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HYBRID AHP-TOPSIS MODEL FOR SELECTING TELUKJAMBE POWER TRANSMISSION LINE ALTERNATIVES

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Abstract

The development of the electric power transmission line along the Telukjambe-Telukjambe II-KTT Indah Kiat route requires careful alternative selection because the corridor is located in an industrial area with limited space, complex permitting, and an urgent need for load connection. This research evaluates which transmission configuration is best suited to the Telukjambe corridor through an integrated AHP-TOPSIS assessment. An expert panel first examined whether the proposed criteria reflected the corridor conditions. The accepted criteria are cost, quality, schedule, social-environmental, regulatory and permitting compliance, and contract management were subsequently prioritized through AHP and combined with alternative-performance data in the TOPSIS analysis to rank for designs which are CLT, SPT, UGC, and CLU. The validation results showed that all of six criteria above met the relevance threshold. AHP identified quality as the dominant criterion, followed by schedule which is schedule to completed the project, and permitting compliance, with an acceptable consistency ratio. Integrating AHP-derived weights into TOPSIS ranked UGC as the best alternative, followed by CLT, CLU, and SPT. Taken together, the findings provide a traceable basis for transmission planning in industrial corridors affected by spatial limitations, permitting requirements, and system-reliability demands.

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Introduction

Electric power transmission infrastructure is one of importance for the reliability of the system, for the growth of load and for the reliable transport of electricity from the generation plants to the load centres without avoidable delay (Ayu et al., 2017). The Indonesian electricity-network expansion is planned through the Electricity Supply Business Plan (*Rencana Usaha Penyediaan Tenaga Listrik*, RUPTL), which translates national electricity policy (*Rencana Umum Ketenagalistrikan Nasional*, RUKN), demand projections, and regional development requirements into planned additions to generation and network capacity (Yuniza & Inggawati, 2022). Electricity infrastructure planning in Indonesia is carried out under a legal framework that governs both electricity supply and public service obligations (Arifin & Hermawan, 2021). To be able to meet the increasing energy demand in Indonesia, good planning and management in generation, transmission and distribution sectors are needed (Sinaga et al., 2021). In this context, the 150 kV Telukjambe-Telukjambe II-KTT Indah Kiat line has been planned by PT PLN [Persero] (2025) in the West Java transmission development plan. The line is to include, among other things, the planned high-voltage link of Indah Kiat Karawang. However, the alignment traverses an industrial area with limited available right-of-way, multiple existing facilities crossing the planned route, and potential objections from land users to overhead crossings. Thus the choice of transmission configuration is a matter of implementation conditions as much as technical performance.

These are multicriteria choice problems because no alternative is optimal in all the relevant aspects. Multi-Criteria Decision Making (MCDM) assists decision makers to analyze many alternatives based on multiple factors and to trade-off conflicting objectives (Sahoo & Goswami, 2023). The choice of its appropriate MCDM method depends on the context of the decision, especially on the available information, uncertainty and complexity of the problem and on the preferences of the decision makers (Komlósi et al., 2026). Similar to the trade-off between overhead and subsurface transmission. Underground lines require a significantly higher capital investment than overhead systems and are only cost effective in cases where local factors justify the extra expense such as the customer density, reliability benefits, size of the project and right-of-way conditions (Larsen, 2016). Transmission towers and right-of-way restrictions might impact neighboring communities and land usage. Constraints on agricultural and natural-resource access can also hurt local livelihoods, producing compensation needs (Kigonya et al., 2024; Kim et al., 2025). Sometimes underground systems are considered to be more publicly acceptable because they have lower visible impact. However, empirical evidence does not always indicate more favorable community responses (Mueller et al., 2019). They are also subject to other reliability difficulties such as longer maintenance time and failure in the cable junctions and terminations (Tuinema et al., 2016).

