From Skills Gaps to Energy Resilience: Building a Territorialized Solar Workforce Ecosystem in Indonesia

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Abstract
Indonesia's electricity plan for 2025–2034 projects 69.5 GW of additional generation capacity, including 17.1 GW of solar power, while government estimates associate the plan with 348,057 solar-related job opportunities. These projections make workforce capability a material implementation issue: renewable infrastructure requires technicians, engineers, safety specialists, project managers and locally available operations-and-maintenance personnel. Yet headline job estimates do not reveal whether workers are available in the required occupations, locations or project phases. This article examines how workforce development can be linked to the resilience of solar infrastructure in an archipelagic state. It uses a focused qualitative documentary analysis, official Indonesian planning and employment documents, and international institutional evidence, interpreted through energy security, capacity development and energy justice perspectives. The analysis identifies four interlocking governance gaps: incomplete skills intelligence; weak alignment between training, certification and project demand; uneven territorial distribution of operational capability; and limited feedback from infrastructure performance into workforce planning. The article proposes a territorialized solar workforce resilience framework in which workforce data, competency standards, work-based learning, local maintenance capacity and critical-infrastructure performance are planned together. The framework is a theory-building contribution, not an estimate of causal effects. Before journal submission, its propositions require validation through comparative project-level fieldwork and verified occupational data.

Keywords: energy resilience; solar photovoltaic; workforce development; skills governance; Indonesia; territorial capacity

DOI: https://doi.org/10.56442/pef.v4i4.1605

1. Introduction

The energy transition is often measured through megawatts, investment commitments and emissions trajectories. Those measures are essential, but they do not show whether the institutions and workers needed to deliver, operate and repair new infrastructure are available when and where they are needed. In electricity systems, a project that has been financed and installed can still underperform if maintenance capability, safety competence, spare-part logistics or grid integration skills are absent. Human capability is therefore part of infrastructure readiness, rather than a secondary social benefit of construction.

Indonesia's 2025–2034 Electricity Supply Business Plan (RUPTL) sets out 69.5 GW of planned additional generation capacity. The Ministry of Energy and Mineral Resources (ESDM) reports that the plan includes 17.1 GW of solar capacity, alongside 7.2 GW of wind, 5.2 GW of geothermal, 11.7 GW of hydropower and other technologies; it also anticipates major transmission and substation expansion (ESDM, 2025a). A separate ESDM release estimates 836,696 employment opportunities across manufacturing, construction, installation, operations and maintenance for generation and storage, of which 348,057 are associated with solar (ESDM, 2025b). The latter is a planning estimate, not a count of existing workers or a direct measure of permanent jobs. It should be read as a signal of the scale and timing of prospective labor demand.

This distinction matters. Employment projections do not specify the number of workers required by occupation, competency level, region, duration or project phase. Nor do they establish that training institutions can supply workers with the relevant qualifications.

The Ministry's own figure spans the value chain, from manufacturing and construction to installation and operations. It therefore cannot by itself answer whether Indonesia has sufficient solar installers, electrical safety professionals, commissioning engineers or technicians able to maintain remote systems. Treating a projected job total as evidence of workforce readiness risks confusing labor demand with effective labor supply.

The book Talenta Energi untuk Ketahanan Nasional (Solihin et al., 2026) frames the issue as a strategic capability challenge. Drawing on an underlying study of solar workforce development, it identifies gaps in technical skills across project stages, regulatory and occupational safety compliance, professional standardization and certification, and project-management and commercial skills. It also highlights the difficulty of mapping national competency supply and the concentration of experienced personnel in Java, which may complicate maintenance of assets in remote areas. These claims provide a valuable problem diagnosis, but the book is not a project-level dataset. They must be treated as propositions to investigate, not as nationally representative measurements.

The central research problem is thus not simply whether Indonesia needs more energy workers. It is how workforce institutions can develop and distribute the capabilities that make solar infrastructure reliable across diverse territories. Existing energy-security scholarship emphasizes the vulnerability of vital energy systems and their relation to resilience (Cherp & Jewell, 2014). Capacity-development approaches further distinguish individual skills from organizational and institutional conditions that allow skills to be used (UNDP, 2009). Energy-justice scholarship asks how the benefits and burdens of energy systems are distributed (Jenkins et al., 2016). Combining these lenses makes it possible to examine workforce planning as a component of system resilience and territorial equity.

