5) multiplying the coefficient of variation (v_j) of each PI (obtained using eq (4)) with corresponding η_j obtained in step 2. The larger value of w_j indicates the higher amount of information assigned to the corresponding PI.

$$v_j = \frac{\sigma_j}{\bar{x}_j}, j = 1, 2, \dots, J \quad (4)$$

$$c_j = \eta_j v_j \quad (5)$$

$$w_j = \frac{c_j}{\sum_{j=1}^J c_j} \quad (6)$$

Step 4: Find out the best value (x_j^b) and worst value (x_j^w) of j^{th} PI.

$$\text{For cost criteria, } x_j^b = \min_i x_{ij} \text{ and } x_j^w = \max_i x_{ij} \quad (7)$$

$$\text{For benefit criteria, } x_j^b = \max_i x_{ij} \text{ and } x_j^w = \min_i x_{ij} \quad (8)$$

Step 5: Calculate the Regret measure (R) using eq (9).

$$R_h = \max_j \left(w_j \cdot \frac{x_j^b - x_{ij}}{x_j^b - x_j^w} \right) \quad (9)$$

Step 6: Calculate the Utility measure (S) using eq (10).

$$S_h = \sum_{j=1}^J (w_j \cdot \frac{x_j^b - x_{ij}}{x_j^b - x_j^w}) \quad (10)$$

Step 7: Calculate the Q function using eq (11) using the crisp values of S_h and R_h .

$$Q_i = \frac{\alpha(S_i - S^b)}{(S^w - S^b)} + \frac{(1-\alpha)(R_i - R^b)}{(R^w - R^b)} \quad (11)$$

Where α is a factor to manage the weights enjoyed by S_h and R_h . For a generalized study it is assumed to be 0.5. If $Q_{h_2} - Q_{h_1} \leq \frac{1}{j-1}$ And $R_{h_2} > R_{h_1}$ And $S_{h_2} > S_{h_1}$, A_1 is the best choice, or else both alternatives are the best choice.

Step 8: Rank the alternatives

Eventually obtained ranks based on subjective and objective data are compared for all regions to identify the regions with maximum variation in the ranks. Thereafter, the performance scores calculated for each PI following eq (12).

$$PS_i = w_j \frac{x_j^b - x_{ij}}{x_j^b - x_j^w} \quad (12)$$

3.2 Case studies

In this case, the proposed evaluation model is applied to seven north-eastern Indian states. These states are Arunachal Pradesh (AP), Assam (AS), Manipur (MN), Meghalaya (ME), Mizoram (MI), Nagaland (NA) and Tripura (TR). The data against the identified PIs is compiled for the year 2020-21, 2019-20 and 2018-19 to observe the SE capacity development in these states in Table 3. Using this objective data the RE capacity development is carried out for the selected states as per the steps mentioned in the methodology section (Section 3.1). The results for the analysis are discussed in the next section.

Table 3. Data For PIs for the selected states for three consecutive years

State	X1	X2	X3	X4	X5
s	Values for PI for the years: 2020-21, 2019-20, 2018-19				
AP	0.065, 0.065, 0.062	6.346, 6.346, 5.211	1.278, 1.278, 1.054	4775, 1159, 1159.438	859, 313, 313
AS	0.313, 0.3, 0.121	16.886, 16.886, 16.990	0.557, 0.531, 0.36	1905, 1891, 1891.165	48, 28, 28.1
MN	0.06, 0.043, 0.024	5.450, 5.450, 5.410	0.102, 0.093, 0.074	283, 283, 283.063	694, 350, 350.156
ME	0.002, 0.002, 0.001	14.143, 14.143, 19.530	0.77, 0.761, 0.737	1235, 1235, 1234.848	176, 176, 175.758
MI	0.017, 0.017, 0.002	21.580, 21.580, 21.183	0.41, 0.41, 0.389	6857, 790, 790.376	761, 400, 400.376
NA	0.014, 0.014, 0.014	16.852, 16.852, 16.484	0.414, 0.414, 0.414	308, 308, 307.545	505, 283, 283.409
SI	0.001, 0.001, 0	19.590, 19.590, 19.545	0.998, 0.998, 0.998	3530, 3530, 3530.303	76, 76, 76.364
TR	0.452, 0.452, 0.245	34.064, 34.064, 33.851	1.173, 1.173, 0.985	6182, 1568, 1567.854	152, 29, 29.244