Several studies have applied MCDM for transmission line selection, yet methodological gaps remain. Simbolon & Ciptomulyono (2022) employed TOPSIS for the 150 kV transmission line in Papua, however, the rankings were sensitive to the weights of criteria, which signifies that a more methodical stage for weighting is needed before TOPSIS. Winowoda & Wasesa (2024) applied Value-Focused Thinking and AHP for Cawang-Gandul project, with the addition of stakeholder interest. However, they did not combine AHP with a distance-based ranking system such as TOPSIS. This research fills these gaps by combining expert screening, AHP weighting and TOPSIS evaluation for Telukjambe corridor. Previous applications have supported the AHP-TOPSIS sequence, in which AHP was used to determine the priorities of the criteria and TOPSIS was used to rank the alternatives according to their relative closeness to the ideal solution (Yaqin et al., 2024). It is also supported by Menon & Ravi (2022) for its suitability to incorporate expert judgment along with quantitative performance data.

This research originality is to build and apply proven hybrid AHP-TOPSIS framework for 150 kV transmission alternative selection in the setting of an industrial corridor. Unlike earlier studies that used either AHP or TOPSIS independently, this research integrates criterion

validation, expert-based weighting, consistency testing and quantitative alternative ranking into an integrated decision model (Ahmad et al., 2022). In this study thus, we investigate if the criteria suggested are the optimal conditions, determine their relative relevance and the alternative with the best aggregate performance after the AHP priorities are implanted in TOPSIS. The work aims at selecting the best appropriate transmission alternative and providing a selection technique transferable to other transmission planning instances with similar implementation restrictions, given these objectives.

Research Methods

A quantitative case study was undertaken to assess the planned 150 kV transmission corridor through an integrated AHP-TOPSIS procedure and was conducted during the 2025-2026 research period in Kutamekar Village, Ciampel District, Karawang Regency, West Java, focusing on the planned 150 kV Telukjambe-Telukjambe II-KTT Indah Kiat transmission corridor. Figure 1 locates the corridor examined in this study.

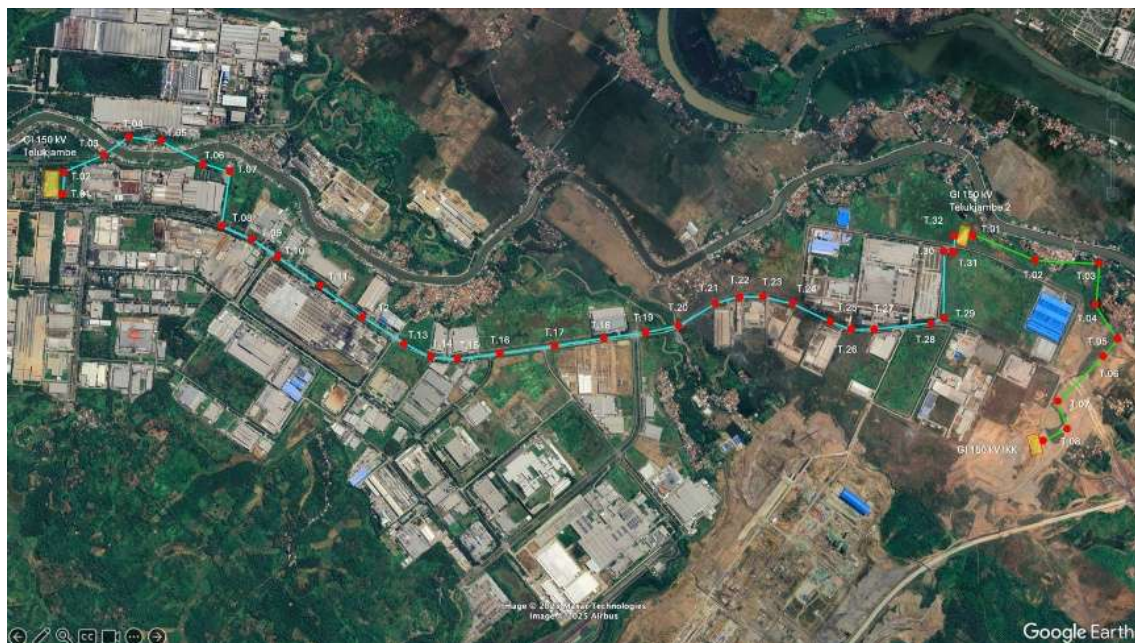


Figure 1. Planned Telukjambe transmission corridor

The research location covers the Telukjambe-Telukjambe II section of approximately 14 km and the Telukjambe II-KTT Indah Kiat section of approximately 3 km, with most of the route following the median of the Suryacipta industrial estate road due to limited right-of-way and tenant objections to overhead transmission crossings. The population consisted of stakeholders involved in transmission planning and implementation, and purposive sampling was applied to select nine PLN UIP JBT managers for criteria validation and nine experts from PLN UIP JBT, and PLN PUSMANPRO. The composition and experience of the panel are summarized in Table 1.