This article asks: (1) what workforce-governance gaps are visible in the current Indonesian policy and planning evidence for solar deployment; (2) through what mechanisms could these gaps affect infrastructure resilience; and (3) what institutional arrangements could connect skills development to local operational capability? Its contribution is a territorialized solar workforce resilience framework. The framework links demand intelligence, competency formation, local deployment and performance feedback, and identifies propositions for subsequent empirical testing. It does not claim that workforce distribution has already been shown to cause measurable differences in project reliability.

2. Literature and analytical framework

2.1 Energy resilience and critical system capability

Energy security has expanded beyond the assurance of fuel supply to encompass the vulnerability of systems that support essential social functions. Cherp and Jewell (2014) define the analytical task around the protection of vital energy systems from threats, with vulnerability shaped by exposure and resilience. For solar infrastructure, the relevant system includes more than photovoltaic modules: it includes inverters, storage where present, control and communications equipment, grid interfaces, maintenance arrangements, safety practices and the organizations responsible for each function. A workforce deficit can become a resilience concern when it limits the ability to detect faults, restore service, maintain safe operation or adapt equipment to changing technical requirements.

Resilience should not be equated with self-sufficiency. External vendors and national specialist teams can be important sources of expertise. The relevant question is whether a system can access the right capability within an acceptable time and whether that capability can be reproduced, transferred or retained locally. This distinction is especially relevant in an archipelago, where travel time, logistics and the distribution of technical institutions may affect response capacity. The article therefore treats territorial availability of skills as a potential

determinant of system response, while recognizing that workforce location is only one factor among design quality, spare parts, finance, grid conditions and management.

2.2 From individual skills to capacity development

Human-capital theory explains how education, training and experience can increase productivity (Becker, 1964). For energy workforce policy, however, an individual-capital lens is incomplete. A certified technician cannot maintain an asset without access to tools, manuals, spare parts, data, management authority and clear service responsibilities. UNDP's capacity-development framework accordingly considers capacities at individual, organizational and enabling-environment levels (UNDP, 2009). This article applies that distinction to solar systems: individual competence concerns what a worker can do; organizational capability concerns whether an employer can deploy and retain that competence; and system capability concerns whether regulations, finance, procurement and intergovernmental arrangements make the capability usable.

This layered view also changes the meaning of a skills gap. A gap can arise because a skill is absent, because the skill is not recognized through a credible qualification, because workers cannot access relevant jobs, or because institutions do not coordinate training with actual project requirements. ILO research on skills for a greener future emphasizes that green structural change alters occupations and skill composition, requiring coordination between labor-market, education and environmental policies (ILO, 2019). IRENA and ILO similarly treat education and training as part of a broader package that includes deployment, investment, industrial policy and inclusive workforce development (IRENA & ILO, 2024).

2.3 Territorial equity and energy justice

The distribution of renewable-energy employment matters to the legitimacy and durability of transition policy. Energy-justice research highlights distributive, procedural and recognition dimensions of energy systems (Jenkins et al., 2016). Applied to workforce governance, distributive justice concerns access to training, certification and decent employment; procedural justice concerns whether workers, communities and local authorities influence project planning; and recognition concerns whether local knowledge and local labor are valued in operational decisions. The framework does not assume that every project must be staffed entirely by local workers. Instead, it asks whether local capacity is meaningfully built and whether residents have fair access to the benefits of investment.

Territorialization is therefore more than placing training centers in additional provinces. It entails mapping demand by project location and occupation, strengthening regional training and assessment capacity, creating pathways from training into paid work, and ensuring that operations-and-maintenance responsibilities are funded over an asset's life. It also requires attention to gender and other access barriers. Global renewable employment estimates show substantial job growth but uneven distribution, while IRENA and ILO call for workforce policies that support inclusion and local value creation (IRENA & ILO, 2024).

2.4 Proposed analytical model

The proposed model connects four stages: (1) workforce-demand intelligence; (2) competency formation and recognition; (3) territorial deployment and retention; and (4) infrastructure-performance feedback. The first stage translates project pipelines into occupational profiles and regional demand. The second aligns curricula, work-based learning, certification and safety requirements with those profiles. The third ensures that qualified personnel can enter jobs, remain available and progress professionally in project regions. The fourth uses maintenance, outage, safety and service data to adjust training and deployment plans. Governance coordination and financing influence every stage.

