

# Toward a Provincial Energy Trilemma Index (PETI): A Systematic Review and Framework for Subnational Energy System Assessment

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## Index Terms:

Energy Trilemma; Provincial Energy Trilemma Index; PETI; energy security; energy equity; environmental sustainability; subnational energy systems; sustainability transition

**Abstract.** The growing complexity of energy systems has increased the need for frameworks that can assess performance beyond traditional national indicators. While research on the Energy Trilemma is expanding, most studies focus on national and cross-country analyses, with limited attention given to the provincial and subnational energy systems where disparities in infrastructure, accessibility, and sustainability conditions are most often pronounced. This study fills that gap by creating a Provincial Energy Trilemma Index (PETI) framework. This framework allows for a localized assessment of energy security, energy equity, and environmental sustainability. Using the PRISMA systematic literature review approach, the study analyzed 67 peer-reviewed articles from the Scopus database related to Energy Trilemma assessments, sustainability transitions, composite energy indices, and decentralized energy systems. The review used thematic synthesis and indicator frequency analysis to identify common indicators, assessment methods, and operational assessment analysis relevant for provincial use. The findings highlighted the electrification rate, electricity affordability, renewable energy share, supply reliability, carbon emissions, and energy efficiency as the most common and applicable indicators for provinces. The review also showed that existing Energy Trilemma studies are methodologically fragmented and not well-localized, limiting its capacity to capture decentralized energy dynamics and spatial disparities across provinces and island systems. In response, the study suggests PETI as a multidimensional and provincially adaptable framework that combines well-founded and measurable indicators across the three main dimensions of the Energy Trilemma. The framework offers a basis for provincial benchmarking, sustainability monitoring, localized assessment and evidence-based energy planning within decentralized and diverse energy systems.

## Introduction

Energy systems around the world are changing quickly as governments seek secure, affordable, and environmentally sustainable energy options. This shift has made it more important to balance the three key aspects of the Energy Trilemma framework: energy security, energy equity, and environmental sustainability (Heffron et al., 2021; Singh et al., 2019). Energy security means having a reliable and stable energy supply. Energy equity deals with making energy services accessible and affordable. Environmental sustainability aims to reduce ecological impacts by using cleaner and more efficient energy systems (Khan et al., 2022; Shirazi, 2022). Together, these aspects provide a clear framework for assessing energy system performance and readiness for transition.

The growing global focus on decarbonization, renewable energy integration, and energy transition has made the Energy Trilemma framework even more relevant in policy and academic discussions. Several studies have looked at how countries balance affordability, sustainability, and energy reliability during economic development and climate commitments (Behera et al., 2024; Song et al., 2023; Yu et al., 2023). Existing research has also examined the links between energy trilemma performance and factors like economic growth, clean energy transitions, technological innovation, and effective policies (Kang, 2022; Lee & Yahya, 2024; Yang et al., 2024). These studies show that improving one aspect of the trilemma often impacts the others, making balanced energy planning more complex.

Despite the growing number of studies on the Energy Trilemma, most focus mainly on national-level assessments and comparisons between countries (Fu et al., 2022; Heffron et al., 2021; Shirazi, 2022). Common methods include creating national energy indices, analyzing energy performance with econometrics, and evaluating sustainability on a macro level. While these methods offer valuable insights into national energy systems, they often miss important variations in energy conditions, infrastructure, resource availability, and development priorities at the subnational level. Energy transition results are often influenced by local realities that differ across provinces, regions, and islands.

This issue is especially important in developing and archipelagic countries like the Philippines. There, energy systems show significant geographical and infrastructural differences. Provinces vary widely in electrification levels, renewable energy potential, grid connectivity, energy costs, frequency of outages, and reliance on imported fuels (Yap et al., 2021). Island and off-grid areas tend to face greater risks of energy insecurity and affordability issues due to logistical challenges, fragmented infrastructure, and limited generation capacity (Lacea et al., 2021; Lozano & Taboada, 2021). Meanwhile, many provinces have substantial renewable energy resources that could help enable localized sustainability transitions.

Recent studies in the Philippine context have examined rural electrification, distributed renewable energy systems, and island-based microgrids (Lacea et al., 2021; Salac et al., 2024). Other studies have assessed renewable energy portfolios and localized energy planning in island provinces such as Bohol (Pojudas & Abundo, 2021; Torrefranca et al., 2022). However, existing research remains fragmented and largely sector-specific, focusing mainly on technical feasibility, electrification strategies, or renewable integration. Limited studies have attempted to systematically measure and compare provincial energy performance using an integrated Energy Trilemma framework.

