# Priority Factors and Strategic Pathways for Accelerating Rooftop Solar Photovoltaic Adoption in Indonesia's Industrial Sector: A Group Analytical Hierarchy Process Approach

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**Abstract**

Rooftop solar photovoltaic (PV) systems offer substantial potential to improve energy efficiency, support decarbonization, and enhance industrial competitiveness in Indonesia. However, their adoption is shaped by multiple interrelated factors, making prioritization essential for directing interventions effectively. This study identifies and prioritizes the factors influencing rooftop solar PV adoption and the strategic pathways for accelerating its implementation in Indonesia's industrial sector. A quantitative expert-judgment approach based on the group Analytical Hierarchy Process (AHP) was applied. Ten experts and practitioners with experience in industrial energy management, PV technology and engineering, procurement, and construction (EPC), energy financing, policy, sustainability, and research were selected through purposive sampling. Pairwise comparisons were conducted using the 1-9 AHP scale, and individual judgments were aggregated using the geometric mean to derive group priority weights. Economics and Financing received the highest factor weight (36.95%), followed by Policy and Regulation (25.68%), Organization and Perception (15.62%), Technical and Infrastructure (13.85%), and Institutional and Market (7.89%). Among the strategic pathways, Strengthening Policy and Regulation ranked first (38.16%), followed by Innovative Financing Development (26.58%). The consistency ratios for the factor and strategic-pathway matrices were 0.0099 and 0.0138, respectively, both well below the 0.10 threshold. The findings reveal an important distinction within the expert panel: Economics and Financing received the highest priority among the evaluated adoption factors, whereas Strengthening Policy and Regulation received the highest priority among the strategic interventions. This suggests that, from the experts' perspective, regulatory strengthening may serve as an enabling mechanism for reducing investment uncertainty and improving conditions for wider industrial rooftop solar PV adoption.

**Keywords:** Rooftop Solar PV, Industrial Sector, Analytical Hierarchy Process, Expert Judgment, Renewable Energy, Strategic Pathways.

## I. INTRODUCTION

The energy transition is a central component of sustainable development because the energy sector contributes substantially to carbon emissions. In Indonesia, continued economic growth and industrialization are increasing energy demand, while the national energy system remains highly dependent on fossil fuels. This dependence underscores the need to accelerate renewable energy deployment, particularly in energy-intensive sectors such as industry [1], [2].

Solar energy is one of Indonesia's most promising renewable energy resources. Rooftop solar photovoltaic (PV) systems are particularly relevant to industrial facilities because factories and warehouses often have large roof areas and substantial daytime electricity demand that coincides with solar generation. This spatial and temporal compatibility creates opportunities to reduce electricity consumption from the grid, lower energy costs and carbon emissions, and strengthen corporate sustainability commitments [3], [4], [5].

Despite this potential, rooftop solar PV adoption is not determined by technical feasibility alone. Regulatory

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conditions, upfront investment requirements, access to financing, infrastructure constraints, market readiness, and managerial perceptions also shape corporate investment decisions [6]. for example, identified costs, regulation, trust in technology providers, and market readiness as barriers to rooftop PV adoption in Indonesia [7]. similarly reported infrastructure limitations, bureaucratic constraints, investment costs, information gaps, and technical-readiness challenges among manufacturing firms; comparable multidimensional barriers have also been identified in developing-country contexts [8].

Taken together, these challenges indicate that rooftop solar PV adoption is a multidimensional decision problem. Previous studies have examined rooftop solar PV from policy, economic, technical, social, and environmental perspectives. However, much of the literature focuses on households, electricity markets in general, or individual dimensions in isolation. Studies that integrate these dimensions and explicitly prioritize interventions for Indonesia's industrial sector remain relatively limited [8], [9].

A further gap concerns the distinction between adoption determinants and intervention priorities. Existing AHP- and multi-criteria-based solar PV studies have primarily focused on ranking barriers, evaluating deployment criteria, assessing technology alternatives, or determining business potential. Although these approaches identify which barriers or criteria are important, they do not necessarily distinguish between the factors that most strongly shape adoption decisions and the strategic interventions that should receive the highest implementation priority. This distinction is important because the factor perceived as most influential in an investment decision may not be identical to the policy or managerial intervention considered most effective for improving adoption conditions.