Table 1. Workforce-to-resilience analytical chain

Stage	Key question	Illustrative indicators for future fieldwork
Demand intelligence	What occupations and competencies are needed, where and when?	Planned MW by location; occupational demand; project phase; skills forecast updates
Competency formation	Do training and certification reflect real work?	Curriculum coverage; practical hours; certification completion; employer recognition
Territorial deployment	Can qualified workers reach and remain in project areas?	Local hiring share; travel and response time; vacancies; retention; regional training access
Performance feedback	Does workforce capability support safe, reliable operations?	Availability; outage duration; maintenance backlog; safety incidents; time to repair

3. Method

3.1 Research design

The study uses focused qualitative documentary analysis and theory building. It is designed to identify policy assumptions, reported workforce gaps and institutional relationships in the available evidence, then develop a framework for empirical testing. It does not report interviews, surveys, site visits or project-performance measurements. No claim in the findings should be interpreted as a causal estimate or as a representative measure of the national workforce.

3.2 Documentary corpus and selection

The core corpus consists of: (a) Solihin et al. (2026), a strategic book whose contents and cited underlying study provide the focal diagnosis; (b) the approved RUPTL 2025–2034, treated as the official planning anchor, together with the ESDM release announcing its approval; (c) the ESDM release reporting projected renewable-energy employment by technology and project stage; and (d) IRENA and ILO's Renewable Energy and Jobs: Annual Review 2024, used to situate Indonesian planning within international workforce evidence. PLN's 2024 statistics and BPS provincial generation-capacity tables are identified as suitable sources for a subsequent spatial analysis, but are not used here to infer solar workforce availability. Inclusion was purposive: sources had to be official or institutional, directly relevant to solar deployment, jobs, skills or system capability, and available by 29 October 2026.

The RUPTL is a plan, not an implementation audit. The 348,057 figure is reported by ESDM as projected solar job opportunities across manufacturing, construction, installation, operations and maintenance. It is not treated as 348,057 permanent positions, a skills-supply estimate or an observed employment outcome. The distinction between planned capacity, modeled employment opportunity and realized employment is maintained throughout the analysis.

3.3 Analytical procedure

Documents were read for four pre-specified themes derived from the analytical framework: demand intelligence; competency formation and recognition; territorial deployment; and performance feedback. Within each theme, claims were classified as (i) documented fact or official planning statement, (ii) diagnosis or interpretation reported by the book, or (iii) analytical proposition developed by this article. This claim-status distinction is important because the source book combines conceptual argument with a study-specific diagnosis, while official releases state plans and projections rather than observed outcomes.

Triangulation was used at the level of claim type. The RUPTL and ESDM releases establish the scale and stated direction of planned expansion; the book identifies workforce and institutional concerns; and IRENA–ILO provides international context on jobs and workforce policy. Where the sources did not provide a measurement—for example, regional availability of certified solar technicians or the effect of technician distance on outage duration—the article treats the issue as a research gap rather than filling it with inference. The framework was then constructed by linking the recurring gaps to plausible capability mechanisms identified in the literature.

3.4 Limitations and validity

The corpus is deliberately focused and is not a systematic review of all Indonesian workforce policies or solar projects. It contains no original field interviews and does not include a province-by-province occupational database. The workforce diagnoses and numerical claims are not independently re-estimated here. ESDM's job projections are policy estimates and may use assumptions about job-years, direct and indirect employment, or project phases that require inspection of the underlying technical methodology before quantitative reuse. These limitations constrain the article to analytical framework development. A submission to a high-impact journal would require a larger, reproducible document corpus and comparative field evidence, as outlined in the conclusion.

4. Result and Disscusion

4.1 Planning creates a large demand signal, not a workforce map

The RUPTL establishes a substantial pipeline for electricity infrastructure and renewables. ESDM reports 69.5 GW of additional generation capacity through 2034, including 17.1 GW of solar, while the renewable portfolio also includes hydro, wind, geothermal and other technologies (ESDM, 2025a). The associated employment release estimates 836,696 opportunities across generation and storage value chains, including 348,057 linked to solar (ESDM, 2025b). These figures position workforce planning as an implementation issue at national scale.

However, the available headline estimates do not provide the occupational and spatial resolution required for workforce deployment. They do not indicate how many positions are expected in manufacturing versus installation or long-term maintenance; the required qualification level; the project location; or the timing of recruitment. As a result, policymakers cannot infer from the job total alone whether regional training supply is adequate, whether the same workers are counted across project phases, or how many jobs will persist after construction. This is the first gap: workforce demand is visible in aggregate, while the operational map of skills demand remains under-specified in the sources reviewed.

