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CHOOSING AN OPERATION AND MAINTENANCE MODEL FOR UTILITY-SCALE SOLAR PLANTS IN UZBEKISTAN THROUGH COST MODELLING AND AN EXPERT PANEL

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Abstract. Uzbekistan has set a goal of 27 GW of renewable capacity and a 40 percent renewable share of electricity production by 2030, and decisions in the sector are moving from building plants to operating them. The study compares three ways of organising operation and maintenance at a utility-scale solar plant, namely a service team of the general contractor, a service company of the project sponsor and a local service organisation. A single annual cost measure, which adds revenue lost to reduced availability to direct spending, is combined with a localisation index and with judgements of 23 experts collected between 14 October and 3 November 2026 through an analytic hierarchy questionnaire. Annual cost is 2,710 thousand USD under a foreign team, 1,568 thousand USD in the current mixed arrangement and 1,309 thousand USD under localisation with a training programme. Experts gave cost (38.2 percent) and equipment availability (35.2 percent) the largest weights, and the local organisation obtained the highest final score (7.79 of 9) ahead of the sponsor's company (6.89) and the contractor (5.65). Agreement among experts is statistically significant (Kendall's W = 0.786 for criteria and 0.682 for arrangements).

Keywords. operation and maintenance; localisation; analytic hierarchy process; solar power; expert survey; Uzbekistan

1. Introduction

Uzbekistan's legislature approved amendments in January 2024 that fix the national goal at 27 GW of renewable capacity and a 40 percent renewable share of electricity production by 2030 (Enerdata, 2024). Utility-scale plants built under long-term power purchase agreements have meanwhile passed from construction into operation. Nur Navoi, a 100 MW photovoltaic plant sponsored by Masdar and financed with loans from the Asian Development Bank (ADB, n.d.), is one such plant. From the day of commissioning the owner faces a question that tender documents seldom settle, namely who will operate and maintain the equipment through a contract life of twenty-five years and with whose employees. The answer fixes annual spending, the availability of the plant, the speed at which national specialists acquire skills and the share of operating expenditure that stays in the domestic economy.

Three arrangements are in use or under discussion. The general contractor that built the plant may keep a service team on site; the work may pass to a specialised service company of the sponsor; or a local organisation, or a division of the owner, may perform it. Each arrangement trades annual cost against equipment availability, the transfer of know-how and the clarity of contractual responsibility. The present paper compares the three quantitatively. A cost model converts reduced availability into lost revenue and adds it to direct spending, a localisation index measures the share of

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spending that remains in the country, and a panel of 23 energy specialists, questioned in October and November 2026, supplied the weights of five selection criteria and rated each arrangement against them.

2. Conceptual and empirical background

Transaction-cost economics supplies the first lens. O. E. Williamson (1979) argued that when investments are specific to a relationship, the parties cannot replace one another without loss, and arm's-length contracting gives way to governance with additional safeguards. Operation of a solar plant fits the argument, because inverter firmware, tracker settings and fault histories accumulate as knowledge attached to one fleet of equipment. P. L. Joskow (1987) documented the same logic in coal markets, where contract duration lengthened with the size of relationship-specific investment between mines and power stations. For the choice among service providers the implication is practical. A provider that already holds the plant-specific knowledge has an advantage in availability, and the owner pays for that advantage through higher cost and a thinner transfer of skills to national staff.

Engineering and policy sources approach the same choice from other sides. K. Ilse and co-authors (2019) quantified soiling alone as a reduction of at least 3–4 percent of global solar output even under optimised cleaning, worth at least 3–5 billion euros a year, so the quality of field service reaches revenue directly. The best-practice guide issued by the National Renewable Energy Laboratory with Sandia National Laboratories and the SunSpec Alliance (2018) describes service agreements written around availability or energy guarantees and points out that an energy guarantee and an uptime indicator are difficult to compare across a portfolio. IRENA and the International Labour Organization (2024) observed growing interest in domestic supply chains as a route to more value and local employment, an interest intertwined with protectionism and geopolitical rivalry. Each source treats one attribute of service, namely availability, contract form or domestic value. The comparison reported below carries the three attributes into a single assessment for one plant.