Table 1. Expert panel profile

Experts	Job Position at PLN	Work Experience
Expert A	Permitting Manager	15 years
Expert B	Planning Manager	21 years
Expert C	Planning Manager	15 years
Expert D	Project Manager	14 years
Expert E	Project Manager	18 years

Expert F	Permitting Manager	14 years
Expert G	HSE Manager	14 years
Expert H	Construction Supervision Manager	17 years
Expert I	Planning Manager	17 years

All nine members of the expert panel hold managerial positions with job tenures between 14 and 21 years, thereby strengthening the credibility of expert judgment in the questionnaire results. Primary data were obtained from validity scale questionnaires and guided AHP questionnaires, while secondary data were collected from comparable transmission projects and internal PLN documents to support the TOPSIS decision matrix. To facilitate the research process and ensure structured planning, Figure 2 summarizes the analytical sequence from the initial identification of criteria to the final recommendation.

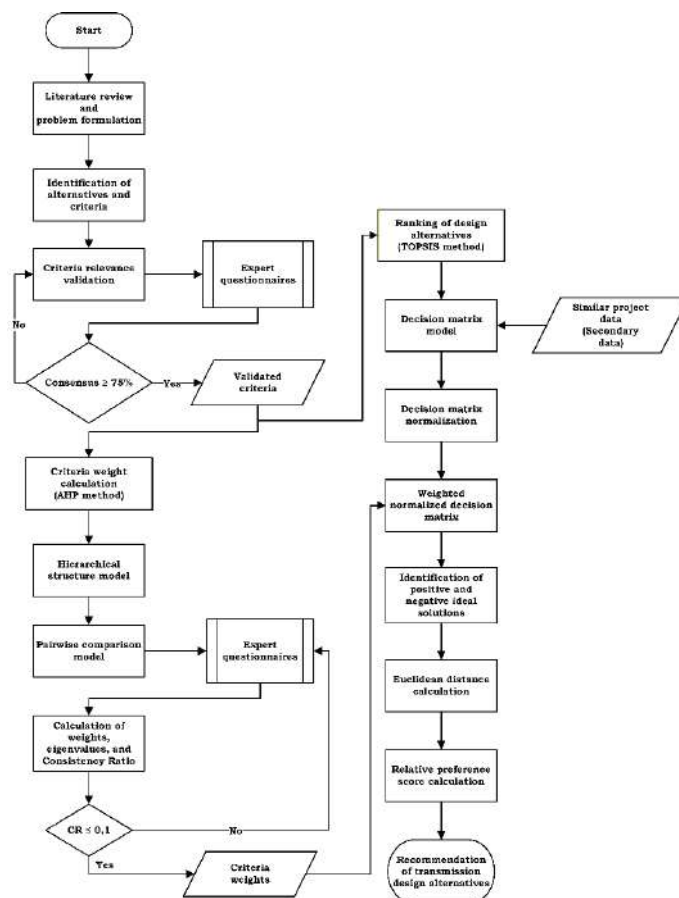


Figure 2. Sequence of the research procedure

The process started with literature based identification of alternatives and criteria followed by expert validation, AHP weighting and TOPSIS ranking. Based on Winowoda & Wasesa (2024), the alternatives were SUTT compact lattice tower (CLT), SUTT steel pole tower (SPT), SKTT underground cable (UGC), and the combined compact lattice tower-underground cable alternative (CLU). The assessment criteria were cost (C), quality (Q), schedule (S), social environmental (SE), regulatory and permitting compliance (RP) and contract management (CM). A Delphi-like assessment Fehr et al. (2022); Niederberger et al. (2024) was used to assess the relevance of the criteria and the experts' confidence in the judgement, and non-evaluative answers were given when information was not available. The criterion was accepted if 75% of the valid answers given by the experts were in the relevance category (scores 1-2) and rejected if the same ratio was in the non-