4.2 Skills formation must connect technical competence to work systems

Diagnosis identifies four broad areas of competence concern: technical expertise across the project life cycle; compliance with regulation and occupational safety; professional standards and certification; and project-management and commercial capability (Solihin et al., 2026). Taken together, these areas suggest that a solar workforce cannot be defined solely by installer skills. Project development and operation also require grid, procurement, quality assurance, safety, finance, data and maintenance competencies.

The international evidence supports this broader interpretation. IRENA and ILO estimate 16.2 million renewable-energy jobs globally in 2023 and report that solar photovoltaic activity accounted for the largest technology-related employment segment. Their review emphasizes that skills policy should be joined to deployment, investment, supply-chain development and inclusion (IRENA & ILO, 2024). The implication for Indonesia is not that global employment ratios can be transferred directly. Rather, they reinforce the need to distinguish occupational demand and industrial structure by national context.

A second gap is the potential separation of education, certification and employer demand. The book identifies standardization and certification as important but also argues that current systems do not yet provide a sufficiently integrated picture of competency supply. Documentary evidence available for this analysis does not allow an independent audit of certification coverage, pass rates, curriculum quality or employer recognition. The finding is therefore a governance diagnosis and a testable proposition: certification can improve labor-market signaling only when standards are current, assessment is credible, and employers use the credential in recruitment and work allocation.

4.3 Territorial distribution is a resilience issue to be tested

The experienced workers are concentrated in Java and raises concern about the operation and maintenance of solar assets in remote regions without local technical support (Solihin et al., 2026). The claim is strategically plausible for an archipelagic electricity system, but the reviewed corpus does not provide a national geocoded inventory of solar workers or a comparative dataset linking workforce location to system availability. It should therefore not be presented as a quantified national disparity.

The analytical importance of the issue lies in the mechanism. When an asset depends on a small pool of specialists located far from the site, travel and dispatch constraints may extend diagnosis or repair time. The mechanism will vary with remote monitoring, service contracts, spare-parts availability, local grid conditions and system design. Workforce localization alone cannot guarantee reliability, but local capability can reduce response constraints and retain knowledge about the operating environment. This is the third gap: territorial deployment and retention are not visibly connected to asset-level performance measures in the public planning evidence reviewed.

4.4 Weak feedback can reproduce the same gaps

The available documents emphasize targets and capability-building needs, but the corpus does not show a unified feedback loop joining project-level operational data to curriculum revisions, certification updates and regional training investments. Without such a loop, workforce planning risks remaining supply-led: training providers produce credentials without clear evidence of project demand, while project developers may recruit for immediate delivery without investing in long-term maintenance capacity.

This fourth gap is institutional rather than individual. Capacity-development theory suggests that individual training produces durable results only when organizations and enabling environments can use and sustain the capability (UNDP, 2009). In a solar context, the relevant institutional conditions include clear maintenance obligations, funded service contracts, accessible technical documentation, occupational-safety enforcement, employer participation in competency standards and transparent reporting of operating performance. These conditions convert training outputs into usable system capability.

5. Discussion

5.1 Reframing workforce policy as infrastructure resilience policy

The analysis supports a shift in policy framing: workforce development should be planned as one of the enabling systems of electricity infrastructure. The proposed framework does not claim that increasing local hiring by itself improves reliability. It identifies a chain of conditions that can be examined: planning produces a location- and occupation-specific demand signal; education and certification generate relevant competencies; employers and public agencies make those competencies deployable; and operational data reveal whether capability is sufficient.

This reframing is consistent with an energy-security perspective centered on the vulnerability of vital systems (Cherp & Jewell, 2014). In this view, the resilience question is not merely “How many jobs will be created?” but “Which capabilities are required to maintain

essential energy services under normal operation and disruption, and how quickly can those capabilities be accessed?" For remote and island locations, this question includes logistics, communications and the balance between local generalist capacity and regional specialist support.

5.2 The contribution of a territorialized workforce framework

The article's conceptual contribution is to connect skills governance with the spatial and operational characteristics of infrastructure. Prior workforce policy can count training completions, certificates or projected jobs. The proposed framework adds two dimensions: territorial availability and performance feedback. It argues that a competency system should be judged not only by how many people it trains but by whether workers with appropriate skills are available at project locations, whether they can access decent work, and whether capability is maintained through the asset life cycle.