Prioritization is particularly important because government agencies, firms, financial institutions, and technology providers operate under resource constraints. Consequently, not all barriers can be addressed simultaneously or with equal intensity. A systematic decision-support approach is therefore needed not only to determine the relative importance of adoption factors, but also to identify which strategic interventions should receive priority under limited resources [10], [11].

Based on the preliminary literature synthesis, five main factor groups were identified: Policy and Regulation, Economics and Financing, Technical and Infrastructure, Institutional and Market, and Organization and Perception. These categories were derived from prior research that grouped the determinants of rooftop solar PV adoption into comparable policy, economic, technical, institutional, and perceptual dimensions [12], [13], [14], [15]. Correspondingly, five strategic intervention pathways were formulated by translating the recurring barriers and enabling conditions identified within these dimensions into actionable intervention areas**.**

To address the identified gap, this study applies two parallel Group Analytical Hierarchy Process (Group-AHP) analyses. The first analysis prioritizes the factors perceived by experts as influencing industrial rooftop solar PV adoption, whereas the second independently prioritizes the strategic pathways considered most important for improving adoption conditions. This dual-prioritization structure enables the study to examine whether the most influential adoption factor is also the intervention that experts consider most urgent. Accordingly, this study has two objectives: (1) to determine the relative priorities of factors influencing rooftop solar PV adoption in Indonesia's industrial sector; and (2) to determine the relative priorities of strategic pathways for accelerating adoption. Methodologically, the study extends conventional barrier-ranking applications of AHP by separately evaluating adoption determinants and actionable interventions within the same decision context. Empirically, it provides multidisciplinary expert evidence from Indonesia's industrial rooftop solar PV context.

From an information-systems perspective, the proposed Group-AHP structure can be viewed as a formal multi-criteria decision-support model, as Group-AHP provides a structured mechanism for aggregating individual expert judgments and deriving group-level priorities in multi-criteria decision problems [16], [17]. Such a computational structure can potentially serve as the analytical layer of a digital decision-support system by transforming heterogeneous expert judgments into structured priority information for comparing adoption factors and intervention priorities.

## II. METHODS

### A. Research Design

This study employed a quantitative expert-judgment design using the group Analytical Hierarchy Process (AHP). AHP is a multi-criteria decision-making method that derives priority weights from systematic pairwise comparisons provided by decision-makers or subject-matter experts [18], [19]. Two AHP analyses were conducted in parallel. The first prioritized the factors influencing rooftop solar PV adoption, whereas the second prioritized the strategic pathways for accelerating adoption. Accordingly, the strategic pathways were not evaluated as alternatives conditionally nested under each factor; instead, they were assessed as a separate set of priorities.

The resulting analytical structure can also be viewed as a decision-support model: the input layer consists of expert pairwise judgments, the processing layer performs judgment aggregation, priority-weight calculation, and consistency assessment, and the output layer produces ranked adoption factors and strategic pathways. Although this study does not develop a software application, the computational structure is compatible with implementation in a digital decision-support environment.

### B. Selection of Factors and Strategic Pathways

The factor structure was developed via a systematic three-step literature synthesis: extracting rooftop solar PV adoption determinants from prior studies, consolidating conceptually overlapping variables to eliminate redundancy, and structuring

the refined items into distinct dimensions suitable for Analytic Hierarchy Process (AHP) pairwise comparisons. This procedure yielded five principal adoption-factor groups: Policy and Regulation, Economics and Financing, Technical and Infrastructure, Institutional and Market, and Organization and Perception.

The five adoption factors and five strategic pathways evaluated in the AHP analyses are presented in Tables 1 and 2, respectively.