4. Results

The weights obtained for PIs are obtained following step 1 to 3 of section 3.1 using equation (1) to (6). The weights obtained for the three consecutive years are mentioned in Table 4. The rank for the alternative states obtained for the two consecutive years, following step 4 to 8 of section 3.1, using equation (7) to (11) are demonstrated in Table 5 along with a Figure 1 indicating the variation in rank over the years. In the process of calculating the rank we obtain the values of regret measure (R), utility measure (S) and Q value using equation (9), (10) and (11) respectively. The S_i is indicative of the overall relative distance of i th administered region from the ideal situation. The R_i identifies the PI under which the i th administered region has observed maximum weighted relative deviation from the ideal value and indicates the worst-performing region of the PI. Whereas the Q value is a weighted combination of R and S values. The lowest Q value is considered as best as it is nearest to the ideal point and based on this idea, ranking of the administered regions (i.e. alternatives) is done. In this analysis while calculating the Q value we give equal weightage to both R and S. The R, S and Q values for different alternative states during the three consecutive years are shown in Table 6.

A decrease in rank over the years indicates an improvement in relative RE capacity development for a state as compared to previous year. As, can be observed in Figure 1, Not much variation in the ranks of the states have been observed over the years for the eight north eastern states as per the analysis. The state that has consistently performed well, on a relative scale, in developing its RE capacity over the span of three years considered in the analysis is Tripura (TR). Whereas, Meghalay (ME) observes a relatively greater rank over these three years indicating a poor performance on relative scale. Although it has observed an improvement in its rank in 2020-21. The contribution of respective PIs in improvement or deterioration of rank for a state is analysed by comparing their yearly performance scores which is calculated using equation (12). The performance scores of all PIs for various states for the three years are mentioned in Table 7. These performance scores represent the weighted deviation of an alternative state from the ideal situation with respect to a given criterion and hence a lower value for them better. This implies that a decrease in performance score of a PI for a given state clearly reflects an improvement in that domain for the state.

For instance as illustrated in Table 7, the state of TR (Tripura) has been consistently ranked 1 and the PIs contributing to it are X1 and X2 where in its 0 score for three years consecutively represents best or ideal performance with respect to those PIS. The other three PIs have observed marginal change for TR over the span of three years. On the other hand, ME (Meghalay) state has observed a relatively higher rank indicating lower performance with respect to its RE power capacity development. The PIs attributed to this relatively poor performance is X1 and X5 which have observed a relatively higher deviation from ideal situation consistently over three years. Also if we observe the case of AS (Assam) we find that its has consistently maintained a second rank and performed very well with respect to X1 but the area of concern for AS is its relatively poor performance in X5 and it must pay special attention on it. This way the overall performance trend for the states can be analyzed using the performance score values for the various PIs. Hence, we achieved all the objectives defined for this paper in section 1.1.

Table 4. Yearly weights of PIs obtained using the CRITIC method.

Years	X1	X2	X3	X4	X5
2020-21	0.350	0.158	0.135	0.139	0.218
2019-20	0.329	0.142	0.122	0.199	0.207
2018-19	0.326	0.140	0.125	0.201	0.208

Table 5. Yearly ranks of states obtained using the VIKOR method.

Years	AP	AS	MN	ME	MI	NA	SI	TR
2020-21	2	2	4	4	3	4	4	1
2019-20	3	2	4	6	4	5	4	1
2018-19	3	2	4	5	4	5	5	1

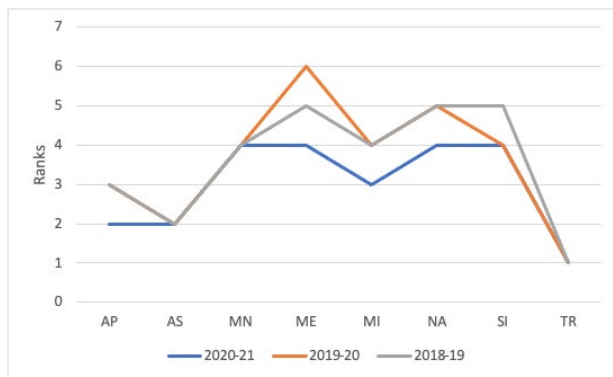


Figure 1. Yearly ranks of states obtained using the VIKOR method

Table 6. R, S and Q values under the PIs for the alternative states.