3. Data and methods

The cost model is calibrated to a 100 MW photovoltaic plant staffed by 27 employees, the number reported in public project documents. Annual service cost X for a given number of foreign specialists is the sum of the wage bill of foreign and local staff, spending on spare parts, materials and external services, annualised training, and the value of availability lost relative to the best attainable level (Equation 1).

$$X = n_f w_f + (n - n_f) w_m + X_b + X_t + p(A_{max} - A) \quad (1)$$

Here n is total staff, w_f and w_m are the full annual costs of a foreign and a local specialist, X_b is spending on spares and external services, X_t is annualised training cost, p is the revenue value of one percentage point of availability and A is the availability attained. Parameter values are the author's assumptions and are tested by sensitivity analysis. A foreign specialist costs 70 thousand USD a year in full, a local one 15 thousand USD, and both sums cover housing, transport and insurance. Spares, materials and external services amount to 820 thousand USD irrespective of staffing, and 60 percent of that sum, or 492 thousand USD, is bought from domestic suppliers. Availability falls linearly as the foreign share declines, from 99.2 percent with an entirely foreign team to 97.0 percent with an entirely local team and no training, or 98.8 percent when a training programme accompanies localisation. One percentage point of availability is valued at 75 thousand USD of revenue. Training costs 10 thousand USD

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per specialist, spread over five years. The localisation index (Equation 2) is the share of operating expenditure that stays in the country.

$$I = (W_m + X_m) / X_u \times 100 \quad (2)$$

In Equation 2, W_m is the wage bill of local staff, X_m the purchases from domestic suppliers and X_u the total operating cost.

The expert survey ran from 14 October to 3 November 2026 as an electronic questionnaire. Twenty-three specialists took part, five from generating companies, four each from service companies, the grid operator and science and education institutions, and three each from the energy ministry system and from design and engineering organisations. Eight were lead specialists, five heads of department, four specialists, four faculty or research staff and two managers; fifteen had more than ten years of energy experience and 21 (91.3 percent) had worked directly with renewable plants, so no single stakeholder type holds a majority. Panels of specialists are an established way to obtain judgements where records are absent (Okoli & Pawlowski, 2004). Respondents compared the ten pairs formed by five criteria (cost, equipment availability, staff qualification and knowledge transfer, localisation, and clarity of responsibility) on the nine-point scale of T. L. Saaty (1990), Distinguished University Professor at the University of Pittsburgh and author of the analytic hierarchy process (Saaty, 1980), and then rated each arrangement from 1 to 9 on every criterion.

Priority weights for each respondent were computed as the normalised geometric mean of the rows of the comparison matrix (Crawford & Williams, 1985). Consistency was checked through the ratio of the consistency index to the random index, set at 1.12 for a five-by-five matrix, with a rejection threshold of 0.10 (Saaty, 1990). Group weights are arithmetic means of individual vectors, and medians are reported beside them, an approach that follows the aggregation of individual priorities discussed by E. Forman and K. Peniwati (1998). The final score of an arrangement for a respondent is the sum of that respondent's weights multiplied by the respondent's ratings. Agreement among respondents was measured with the coefficient of concordance W of M. G. Kendall and B. Babington Smith (1939), corrected for ties and tested through chi-square equal to $m(n-1)W$, where m is the number of respondents and n the number of objects ranked. Optional blocks asked for three-point estimates of training cost and other quantities and for staffing levels by scenario; 19 to 21 respondents answered them, and medians are reported.

4. Results

Table 1 reports the model results. An entirely foreign team costs 2,710 thousand USD a year. The current mixed team of five foreign and 22 local specialists, trained within the sponsor's own system, costs 1,568 thousand USD at 98.9 percent availability. Full localisation without training costs 1,389 thousand USD, of which 164 thousand USD is revenue lost as availability falls to 97.0 percent. With the training programme, wages of 405 thousand USD, spares and services of 820 thousand USD, training of 54 thousand USD and an availability loss of 30 thousand USD add up to 1,309 thousand USD, which is 259 thousand USD below the current arrangement. The 54 thousand USD spent on training removes 134 thousand USD of loss, roughly 2.5 dollars for each dollar. Lowering the foreign specialist's cost to 50 thousand USD cuts the saving to 159 thousand USD, and raising the local one to 20 thousand USD cuts it to 234 thousand USD, yet the localised arrangement remains the cheapest in both cases. The localisation index rises from 18 percent to 52 and then 69 percent across the three arrangements.