Table 1. Key Factors Influencing Rooftop Solar PV Adoption

| ID | Factor | References |
|---|---|---|
| C1 | Policy and Regulation | [12], [13], [20] |
| C2 | Economics and Financing | [4], [21] |
| C3 | Technical and Infrastructure | [5], [8] |
| C4 | Institutional and Market | [6], [9] |
| C5 | Organization and Perception | [14], [15] |

Table 2. Strategic Pathways for Accelerating Rooftop Solar PV Adoption

| ID | Strategic Pathway | References |
|---|---|---|
| S1 | Strengthening Policy and Regulation | [13], [22] |
| S2 | Innovative Financing Development | [23], [24] |
| S3 | Improved Technical and Infrastructure Readiness | [5], [7] |
| S4 | Institutional Strengthening and Collaboration | [6], [8] |
| S5 | Education and Industry Trust Enhancement | [14], [15] |

The five strategic pathways were formulated by translating the identified barriers and enablers into actionable interventions. Specifically, challenges related to regulation, financing, infrastructure, institutional coordination, and industry perception were directly mapped onto five corresponding pathways: Strengthening Policy and Regulation, Innovative Financing Development, Improved Technical and Infrastructure Readiness, Institutional Strengthening and Collaboration, and Education and Industry Trust Enhancement. Consequently, these pathways function as targeted, intervention-oriented responses to the synthesized literature rather than independent constructs.

### C. Expert Panel and Sampling

This study employed purposive expert selection to recruit panel members with relevant expertise in industrial rooftop solar PV adoption. Selecting experts based on functional roles and professional knowledge represents a standard approach in Analytic Hierarchy Process (AHP) research, as demonstrated by[25], [26] to establish decision criteria and derive priority weights.

Eligible expert were required to possess professional experience in energy, PV technology, financing, policy, ESG, or academic research, as well as sufficient familiarity with rooftop solar PV to provide informed pairwise judgments. The final panel comprised 10 experts to generate structured evaluations for the AHP analysis rather than to achieve statistical population representation. This focused panel size aligns with empirical precedents from prior studies, such as [25], [26], which demonstrate that small expert panels are sufficient provided that participants possess relevant expertise and satisfy consistency criteria. The composition of the expert panel is summarized in Table 3.

Table 3. Expert Composition by Area of Expertise

| Area of Expertise | Experts (n) |
|---|---|
| Industrial energy/utility/facility management | 3 |
| Engineering/EPC/PV technology | 2 |
| Finance/investment/energy financing | 2 |
| Energy policy/regulation | 1 |
| Sustainability/ESG | 1 |
| Academic/research | 1 |
| **Total** | 10 |

Four experts had more than 10 years of professional experience, four had 6-10 years of experience, and two had 3-5 years. Four participants had been directly involved in the planning or implementation of rooftop solar projects; three had experience in decision-making, policy, or financing; two had research experience; and one had relevant professional knowledge without direct project involvement.

### D. Construction of the Pairwise-Comparison Matrix

Each expert compared pairs of elements using the fundamental 1-9 AHP scale [18]. The scale and its interpretation are presented in Table 4.

Table 4. Fundamental AHP Scale for Pairwise Comparisons

| Value | Interpretation |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2, 4, 6, 8 | Intermediate values |

The pairwise-comparison matrix is expressed generally in Equation (1):

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & 1 \end{bmatrix} \quad (1)$$

The reciprocal property of the AHP matrix is expressed in Equation (2):

$$a_{ji} = \frac{1}{a_{ij}}, a_{ii} = 1 \quad (2)$$

**E. Aggregation of Expert Judgments**

Because multiple experts participated, the individual pairwise-comparison matrices were aggregated using the geometric mean. This approach preserves the ratio-scale and reciprocal properties of AHP judgments. The aggregated comparison value is calculated using Equation (3):

$$\overline{a_{ij}} = \left(\prod_{k=1}^{m} a_{ij}^{k}\right)^{1/m} \quad (3)$$

where $\overline{a}_{ij}$ denotes the aggregated group judgment comparing element $i$ with element $j$, $a_{ij}^{(k)}$ denotes the corresponding pairwise judgment provided by expert $k, k = 1, \dots, m$) denotes the total number of experts. In this study, $m = 10$, therefore (Equation 4):

$$\overline{a_{ij}} = \left(\prod_{k=1}^{m} a_{ij}^{k}\right)^{1/10} \quad (4)$$

Where $i$ is row element, $j$ is column element, $k$ is expert and $m$ is total expert