States	2017-18			2018-19			2019-20		
	R	S	Q	R	S	Q	R	S	Q
AP	0.551	0.303	0.427	0.633	0.622	0.627	0.466	0.691	0.579
AS	0.751	0.005	0.378	0.596	0.005	0.301	0.649	0.176	0.413
MN	1.000	0.729	0.864	1.000	0.752	0.876	0.933	0.716	0.824
ME	0.851	0.987	0.919	0.951	0.996	0.973	1.000	0.997	0.998
MI	0.678	0.978	0.828	0.667	0.908	0.787	0.527	0.925	0.726
NA	0.888	0.848	0.868	0.924	0.927	0.925	0.912	0.940	0.926
SI	0.696	1.000	0.848	0.756	1.000	0.878	0.873	1.000	0.937
TR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 6. Performance scores under the PIs for the alternative states for three consecutive years (2020-21, 2019-20, 2018-19).

States	Total renewable energy potential harnessed by a state	Solar energy potential harnessed by a state	Small hydro power potential harnessed by a state	Annual off-grid solar lamp addition per capita	Annual off-grid street solar light addition per capita
AP	0.3, 0.283, 0.243	0.153, 0.137, 0.14	0, 0, 0	0.043, 0.089, 0.092	0, 0.049, 0.049
AS	0.108, 0.112, 0.165	0.095, 0.085, 0.082	0.083, 0.077, 0.089	0.101, 0.062, 0.063	0.218, 0.207, 0.208
MN	0.304, 0.299, 0.294	0.158, 0.142, 0.139	0.135, 0.122, 0.125	0.135, 0.122, 0.125	0.044, 0.028, 0.028
ME	0.349, 0.329, 0.325	0.11, 0.099, 0.07	0.058, 0.053, 0.041	0.115, 0.086, 0.089	0.184, 0.125, 0.125
MI	0.338, 0.318, 0.323	0.069, 0.062, 0.062	0.099, 0.09, 0.085	0, 0.103, 0.106	0.026, 0, 0
NA	0.34, 0.32, 0.308	0.095, 0.085, 0.085	0.099, 0.089, 0.082	0.134, 0.121, 0.124	0.095, 0.065, 0.065

SI	0.35, 0.329, 0.326	0.08, 0.072, 0.07	0.032, 0.029, 0.007	0.068, 0, 0	0.211, 0.18, 0.181
TR	0, 0, 0	0, 0, 0	0.012, 0.011, 0.009	0.014, 0.074, 0.076	0.19, 0.207, 0.207

5. Conclusion

North-eastern Indian states has a large untapped potential of clean energy generation through RE and has set ambitious plans for harnessing it. Comparative analysis of installed RE capacity development in these states shall help in planning the expansion of RE projects by identifying the development trends in states that are performing better than others and pinpointing areas of concern for the states that are lagging behind on a relative scale. This study proposes and empirically validates a quantitative evaluation model for assessing the same.

The combination of modified CRITIC and VIKOR methods is used for getting the compromised rankings for the selected states. The yearly trends of performance scores for five PIs of RE capacity development included in the evaluation index are compared with yearly trend of performance rank for all the selected states. This is critical for obtaining meaningful insights to identify weaker performance areas among state(s) considering relative performance ranks. Finally, the suggested framework, a combination of modified CRITIC, VIKOR, acts as an effective tool for the evaluation of RE development status in various geographical alternatives.

We conclude by highlighting possible extensions of the study. First, while the study has been undertaken based on secondary data from north-eastern states of India, the proposed framework can be easily generalized using RE development data from other geographical alternatives. Second, a more robust evaluation index system can be developed by including a larger number of input parameters and PIs. This will help in creating a region-specific evaluation index system. Thus, the governments and policymakers can use the insights for enhancing the utilization of RE potential through proper planning of RE development.

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