The absence of a localized and standardized assessment framework creates a significant gap in both policy and academic literature. Without a provincial-level energy assessment mechanism, policymakers may face difficulty identifying disparities in energy performance, prioritizing investments, monitoring transition outcomes, and designing evidence-based energy interventions. Moreover, national-level indices may obscure localized vulnerabilities and strengths that are critical for decentralized energy planning and regional sustainability strategies.

Addressing this gap requires the development of a subnational assessment framework capable of capturing provincial variations in energy security, energy equity, and environmental sustainability. A Provincial Energy Trilemma Index (PETI) may provide a systematic approach for evaluating and comparing energy performance across provinces using localized indicators and measurable dimensions. Such a framework can support evidence-based planning, strengthen energy policy analysis, and contribute to more targeted sustainability interventions at the provincial level.

This study therefore aims to develop a Provincial Energy Trilemma Index (PETI) for assessing subnational energy performance across the dimensions of energy security, energy equity, and environmental sustainability. Specifically, the study seeks to systematically identify indicators and methodological approaches used in Energy Trilemma assessment literature and synthesize an evidence-based framework suitable for provincial-level application. Through this approach, the study intends to contribute to the growing literature on energy sustainability assessment by localizing the Energy Trilemma framework for subnational and decentralized energy systems.

## Methodology

### *Data Sources and Search Strategy*

This study employed a systematic literature review (SLR) methodology to identify and synthesize scholarly literature relevant to the development of a Provincial Energy Trilemma Index (PETI). The review process was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework to ensure methodological transparency, rigor, and replicability (Page et al., 2021). The PRISMA framework guided the identification, screening, eligibility assessment, and final inclusion of studies relevant to Energy Trilemma assessment, energy sustainability measurement, and subnational energy performance analysis. The literature search primarily utilized the Scopus database due to its extensive coverage of peer-reviewed journals across the fields of energy, sustainability, environmental science, economics, and public policy. Scopus was selected because of its strong indexing standards and its relevance to multidisciplinary energy transition research. The search strategy was developed iteratively through preliminary exploratory searches to identify appropriate terminology and relevant subject areas associated with Energy Trilemma assessment and energy sustainability evaluation.

Boolean operators and keyword combinations were used to improve search precision and comprehensiveness. The primary search string employed in the review was: (“energy trilemma” OR “energy sustainability”) AND (index OR indicator OR assessment OR measurement) AND (subnational OR provincial OR regional OR local OR decentralized). Additional search terms included “energy security,” “energy equity,” “energy affordability,” “energy poverty,” “renewable energy,” “energy transition,” and “sustainability assessment.” The review was limited to peer-reviewed journal articles written in English and published between 2015 and 2026 to ensure contemporary relevance and consistency with recent developments in sustainable energy transition research. The initial database search yielded 181 records from Scopus. Duplicate records were subsequently identified and removed through manual screening of titles, authors, publication years, and digital object identifiers (DOIs). Following duplicate removal, the remaining studies underwent title and abstract screening based on predefined inclusion and exclusion criteria. The PRISMA diagram in Figure 1 below provides a visual representation of the selection process.