**F. Calculation of Priority Weights**

Priority weights were calculated using the row geometric mean method. The geometric mean for each row is calculated using Equation (5):

$$GM_i = \left(\prod_{j=1}^{n} \bar{a}_{ij}\right)^{\frac{1}{n}} \quad (5)$$

The row geometric means are then normalized to obtain the priority weights using Equation (6):

$$w_i = \frac{GM_i}{\sum_{n=1}^{n} GM_i} \quad (6)$$

where $GM_i$ denotes the geometric mean of row $i$, $n$ is the number of elements being compared, and $w_i$ denotes the normalized priority weight of element $i$. The vector $w = [w_1, w_2, \dots w_n]^T$ represents the complete priority-weight vector, with indicates a higher relative priority within the evaluated decision structure. The normalized weights satisfy the condition shown in Equation (7).

$$\sum_{n=1}^{n} w_i = 1 \quad (7)$$

A larger value of $w_i$ indicates a higher relative priority for the corresponding factor or strategic pathway.

**G. Consistency Assessment**

AHP requires an assessment of judgment consistency [8], [18]. After the priority weights are obtained, the comparison matrix A is multiplied by the priority-weight vector $w$, as shown in Equation (8).

$$A_w = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_m \end{bmatrix} \quad (8)$$

The maximum eigenvalue is then calculated using Equation (9):

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \quad (9)$$

where $\lambda_{max}$ is the maximum eigenvalue of the pairwise-comparison matrix and $n$ is the matrix order. The Consistency Index (CI) is calculated using Equation (10):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (10)$$

The Consistency Ratio (CR) is calculated using Equation (11):

$$CR = \frac{CI}{RI} \quad (11)$$

where $CI$ denotes the Consistency Index, $RI$ denotes the Random Index corresponding to matrix order $n$, and $CR$ denotes the Consistency Ratio.

For a 5 x 5 matrix, the Random Index (RI) is 1.12, as shown in Equation (12).

$$RI = 1.12 \quad (12)$$

The consistency-acceptance criterion is stated in Equation (13):

$$CR \leq 0.10 \quad (13)$$

A matrix is considered acceptably consistent when CR ≤ 0.10. If CR > 0.10, the judgments should be reviewed because the level of inconsistency is considered excessive.

## III. RESULTS AND DISCUSSION

### A. Priority Analysis of Rooftop Solar PV Adoption Factors

**Aggregate Factor Matrix**

The judgments of the 10 experts were aggregated using geometric means to obtain the group pairwise-comparison matrix for the five adoption factors:

$$A_c = \begin{bmatrix} 1.0000 & 0.5451 & 2.2587 & 3.000 & 1.8661 \\ 1.8346 & 1.0000 & 2.7339 & 3.7521 & 2.2587 \\ 0.4427 & 0.3658 & 1.0000 & 2.0828 & 0.9330 \\ 0.3333 & 0.2665 & 0.4801 & 1.0000 & 0.4427 \\ 0.5359 & 0.4427 & 1.0718 & 2.2587 & 1.0000 \end{bmatrix}$$

where C1 = Policy and Regulation, C2 = Economics and Financing, C3 = Technical and Infrastructure, C4 = Institutional and Market, and C5 = Organization and Perception. Normalization of the row geometric means yielded the following priority-weight vector:

$$w_c = \begin{bmatrix} 0.2568 \\ 0.3695 \\ 0.1385 \\ 0.0789 \\ 0.1562 \end{bmatrix}$$

As summarized in Table 5, Economics and Financing (C2) received the highest priority weight (36.95%), followed by Policy and Regulation (25.68%), Organization and Perception (15.62%), Technical and Infrastructure (13.85%), and Institutional and Market (7.89%). The maximum eigenvalue was subsequently calculated to assess the consistency of the aggregate matrix.