relevance category (scores 4-6) (Bellia et al., 2021). In Delphi studies consensus is usually operationalized as percentage agreement. The most common cut-offs are 70%, 75% and 80%. Items that did not reach this threshold or exhibited ambiguous response patterns were re-rated in the second round with structured feedback, according to Policy Delphi procedures that use iterative rounds to clarify divergent judgements and determine the level of agreement across single or adjacent response categories (Schifano & Niederberger, 2025).

In the AHP stage, the validated criteria were arranged in a hierarchical structure, compared pairwise using Saaty's 1-9 scale, transformed into priority weights through the principal eigenvector, and tested using CI and CR, with $CR \leq 0.10$ used as the acceptance threshold for consistent expert judgment (Bozorg-Haddad et al., 2021). After each expert's pairwise comparison matrix satisfied the consistency requirement, only matrices meeting the consistency requirement were retained. Their corresponding entries were then synthesized through geometric means to produce a single group matrix, following the aggregation-of-individual-judgments procedure described by Lin et al. (2022). The TOPSIS stage used the quantitative data structure in Table 2. The selection for these 6 criteria for this research was based on the result of Winowoda & Wasesa (2024).

Table 2. Quantitative data source for each criterion

Criterion	Literature Source	Quantitative Data Source
Cost (C)	(Choudhary & Shankar, 2012; Simbolon & Ciptomulyono, 2022; Soetjipto et al., 2023)	Construction cost estimate value (Rp/kmr)
Quality (Q)	(Asmar et al., 2013; Cleary & Lamanna, 2022; Ibrahim et al., 2020)	Number of outstanding punch list items at handover (Items/kms)
Schedule (S)	(Jin et al., 2024; Ors et al., 2023; Zumrut et al., 2022)	Construction contract duration until project handover (Weeks/kms)
Social-Environment (SE)	(Nicolaou et al., 2011; Tarko et al., 2021; Tourab & Babouri, 2016)	Monitoring results of electric field measurements (kV/m)
regulatory and permitting compliance (RP)	(Adiningsih et al., 2023; Wiseli & Fitriyani, 2022)	Processing duration for Spatial Utilization Activity Conformity documents (Weeks)
Contract Management (CM)	(Alkhatabi et al., 2023; Anees et al., 2013; Mattar et al., 2024)	Percentage change in contract value from the baseline to the final contract amount (%)

These secondary data are an important component in building the TOPSIS decision matrix. They provide an objective and measurable summary of how each design alternative being considered performs. The normalised performance values were scaled by using the priorities obtained from AHP. The obtained matrix was then used to determine the most and least preferred reference profiles, compute the Euclidean separation and then derive a closeness score for each option (C & Subramaniam, 2024). The option recording the largest coefficient occupied the leading position in the final ranking.

Research Results and Discussion

The research results are presented in three consecutive stages because each stage answers one research question, such as criteria relevance, criteria weighting, and transmission alternative

ranking. In the criteria validation stage, the first-round expert questionnaire was recapitulated in Table 3 using a validity scale from 1 to 6 and a blank option.

Table 3. First-round expert panel questionnaire results

Criterion	Validity Scale						
	Certain (1)	Reliable (2)	Not determinable (3)	Risky (4)	Unreliable (5)	Not relevant (6)	No judgement (Blank)
C	4	5	0	0	0	0	0
Q	6	2	0	0	0	1	0
S	6	3	0	0	0	0	0
SE	6	3	0	0	0	0	0
RP	7	2	0	0	0	0	0
CM	7	0	0	1	0	1	0

For the C criterion, all nine experts assigned either “certain” or “reliable” scores, and the same response pattern was also observed for the S, SE, and regulatory and permitting criteria. For the Q criterion, one expert assigned the score “not relevant”, meanwhile, for CM, one expert assigned “risky” and another assigned “not relevant.” No expert selected score 3 or blank for any criterion, indicating that the panel had sufficient information to provide a clear judgment rather than postponing the decision. For the purpose of consensus analysis, the classification of the responses is presented in Figure 3.