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Table 1. Model results for the three operation and maintenance arrangements

Indicator	General contractor	Sponsor's company	Local organisation with training
Annual total cost, thousand USD	2,710	1,568	1,309
Availability, %	99.2	98.9	98.8
Localisation index, %	18	52	69
Knowledge transfer	low	medium	high
Clarity of responsibility	high	high	medium
Time to introduce, years	not applicable	1	3–5

Note. Cost, availability and the index are model outputs under the assumptions of Section 3. The two qualitative rows and the introduction time are the author's assessment.

The panel placed cost first with a mean weight of 38.2 percent (individual range 20.6–51.0) and equipment availability second with 35.2 percent (19.7–51.8). Clarity of responsibility received 10.1 percent (3.4–18.6), staff qualification and knowledge transfer 9.4 percent (5.3–13.9) and localisation 7.1 percent (3.4–16.6). The median for localisation was only 4.8 percent, so a few respondents with high weights lift its mean. Judgements were internally consistent, with a mean consistency ratio of 0.058 and a range from 0.025 to 0.082, and no questionnaire exceeded the 0.10 threshold, so none was dropped. Respondents agreed on the order of the criteria ($W = 0.786$, $\chi^2 = 72.3$, 4 degrees of freedom, $p < 0.001$), and cost and availability together carry 73.4 percent of the weight.

Mean ratings differ sharply by criterion (Table 2). The general contractor's service is rated highest for availability (8.78) and clarity of responsibility (8.65) and lowest for cost (3.00) and localisation (2.43). The local organisation shows the opposite profile, with 8.43 for cost, 8.13 for localisation and 8.00 for qualification and knowledge transfer, but only 5.74 for clarity of responsibility. The sponsor's company sits between the two on all five criteria. Weighted by each respondent's own priorities, the local organisation received a mean final score of 7.79 (median 7.91), the sponsor's company 6.89 (6.81) and the general contractor 5.65 (5.53), as Figure 1 shows. Eighteen of the 23 respondents placed the local organisation first and five the sponsor's company, while none gave the contractor first place. Agreement on the order of the arrangements is also significant ($W = 0.682$, $\chi^2 = 31.4$, 2 degrees of freedom, $p < 0.001$). When the mean ratings are re-weighted and the other four weights scaled proportionally, the local organisation keeps first place until the weight of clarity of responsibility reaches about 36 percent, nearly twice the largest weight any respondent assigned (18.6 percent).

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Table 2. Mean criterion weights and mean ratings of the arrangements (1–9 scale, 23 experts)

Criterion	Mean weight, %	General contractor	Sponsor's company	Local organisation
Cost	38.2	3.00	6.00	8.43
Equipment availability	35.2	8.78	8.13	7.52
Clarity of responsibility	10.1	8.65	7.91	5.74
Staff qualification, knowledge transfer	9.4	3.83	6.04	8.00
Localisation	7.1	2.43	5.22	8.13
Final score (mean)	100.0	5.65	6.89	7.79
Experts ranking the arrangement first		0	5	18

Note. Final scores are computed for each expert with that expert's own weights and then averaged, so they differ slightly from the product of mean weights and mean ratings.

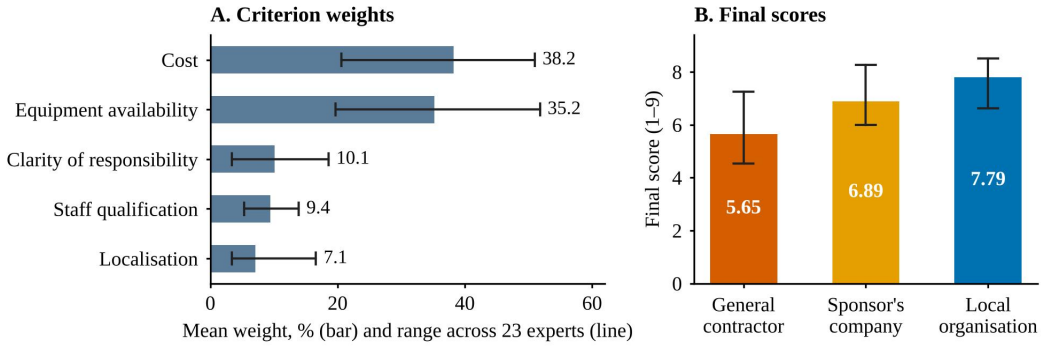


Figure 1. Mean criterion weights (A) and mean final scores (B) with minimum–maximum ranges across the 23 experts.