Table 5. Priority Weights of Rooftop Solar PV Adoption Factors

| Factor | Weight | Share (%) |
|---|---|---|
| Economics and Financing | 0.3695 | 36.95% |
| Policy and Regulation | 0.2568 | 25.68% |
| Organization and Perception | 0.1562 | 15.62% |
| Technical and Infrastructure | 0.1385 | 13.85% |
| Institutional and Market | 0.0789 | 7.89% |

**Consistency of the Factor Matrix**

The maximum eigenvalue obtained from the aggregate factor matrix was:

$$\lambda_{max} = 5.0445$$

Therefore:

$$CI = \frac{5.0445 - 5}{5 - 1}$$
$$CI = 0.0111$$

Using RI = 1.12:

$$CR = \frac{0.0111}{1.12}$$
$$CR = 0.0099$$

Because CR = 0.0099 < 0.10, the aggregate factor matrix satisfied the AHP consistency criterion.

**Economics and Financing as the Dominant Factor**

Economics and Financing received the highest weight (36.95%). Within the present expert panel, this result indicates that economic and financing considerations were perceived as the most important among the five evaluated factors influencing industrial rooftop solar PV adoption [27], [28].

The economic dimension encompasses upfront investment, expected electricity cost savings, payback period, financing costs, and access to alternative financing. Previous research has likewise emphasized the importance of economic performance in industrial rooftop PV projects [1], [29]. The experts' open-ended comments reinforced this result: several highlighted lending rates, the need for credit-guarantee facilities, and standardized power purchase agreement (PPA) contracts. These observations suggest that economic barriers extend beyond equipment and installation costs to include the allocation of financing risk and capital across project stakeholders.

Taken together, the expert assessments and supporting literature suggest that industrial rooftop solar PV can be viewed not only as a technology-selection decision but also as an investment decision involving financing costs, expected returns, and risk allocation [1], [29].

**Policy and Regulation**

Policy and Regulation received a weight of 25.68%, making it the second-highest-priority factor. Rooftop solar PV projects involve long investment horizons; therefore, regulatory certainty is important for credible financial projections. Uncertainty regarding interconnection rules, capacity quotas, permitting, or policy changes can increase perceived project risk [13], [15], [30].

The experts also emphasized the need for transparent interconnection quotas, harmonized regulations across agencies, and clear mechanisms for allocating rooftop solar PV capacity in industrial estates. These observations indicate that regulation is not merely an administrative requirement but an important determinant of investment certainty. This interpretation is consistent with previous studies showing that stakeholder perceptions of policy influence the acceptance of rooftop PV [15], [20].

**Organization and Perception**

Organization and Perception received a weight of 15.62% and ranked third. Corporate investment decisions regarding rooftop solar PV are not determined solely by financial metrics. Management understanding, sustainability commitments, environmental, social, and governance (ESG) considerations, perceptions of technological risk, and confidence in PV benefits all influence organizational readiness to invest [7], [14], [31]. These findings reinforce previous evidence that firms with stronger sustainability and emissions-reduction commitments are generally more receptive to rooftop solar PV [7], [32].

**Technical and Infrastructure**

Technical and Infrastructure received a weight of 13.85%. Although this weight was lower than those of Economics and

Financing and Policy and Regulation, technical considerations remain important because industrial facilities require reliable, high-quality electricity supply. Experts highlighted the structural adequacy of existing factory roofs, relay-protection readiness, integration with internal substations, production-equipment stability, the availability of inverter spare parts, and after-sales support [2], [5].

These findings indicate that successful implementation requires system designs tailored to the characteristics of individual facilities. Previous research has also shown that PV grid integration may create challenges related to power quality, voltage regulation, harmonics, and system stability [2], [33].

**Institutional and Market**

Institutional and Market received the lowest weight (7.89%). This lower weight should not be interpreted as evidence that institutional factors are unimportant; rather, it reflects their relative priority within the present decision structure. Rooftop solar PV implementation still requires coordination among government agencies, electricity providers, industrial firms, EPC contractors, financial institutions, industry associations, and academic institutions [9], [12]. Institutional and market conditions therefore function as a supporting ecosystem that enables economic, regulatory, and technical dimensions to operate effectively [9], [12].