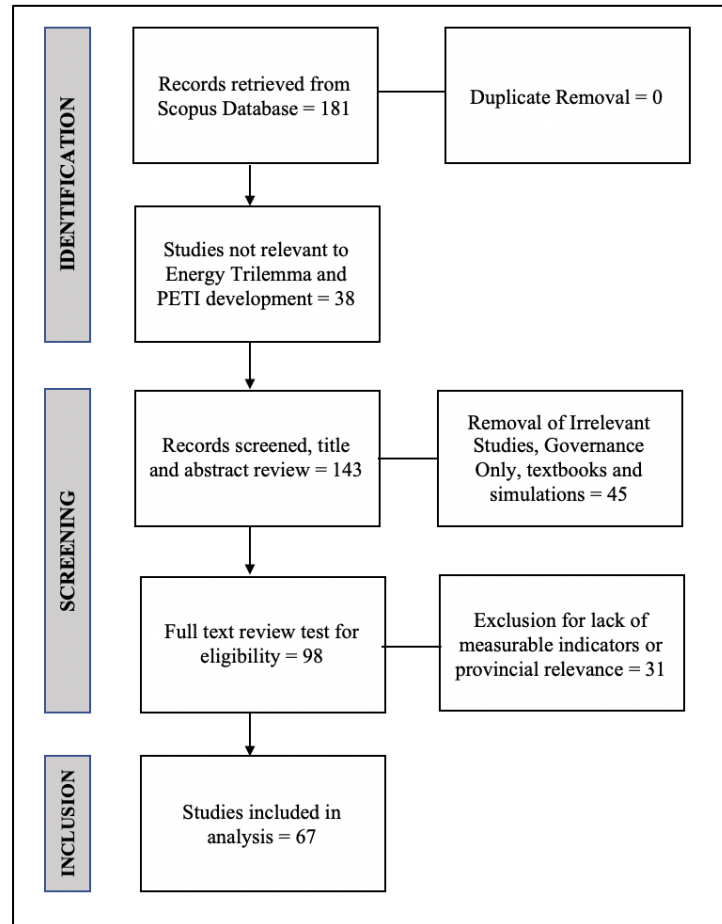


Figure 1. PRISMA Diagram Selection Process

Studies were included if they discussed Energy Trilemma dimensions, energy sustainability assessment, energy performance measurement, or index development methodologies and contained measurable indicators related to energy security, energy equity, or environmental sustainability. Studies focusing exclusively on methodological textbooks, governance discussions without measurable energy indicators, highly technical optimization simulations without broader assessment implications, and non-peer-reviewed publications were excluded from the review. The remaining eligible studies underwent full-text assessment to determine their conceptual relevance, methodological applicability, and suitability for indicator extraction. Final included studies formed the evidence base for the development of the Provincial Energy Trilemma Index (PETI).

### *Method of Analysis*

The study employed thematic synthesis, document analysis, and comparative indicator analysis to systematically examine the selected literature. Thematic synthesis was utilized to identify recurring concepts, dimensions, indicators, and methodological approaches associated with Energy Trilemma assessment. This approach enabled the identification of common patterns and relationships across studies while supporting the development of a localized subnational energy assessment framework.

Document analysis was conducted to extract key information from the included studies, including research objectives, methodologies, Energy Trilemma dimensions, index construction techniques, weighting approaches, normalization procedures, and energy performance indicators. Extracted data were systematically organized using a structured literature extraction matrix to facilitate comparison and synthesis. The analysis focused on the three core dimensions of the Energy Trilemma framework: energy security, energy equity, and environmental sustainability. Indicators appearing consistently across multiple studies were identified as potential candidates for inclusion in the Provincial Energy Trilemma Index (PETI). Comparative analysis was further conducted to assess the applicability of identified indicators to provincial and subnational energy systems. Descriptive synthesis techniques were also employed to determine the frequency and recurrence of indicators and methodological approaches across the reviewed studies. This process supported the identification of dominant indicators and commonly applied index construction methodologies within Energy Trilemma literature.

### *Indicator Set and Codebook*

The study operationalized provincial energy performance using the three core dimensions of the Energy Trilemma framework: (1) energy security, (2) energy equity, and (3) environmental sustainability. A preliminary indicator codebook was developed to organize and classify the indicators extracted from the reviewed studies. The codebook provided detailed definitions for each indicator, including units of measurement, conceptual descriptions, extraction procedures, and potential provincial-level data sources. Indicators under the energy security dimension included measures associated with electricity reliability, electrification access, reserve capacity, diversification of energy sources, and energy supply stability. Energy equity indicators focused on affordability, accessibility, household energy burden, and energy poverty considerations. Environmental sustainability indicators included renewable energy share, carbon emissions, energy efficiency, and clean energy adoption metrics. The inclusion of indicators in the preliminary PETI framework was guided by four primary considerations: theoretical relevance, frequency of occurrence in literature, measurability, and applicability to provincial-level assessment. Indicators lacking sufficient conceptual clarity or provincial data applicability were excluded from the proposed framework.

### *Indicator Frequency and Relevance Analysis*

Indicator frequency analysis was conducted to identify the most consistently utilized indicators across the reviewed literature. The frequency of occurrence of each indicator was examined to determine its prominence and conceptual significance within Energy Trilemma assessment studies. Indicators repeatedly appearing across multiple studies were considered to possess stronger empirical support and greater relevance for inclusion in the Provincial Energy Trilemma Index. Relevance analysis was likewise conducted to evaluate the suitability of identified indicators for provincial-level assessment. Particular attention was given to indicators that could be operationalized using publicly accessible provincial data sources and those capable of capturing localized variations in energy performance. This process ensured that the proposed PETI framework remained both theoretically grounded and practically implementable.