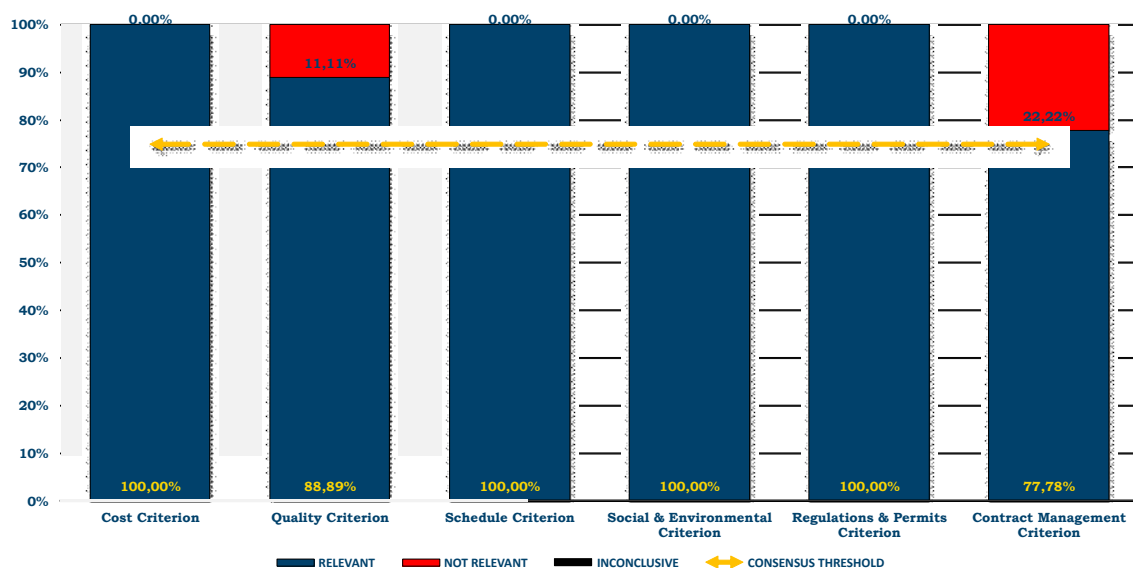


Figure 3. Classification and consensus analysis of the first-round questionnaire results

Figure 3 explained the consensus results provide more than an indication that all six criteria can proceed to the weighting stage. The complete agreement obtained for C, S, SE, and RP suggests that these criteria were consistently regarded as relevant to the conditions of the Telukjambe corridor, whereas the lower agreement for Q (88.89%) and particularly CM (77.78%) indicates a greater variation in expert views. Nevertheless, both criteria remained above the predefined 75% threshold and were therefore retained. This treatment is consistent with recent evidence showing that percentage agreement remains the most frequently used approach for operationalizing consensus in Delphi studies, although the selected threshold should be established before evaluating the responses (Schifano & Niederberger, 2025). The relatively narrow margin between the CM consensus value and the threshold also suggests that contract-management considerations may be more context-dependent than the other criteria and should therefore be interpreted with greater caution when the framework is transferred to other transmission projects. The decision hierarchy developed for the AHP stage is presented in Figure 4.