**Concentration of Factor Priorities**

The two highest-ranked factors were Economics and Financing and Policy and Regulation. Their cumulative weight was:

$$W_{C1+C2} = 0.3695 + 0.2568 = 0.6263 = 62.63\%$$

Within the present decision structure, these two factors accounted for 62.63% of the total priority weight, this concentration indicates that the expert panel placed particular emphasis on economic-financing and policy-regulatory considerations. Together with evidence from previous studies, the result suggests that financially attractive projects and greater regulatory certainty are important areas for policy and managerial attention [13], [21].

## B. Consistency Assessment

**Aggregate Strategic-Pathway Matrix**

Aggregating the 10 experts' judgments on the five strategic pathways yielded the following pairwise-comparison matrix:

$$A_S = \begin{bmatrix} 1.0000 & 1.8131 & 2.6564 & 3.2704 & 3.4641 \\ 0.5515 & 1.0000 & 2.0828 & 2.7399 & 2.8471 \\ 0.3764 & 0.4801 & 1.0000 & 2.0000 & 2.0828 \\ 0.3058 & 0.3658 & 0.5000 & 1.0000 & 1.4142 \\ 0.2887 & 0.3512 & 0.4801 & 0.7071 & 1.0000 \end{bmatrix}$$

The row geometric means were:

$$GM_s = \begin{bmatrix} 2.2253 \\ 1.5498 \\ 0.9448 \\ 0.6020 \\ 0.5098 \end{bmatrix}$$

with a total geometric mean of:

$$\sum GM_i = 5.8317$$

Normalizing these values produced the following priority weights:

$$w_s = \begin{bmatrix} 0.3816 \\ 0.2658 \\ 0.1620 \\ 0.1032 \\ 0.0874 \end{bmatrix}$$

Table 6. Priority Weights of Strategic Pathways for Accelerating Rooftop Solar PV Adoption

| Strategic Pathway | Weight | Share (%) |
|---|---|---|
| Strengthening Policy and Regulation | 0.3816 | 38.16% |
| Innovative Financing Development | 0.2658 | 26.58% |
| Improved Technical and Infrastructure Readiness | 0.1620 | 16.20% |
| Institutional Strengthening and Collaboration | 0.1032 | 10.32% |
| Education and Industry Trust Enhancement | 0.0874 | 8.74% |

**Consistency of the Strategic-Pathway Matrix**

The consistency calculations produced:

$$\lambda_{max} = 5.0617$$

Therefore:

$$CI = \frac{5.0617 - 5}{5 - 1}$$
$$CI = 0.0154$$

Using RI = 1.12:

$$CR = \frac{0.0154}{1.12}$$
$$CR = 0.0138$$

Because CR = 0.0138 < 0.10, the aggregate strategic-pathway matrix satisfied the AHP consistency criterion.

**Strengthening Policy and Regulation as the Highest-Priority Strategy**

Strengthening Policy and Regulation received the highest strategic weight (38.16%). This result is noteworthy because Economics and Financing was the highest-ranked adoption factor, whereas Policy and Regulation was the highest-ranked strategic intervention. The distinction indicates that the factor assigned the highest priority by the expert panel is not necessarily identical to the strategic intervention that the same panel considers most important for improving adoption conditions. Conceptually, this relationship is illustrated in Figure 1.




Figure 1. Conceptual Pathway Linking Regulatory Certainty to Rooftop Solar PV Adoption

Thus, although Economics and Financing received the highest priority among the evaluated adoption factors, the expert panel assigned the highest strategic priority to regulatory strengthening. One possible interpretation, supported by the literature, is that a more stable and predictable policy environment can indirectly improve project economics by reducing policy risk, improving the credibility of project cash-flow expectations, clarifying interconnection procedures, and strengthening financial institutions' confidence in rooftop solar PV investments [13], [34].

**Innovative Financing Development**

Innovative Financing Development ranked second, with a weight of 26.58%. This pathway directly addresses the highest-ranked Economics and Financing factor. Financing arrangements such as power purchase agreements (PPAs), leasing, green loans, third-party ownership, and guarantee schemes can reduce firms' upfront capital requirements [23], [29]. Expert comments regarding PPA standardization and credit-guarantee facilities further suggest that financing innovation can accelerate adoption without requiring firms to purchase rooftop solar PV systems outright.