Splitting the panel by employer gives a pattern that cannot be tested statistically with groups of three to five people but is worth reporting. All generating companies (5 of 5), all science and education respondents (4 of 4) and all three from the energy ministry system placed the local organisation first, as did three of four service companies and two of three design and engineering organisations. The grid operator differed, since three of its four respondents preferred the sponsor's company, and its mean scores for the two arrangements (7.43 and 7.10) were the only ones in which the sponsor's company led. The energy ministry group gave cost the highest mean weight (49.9 percent), while the grid operator, the design organisations and the science institutions put availability ahead of cost (37.6, 43.0 and 41.6 percent).

The optional blocks, answered by 19 to 21 respondents, offered an outside check on several assumptions (Table 3). The median training cost, 10 thousand USD per specialist, coincides with the model value, and the low and high estimates have medians of 8 and 13 thousand USD. Respondents put the share of service work done by local organisations at 50 percent today and 70 percent attainable by 2030. The notion differs from the localisation index, since the index measures money that stays in the country while respondents judged who performs the work, yet the levels are close to the index values of 52 percent for the sponsor's company and 69 percent for the localised

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arrangement. Medians of staff per plant were 30, 27 and 24 across the three development scenarios, and the model value of 27 equals the middle one.

Table 3. Expert medians compared with model assumptions

Quantity	Expert median	Model value
Training cost per specialist, thousand USD	10 (low 8, high 13)	10
Share of service work done by local organisations, now and in 2030, %	50 and 70	52 and 69 (index)
Staff per plant across three scenarios, persons	30; 27; 24	27

Note. The share of local organisations and the localisation index are related but not identical measures.

Open answers, grouped by the author into recurring themes, indicate where respondents saw obstacles. A shortage of certified local specialists was named in 19 questionnaires, dependence on imported spares and special tools in 18, and the absence of a local-share requirement in service contracts in 12; manufacturer warranty and accreditation conditions (4) and the difficulty of local service firms in obtaining bank guarantees and working capital (3) appeared less often. Of 22 respondents who answered the question on training, 18 proposed a shared training centre for several stations, 14 proposed writing a training obligation into the service contract and 13 proposed certification of staff.

5. Discussion

Results agree with the transaction-cost reasoning of O. E. Williamson (1979). Localisation without training lowers availability from 99.2 to 97.0 percent, and the missing asset is plant-specific knowledge; the training programme closes most of the gap, leaving only 0.4 percentage points. Cost and localisation do not conflict in this case, because a foreign specialist costs more than four times a local one, so the cheapest arrangement is also the one that keeps the most money in the country. The general contractor keeps its lead on clarity of responsibility and availability, advantages that belong to contract design as much as to technology, and the panel accepted a weaker position on both in exchange for cost.

Practical steps follow from the weakest rating of the local organisation. Table 1 shows a transition of three to five years against one year for the sponsor's company, so a staged handover looks sensible, with sponsor support retained in early years under an availability guarantee and liquidated damages. Open answers name a shared training centre, a training obligation inside the service contract and staff certification as instruments. IRENA and ILO (2024) link domestic supply chains with protectionist pressure, and a requirement tied to measured availability and training milestones carries less of that risk than a fixed local-content quota.

Limitations are considerable. The model describes one plant, its cost parameters are the author's assumptions, and the linear link between foreign share and availability has not been estimated from operating records, which were not accessible. The panel of 23 was assembled purposively, not by random draw, and most respondents are not investors or lenders, whose weights could favour availability and clarity of responsibility more strongly. Ratings are subjective judgements, open answers were grouped by a single coder, and the plant is a solar one, so wind service, with different equipment and skills, needs a separate test.

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6. Conclusions

The cost model and a panel of 23 specialists give a consistent ordering of three ways of organising operation and maintenance at a 100 MW solar plant in Uzbekistan. Localisation combined with training costs 1,309 thousand USD a year against 1,568 thousand USD in the current arrangement and 2,710 thousand USD under a foreign team, while the share of spending kept in the country rises from 18 to 69 percent. Experts assign 73.4 percent of the weight to cost and availability and place the local organisation first (7.79 of 9) ahead of the sponsor's company (6.89) and the contractor (5.65), with significant agreement. The weakest rating of the local organisation concerns clarity of responsibility, a matter of contract design, and a shared training centre, training obligations in service contracts and staff certification are the instruments named most often. Repeating the exercise with operating records from the plants and with a wind farm would test whether the linear availability assumption holds.

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