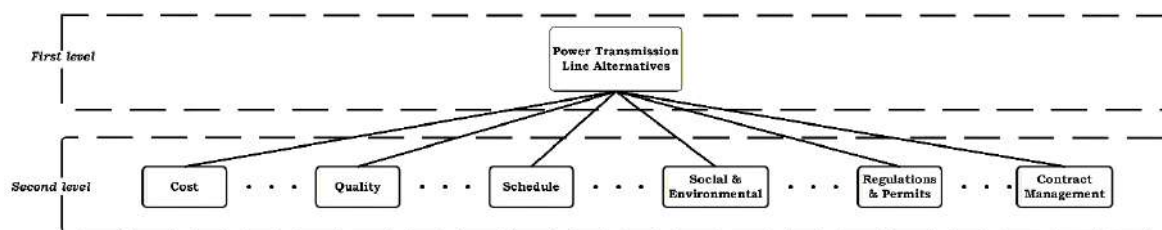


Figure 4. Hierarchy used to evaluate the transmission alternatives

The choice of a transmission configuration occupied the upper level of the hierarchy, while the six validated criteria formed the level beneath it and served as the basis for pairwise judgments. After each individual expert matrix met the consistency requirement, the pairwise judgments were aggregated through the geometric aggregation of the consistent individual assessments produced the group matrix reported in Table 4.

Table 4. Consensus pairwise comparison matrix

Criterion	C	Q	S	SE	RP	CM
C	1	1/4	1/3	1	1/3	1/2
Q	3 7/8	1	1 3/7	4 2/7	2	2 1/3
S	2 3/4	5/7	1	2 2/5	1 1/7	2
SE	1	1/4	2/5	1	3/5	4/7
RP	2 5/6	1/2	7/8	1 2/3	1	1 3/5
CM	1 8/9	3/7	1/2	1 3/4	5/8	1
Σ	13.28	3.12	4.56	12.17	5.71	8.14

The column total for C was the highest at 13.28, while the column total for Q was the lowest at 3.12, suggesting an early indication that Q would become the dominant criterion after normalization. Table 4 was subsequently normalized. The corresponding normalized entries are reported in Table 5.

Table 5. Normalized consensus pairwise comparison matrix

Criterion	C	Q	S	SE	RP	CM
C	0.08	0.08	0.08	0.09	0.06	0.06
Q	0.29	0.32	0.31	0.35	0.35	0.29
S	0.21	0.23	0.22	0.20	0.20	0.25
SE	0.07	0.07	0.09	0.08	0.11	0.07
RP	0.21	0.16	0.19	0.14	0.18	0.20
CM	0.14	0.14	0.11	0.14	0.11	0.12

Table 5 normalized the consensus matrix by dividing each cell by its column total. Subsequently, the analysis of criteria weights and the maximum eigenvalue ($\lambda_{\max}$) yields the results summarized in Table 6.

Table 6. Criteria weights and maximum eigenvalue analysis results

Criterion	w_j	$A.w$	λ
	(1)	(2)	(2/1)
C	0.0756	0.4564	6.0353
Q	0.3189	1.9275	6.0436
S	0.2175	1.3150	6.0467
SE	0.0823	0.4973	6.0454
RP	0.1793	1.0839	6.0470
CM	0.1265	0.7641	6.0420
$\lambda_{\max}$ (<i>Ave. λ</i>)			6.0433

The criteria weights (w_j) are obtained from the mean of the normalized entries across the relevant row in the matrix of Table 5. Meanwhile, $A.w$ is derived from the multiplication of w_j in Table 6 by the matrix in Table 4, and λ is calculated by $A.w/w_j$. With a 6×6 matrix, the consistency index (CI) was 0.0087 and the resulting Consistency Ratio (CR) of 0.0069 remained well within the admissible limit of 0.10. Thus, the AHP results as shown in Table 7 were considered consistent and could be used in TOPSIS.

Table 7. Analysis results of AHP criteria weights

Criterion	w_j	Priority Ranking
C	0.0756	6
Q	0.3189	1
S	0.2175	2
SE	0.0823	5
RP	0.1793	3
CM	0.1265	4