**Technical, Institutional, and Educational Strategies**

Improved Technical and Infrastructure Readiness received a weight of 16.20%. Expert recommendations included certification of PV technicians, technical guidelines for industrial interconnection testing, implementation of energy management systems (EMS), integration of battery energy storage systems (BESS), and procurement standards for PV modules and inverters.

Institutional Strengthening and Collaboration received a weight of 10.32%. This pathway can be advanced through stronger coordination among government agencies, electricity providers, industrial firms, EPC contractors, financial institutions, and industrial-estate managers [6], [7].

Education and Industry Trust Enhancement received a weight of 8.74%. Although it ranked last, this pathway remains important for improving managerial understanding, strengthening energy literacy, and disseminating evidence from successful rooftop solar PV projects [14], [35].

**Concentration of Strategic Priorities**

The combined weight of the two highest-ranked strategic pathways was:

$$W_{S1+S2} = 0.3816 + 0.2568 = 0.6474 = 64.74\%$$

Together, Strengthening Policy and Regulation and Innovative Financing Development accounted for 64.74% of the total strategic priority weight. This concentration indicates that the experts favored focused intervention in the regulatory and financing domains rather than an equal distribution of effort across all pathways.

### C. Three-Stage Strategic Pathway Model for Accelerating Adoption

Based on the priority weights, the proposed acceleration pathway was organized into three sequential stages, as illustrated in Figure 2.

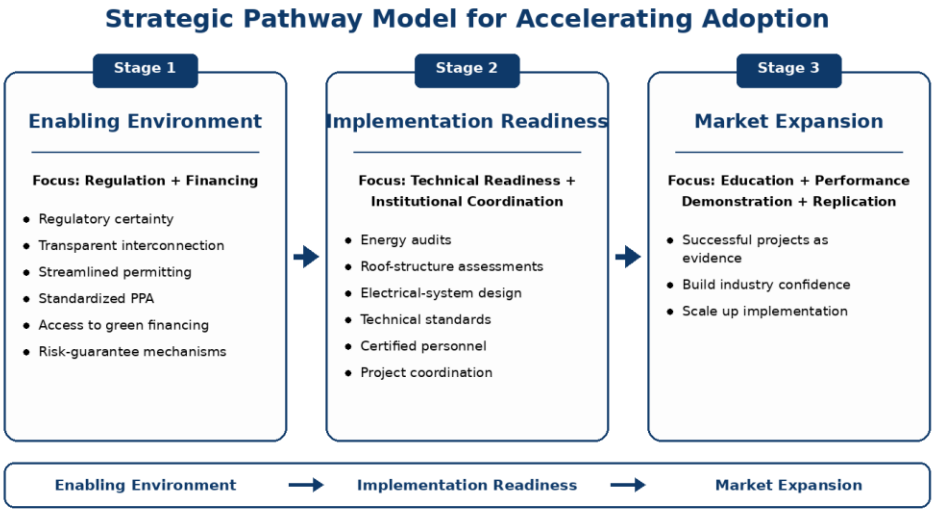


Figure 2. Three-Stage Strategic Pathway Model for Accelerating Rooftop Solar PV Adoption

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Figure 2 presents a three-stage strategic pathway for accelerating rooftop solar PV adoption in Indonesia's industrial sector. The first stage, Enabling Environment, focuses on establishing external conditions that support investment through regulatory strengthening and improved access to finance. Priorities include regulatory certainty, transparent interconnection procedures, streamlined permitting, standardized PPA arrangements, expanded access to green financing, and risk-guarantee mechanisms. This stage provides the foundation for subsequent implementation because greater policy certainty and easier access to financing can reduce investment risk and improve project feasibility.

The second stage, Implementation Readiness, focuses on strengthening technical preparedness and institutional coordination before projects are deployed at scale. Key activities include energy audits, roof-structure assessments, electrical-system design, technical standardization, access to certified personnel, and coordination among project stakeholders. These measures are intended to ensure that rooftop solar PV systems can be installed safely and reliably while remaining compatible with the operational requirements of industrial facilities.