This contribution also connects energy resilience with energy justice. A workforce strategy that concentrates higher-value technical employment in established centers may deliver projects efficiently in the short term but leave host regions dependent on external service teams. Conversely, a local-training requirement without adequate quality assurance could create unsafe work or credentials with limited portability. A just and resilient approach therefore combines fair access with credible standards, career progression and local participation in planning. It does not treat local employment and technical quality as opposing objectives.

5.3 Governance implications

First, workforce intelligence should be attached to the RUPTL project pipeline. For each technology and project stage, planning should estimate occupations, skill levels, credential requirements, work duration, region and timing. This would allow government, PLN, developers and education providers to compare the project pipeline with current and projected labor supply. The dashboard should distinguish jobs, job-years, direct and indirect employment, construction peaks and permanent operational roles.

Second, competency standards should be maintained through structured employer and worker participation. Technical standards need periodic review as photovoltaic modules, inverters, storage systems, remote monitoring and grid codes change. Training should combine classroom learning with supervised work on real equipment, and certification should assess demonstrated competence, safety and problem-solving rather than attendance alone. Results should be disaggregated by sex, age, region and disability where lawful and methodologically appropriate, so that aggregate growth does not conceal unequal access.

Third, territorial capacity should be organized as a tiered service model. Local technicians can handle routine inspection and first-line maintenance; regional hubs can provide advanced troubleshooting, testing equipment and specialist teams; national centers can support complex engineering, training-of-trainers and technology updates. This model may be more feasible than duplicating every specialized capability in every province. Its performance should be assessed through response times, repair duration, maintenance backlog, safety outcomes and service availability, not only local hiring shares.

Fourth, procurement and finance should cover the full operating life of assets. If contracts reward construction completion but leave maintenance capability unfunded, the system may create a skills pipeline for installation while neglecting operations. Tender requirements can specify maintenance plans, local training, documentation transfer, spare-parts arrangements and reporting obligations. Such requirements should be designed carefully so they do not become unworkable localization quotas or barriers to competition.

5.4 Propositions for empirical testing

The documentary analysis generates four propositions for future research:

a. P1. Project-level workforce forecasts that specify occupations, locations and project phases are associated with closer alignment between training provision and employer demand.
b. P2. Work-based training combined with recognized certification is more strongly associated with employer use of trained workers than classroom training or certification alone.
c. P3. Local or regional maintenance capability is associated with shorter fault-response and repair times, conditional on spare-parts access, remote monitoring, service-contract design and grid conditions.
d. P4. Routine feedback from asset-performance and safety data into workforce planning is associated with more adaptive training and certification systems.

These are propositions, not findings established by the present study. A suitable empirical design would compare solar projects across at least two contrasting regions and combine interviews with project logs, workforce rosters, certification data and service-level indicators. Process tracing could clarify how capability affects maintenance outcomes, while quantitative analysis could test whether response times differ after controlling for system size, technology, remoteness and service-contract arrangements.

6. Conclusion

Indonesia's RUPTL 2025–2034 creates a substantial solar deployment and employment signal. The official estimate of 348,057 solar-related job opportunities is important, but it does not show whether workers with the right competencies will be available in the places and project phases where they are needed. The key policy challenge is to convert aggregate labor demand into a functioning capability system that links workforce intelligence, education, certification, employment and infrastructure operations.

This article has used focused documentary analysis to identify four connected gaps: limited occupational and spatial resolution in demand information; incomplete alignment among training, certification and employer requirements; insufficiently documented territorial distribution of operating capability; and an underdeveloped feedback link between infrastructure performance and workforce planning. It proposes a territorialized solar workforce resilience framework to address these gaps. Its novelty lies in treating workforce geography and performance feedback as integral dimensions of energy resilience, while embedding access and local participation within an energy-justice perspective.

The study is analytically bounded. It does not establish that local workforce distribution causes better reliability, and it does not independently verify the national skills gap described. For a Q1 journal submission, the next stage should expand the documentary corpus, inspect the technical basis of employment projections, construct an occupational and regional workforce baseline, and conduct comparative field research at operating solar projects. Until then, the framework should be read as a research proposition and policy design tool, rather than a completed causal evaluation.

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