The results in Table 7 indicate a clear concentration of expert priorities. Quality received the largest weight (0.3189), followed by schedule (0.2175) and regulatory and permitting compliance (0.1793). Together, these three criteria account for approximately 71.6% of the total decision weight. In contrast, the cost was assigned the lowest weight (0.0756) meaning that the smallest initial investment was not the most important factor for the experts when choosing the preferred transmission configuration. This is in line with characteristics of Telukjambe industrial corridor, where certainty of construction, timely load connection and regulatory feasibility could have bigger project consequences than capital expenditure alone. A consistency ratio of 0.0069 indicates a very consistent set of pairwise judgments well below the conventionally accepted limit. Consistency means logical consistency and not the accuracy of objective weight (Pant et al., 2022). Recent reviews of AHP based decision models also show that the hybridization with complementary ranking methods and consistency assessment could enhance the reliability and interpretability of multicriteria decisions (Ashour & Mahdiyar, 2024). The focus on schedule is also relevant to transmission planning more generally since recent studies suggest that delay of implementation could have material implications on the robustness and operational implications of transmission expansion plans (Moutinho et al., 2023). Table 8 Decision matrix for the TOPSIS analysis The decision matrix contains the quantitative performance indicators of four alternatives for the six criteria.

Table 8. TOPSIS decision matrix model

Criterion Alternative	C (Rp)	Q (items)	S (Weeks)	SE (kV/m)	RP (Weeks)	CM (%)
CLT	260.561.493.600,00	6	73	0.288	32	2.52
SPT	397.400.052.000,00	7	93	0.288	39	14.07
UGC	502.585.529.600,00	1	61	0.514	12	0.21
CLU	441.334.237.834,00	9	78	0.363	15	13.78

Table 8 shows that CLT had the lowest construction C and UGC had the highest construction C. However, the UGC was the best performer in Q, S, RP and CM as it had the least pending items, the shortest construction duration, the fastest Spatial Utilization Activity Conformity processing duration and the least contract value change. Vector normalization was applied to the values in Table 8, producing the dimensionless entries reported in Table 9.

Table 9. Normalized TOPSIS decision matrix

Criterion Alternative	C	Q	S	SE	RP	CM
CLT	0.3176	0.4643	0.4734	0.3839	0.5944	0.1272
SPT	0.4844	0.5417	0.6030	0.3839	0.7186	0.7085
UGC	0.6126	0.0774	0.3955	0.6858	0.2246	0.0103
CLU	0.5379	0.6964	0.5058	0.4846	0.2827	0.6941

Table 9 transformed the decision matrix into a normalized matrix so that indicators with different units were placed on a common dimensionless basis. Subsequently, the AHP criteria weight matrix is constructed (Table 10) and multiplied by the matrix in Table 9 to generate the weighted decision matrix reported in Table 11.

Table 10. AHP criteria weight matrix

Criterion Alternative	C	Q	S	SE	RP	CM
CLT	0.0756	0.3189	0.2175	0.0823	0.1793	0.1265
SPT	0.0756	0.3189	0.2175	0.0823	0.1793	0.1265
UGC	0.0756	0.3189	0.2175	0.0823	0.1793	0.1265
CLU	0.0756	0.3189	0.2175	0.0823	0.1793	0.1265

Table 11. Weighted decision matrix

Criterion Alternative	C	Q	S	SE	RP	CM
CLT	0.0240	0.0351	0.0358	0.0290	0.0450	0.0096
SPT	0.0366	0.0410	0.0456	0.0290	0.0543	0.0536
UGC	0.0463	0.0059	0.0299	0.0519	0.0170	0.0008
CLU	0.0407	0.0527	0.0382	0.0366	0.0214	0.0525

This operation transfers the AHP priorities into the TOPSIS evaluation, because each normalized performance value is scaled according to the priority assigned to its criterion. Next, Table 11 was subsequently used to construct the preferred and least favorable reference profiles, with the results presented in Table 12.

Table 12. Positive and negative ideal solution identification

Solution \ Criterion	C	Q	S	SE	RP	CM
Positive Ideal Solutions (a^+)	0.0240	0.0059	0.0299	0.0290	0.0170	0.0008
Negative Ideal Solutions (a^-)	0.0463	0.0527	0.0456	0.0519	0.0543	0.0536

Since all criteria were treated as cost attributes, Table 12 identified the smallest weighted entry defined the preferred reference for a criterion, whereas the largest entry defined its least favorable reference. Following the identification of distances from both reference profiles (D_i^+ and D_i^-) were then calculated for every alternative to determine the relative closeness coefficient (C_i^+) reported in Table 13.