The third stage, Market Expansion, emphasizes education, demonstration of project performance, and replication. Successful early projects can provide empirical evidence of technical and economic performance, thereby strengthening confidence among prospective adopters. Disseminating implementation experience, improving energy literacy, and replicating successful projects across additional facilities can support wider diffusion of rooftop solar PV in the industrial sector.

Within the proposed expert-informed framework, each stage is interpreted as creating enabling conditions for the subsequent stage. The three-stage sequence should therefore be viewed as a decision-support framework derived from the present expert priorities rather than as a universally prescribed implementation sequence for all industrial firms.

### D. Decision-Support and Information-System Implications

The Group-AHP framework developed in this study has implications beyond energy-policy prioritization because it provides a structured computational model for multi-criteria decision support. The framework transforms qualitative expert judgments into quantitative priority weights through a sequence of pairwise comparison, judgment aggregation, normalization, and consistency evaluation. This structure can be incorporated into a digital decision-support system in which policymakers, industrial energy managers, financing institutions, and PV project developers enter judgments and receive transparent rankings of adoption factors and intervention priorities.

Such an implementation could support scenario comparison, stakeholder-specific weighting, consistency monitoring, and periodic updating of priorities when regulatory, financing, or technical conditions change. The present study therefore provides the analytical foundation for a potential information-system application, although software development, user-interface design, database architecture, and system validation are beyond the scope of the current work.

## IV. CONCLUSION

This study prioritized the factors and strategic pathways for accelerating rooftop solar PV adoption in Indonesia's industrial sector using group AHP based on judgments from 10 experts.

Based on the aggregated judgments of the 10-expert panel, Economics and Financing received the highest priority among the evaluated adoption factors (36.95%), followed by Policy and Regulation (25.68%), Organization and Perception (15.62%), Technical and Infrastructure (13.85%), and Institutional and Market (7.89%). The two highest-ranked factors accounted for 62.63% of the total priority weight assigned by the panel, indicating a concentration of expert judgment on economic-financing and policy-regulatory considerations.

For the strategic pathways, the expert panel assigned the highest priority to Strengthening Policy and Regulation (38.16%), followed by Innovative Financing Development (26.58%), Improved Technical and Infrastructure Readiness (16.20%), Institutional Strengthening and Collaboration (10.32%), and Education and Industry Trust Enhancement (8.74%). The aggregate matrices were highly consistent, with CR = 0.0099 for the factor matrix and CR = 0.0138 for the strategic-pathway matrix, both below the 0.10 acceptance threshold.

The main contribution of this study is the distinction between the adoption factor assigned the highest priority and the strategic intervention assigned the highest priority by the expert panel. Economics and Financing received the highest relative priority among the evaluated adoption factors, whereas Strengthening Policy and Regulation received the highest priority among the strategic pathways. This pattern suggests, from the perspective of the participating experts, that regulatory strengthening may operate as an enabling mechanism through which investment risk, project uncertainty, bankability, and access to finance can be improved. Accordingly, the proposed three-stage pathway—Enabling Environment, Implementation Readiness, and Market Expansion—should be interpreted as an expert-informed decision-support framework rather than as a statistically generalizable sequence for all Indonesian industrial firms.

In addition to its policy and managerial relevance, the proposed Group-AHP structure can serve as the analytical foundation for a future digital decision-support system for industrial rooftop solar PV planning and prioritization.

## V. LIMITATIONS AND FUTURE RESEEARCH

Several limitations should be acknowledged. First, the study relied on a purposively selected panel of 10 experts; consequently, the findings represent structured expert judgment rather than population-level statistical estimates for all industrial firms in Indonesia. Second, the adoption factors

and strategic pathways were evaluated using two parallel AHP matrices; the study did not assess each strategic pathway conditionally under each factor. Third, the resulting weights are context-dependent and reflect the criteria structure used in this study. Future research could develop a full hierarchical AHP model in which each strategic alternative is evaluated under each factor, include a larger and more diverse expert panel, integrate AHP with methods such as ANP, DEMATEL, or fuzzy AHP, and combine decision analysis with techno-economic assessment in specific industrial case studies also operationalize the proposed framework in a web-based or enterprise decision-support system, integrate dynamic policy and techno-economic data, and evaluate system usability and decision quality across different industrial user groups.

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