Table 13. Final results of the TOPSIS analysis

Alternative	D_i^+	D_i^-	C_i^+	Ranking
(1)	(2)	(3)	(4 = $\frac{3}{2+3}$)	(5)
CLT	0.0418	0.0587	0.5838	2
SPT	0.0763	0.0274	0.2644	4
UGC	0.0319	0.0814	0.7183	1
CLU	0.0727	0.0375	0.3401	3

The TOPSIS results in Table 13 shows a pronounced trade-off between initial cost and implementation performance. CLT recorded the lowest construction cost, while UGC had the highest initial cost. However, UGC performed more favorably in quality, schedule, regulatory and permitting compliance, and contract management, which are also among the most influential criteria identified by AHP. Thus, UGC was the preferred alternative since it had the maximum relative closeness coefficient although it was less cost effective. The result shows the analytical benefit of the combination of AHP and TOPSIS. The relative importance of each criterion is obtained using AHP based on expert judgment, and TOPSIS is used to rank the alternatives using the weighted decision framework. This separation of roles has been utilized in recent similar applications where AHP is employed to identify the criterion priorities and TOPSIS is used to convert these priorities into an overall ranking based on the distance from the preferred solution (Boonsothonsatit et al., 2024; Chanpuypetch et al., 2024). So, the UGC ranking is not a proof of the universal superiority of underground transmission but a sign that it has a performance profile closest to the priorities set for this particular industrial corridor.

This preference for UGC is also consistent with the broader trade-offs documented in recent transmission research. Underground transmission infrastructure can reduce the visual impact of transmission infrastructure and is generally an option in situations where there are more substantial spatial or community constraints on overhead infrastructure. However, empirical studies found public preferences for undergrounding heterogeneous, and the additional economic burden remains an important consideration (Choi et al., 2024). Therefore, the present finding does not eliminate the economic advantage of overhead alternatives. Instead, it demonstrates that under the conditions of the Telukjambe-Telukjambe II-KTT Indah Kiat corridor, the advantages associated with implementation certainty, permitting, quality, and contract performance were sufficient to offset UGC's higher initial cost within the weighted decision model. This interpretation is particularly important for infrastructure decision makers because it shifts the evaluation from a lowest-cost perspective toward project value across multiple implementation dimensions. The result also reinforces the need to treat the final ranking as context-specific, changes in corridor conditions, expert composition, project data, or criterion weights may alter the

relative position of the alternatives and should therefore be examined through sensitivity analysis in future applications.

Conclusion

In general, the comprehensive assessment showed that the UGC configuration is the preferred alternative for balancing the quality, delivery, permitting, and contractual priorities of the Telukjambe corridor. Within the evaluated alternatives, UGC also provides the most suitable response to the three principal constraints identified at the outset of the study. Its underground configuration reduces dependence on above-ground tower locations within the spatially constrained industrial corridor, while its comparatively favorable permitting performance and shorter implementation schedule address the complexity of regulatory approvals and the urgency of connecting the planned industrial load. Expert validation confirmed that cost, quality, schedule, social-environmental aspects, regulatory and permitting compliance, and contract management are relevant criteria for evaluating transmission alternatives in a constrained industrial corridor. The AHP results indicate that quality, schedule, and regulatory and permitting compliance are the most influential considerations, showing that the decision should not be based exclusively on initial construction cost. When these weights were incorporated into TOPSIS, UGC emerged as the preferred alternative because of its stronger overall performance, particularly in construction quality, implementation time, permitting certainty, and contract management.

The practical implication of this study is that infrastructure owners, especially PLN and related project-planning units, can implement the validated hybrid AHP-TOPSIS framework as a decision-support tool for the selection of transmission alternatives within corridors with spatial, regulatory, social, and contractual constraints. The methodology can also provide transparency for practitioners in their alternative selection by integrating expert judgement to measurable project facts. The findings highlight to policy makers the necessity to institutionalize multicriteria evaluation in transmission planning to address the technical, implementation, permitting and governance aspects, in an integrated manner. Future researchers can improve this model by testing it on different transmission corridors, including sensitivity analysis, or comparing the results with other MCDM methods to improve the robustness of the decision-making conclusions.

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