### *Development of the Provincial Energy Trilemma Index (PETI)*

The development of the Provincial Energy Trilemma Index (PETI) was guided by the synthesized findings of the systematic literature review. The proposed framework integrates indicators across the dimensions of energy security, energy equity, and environmental sustainability to assess and compare provincial energy performance. The resulting framework is intended to provide a localized and systematic approach for assessing subnational energy performance and identifying disparities across provincial energy systems.

## **Results and Discussion**

The literature revealed several important trends in contemporary Energy Trilemma research. Publication frequency increased substantially after 2020, reflecting intensified global attention toward energy transition, decarbonization, renewable energy integration, and sustainability-oriented energy planning. The reviewed studies were geographically

diverse, although a strong concentration originated from Asia and Europe, particularly within emerging economies and rapidly transitioning energy systems. Quantitative methodologies dominated the reviewed studies, particularly composite index construction, econometric analysis, entropy weighting, and spatial analysis approaches. This methodological pattern reflects the increasing preference for empirical and multidimensional approaches in sustainability assessment and energy system evaluation.

Category	Subcategory	Frequency	Percentage (%)	Description
Publication Period	2015–2017	8	11.94	Early conceptual and sustainability-oriented Energy Trilemma studies
	2018–2020	16	23.88	Expansion of renewable transition and sustainability assessment literature
	2021–2023	27	40.3	Rapid increase in Energy Trilemma and transition measurement studies
	2024–2026	16	23.88	Emerging emphasis on localized and subnational energy assessment
Methodological Approach	Quantitative	49	73.13	Econometric analysis, composite indices, spatial models, and optimization approaches
	Qualitative	8	11.94	Policy and governance-oriented sustainability assessment
	Mixed Methods	10	14.93	Integrated policy and quantitative evaluation
Study Focus	Energy Trilemma Assessment	24	35.82	Direct assessment of energy security, equity, and sustainability
	Energy Index Construction	15	22.39	Composite indicator and weighting methodologies
	Subnational / Localized Systems	14	20.90	Provincial, island, and decentralized energy systems
	Sustainability Transition	14	20.90	Renewable energy and decarbonization transition studies

Table 1. Descriptive Characteristics of Included Studies

The increasing publication trend after 2020 reflects the growing academic and policy relevance of Energy Trilemma assessment within global sustainability discourse. This growth coincides with intensified climate commitments, renewable energy expansion, and heightened concerns regarding energy resilience amid economic and geopolitical disruptions. This suggests that the Energy Trilemma has evolved into a significant analytical framework for evaluating sustainable energy transitions. The dominance of quantitative methodologies, particularly composite index construction, further indicates strong scholarly preference for multidimensional assessment models capable of integrating energy security, equity, and sustainability into unified performance measures.

This supports the conceptual foundation of PETI as a composite provincial assessment framework. Another gap in existing literature is the limited number of subnational and localized studies. Despite increasing recognition of decentralized energy systems and localized sustainability planning, most research remains concentrated on national or cross-country analyses. However, the emergence of localized and island-focused studies after 2020 demonstrates growing awareness that energy transition outcomes are shaped by local infrastructure conditions, geographical fragmentation, electrification disparities, and renewable resource availability. These findings provide strong conceptual justification for localizing Energy Trilemma assessment through PETI within the Philippine context.

#### Thematic Classification

The studies were classified into four major thematic clusters according to their primary focus and contribution to Energy Trilemma assessment and PETI framework development.

Theme	Description	Representative Studies	Relevance to PETI	References
Energy Trilemma Assessment	Evaluation of energy security, equity, and sustainability performance	Heffron et al. (2021); Shirazi (2022); Fu et al. (2022)	Establishes core PETI dimensions	Heffron et al. (2021); Singh et al. (2019); Khan et al. (2022); Shirazi (2022)

Theme	Description	Representative Studies	Relevance to PETI	References
Energy Index Construction	Composite index methodologies and weighting approaches	Wu et al. (2024); Wang et al. (2023)	Supports PETI methodological framework	Wu et al. (2024); Wang et al. (2023); Patro et al. (2025); Davtyan et al. (2023)
Subnational Energy Systems	Provincial, regional, and island energy assessment	Yap et al. (2021); Jing et al. (2020)	Supports localization and provincial applicability	Jing et al. (2020); Yap et al. (2021); Lacea et al. (2021); Zhao et al. (2024)
Sustainability Transition	Renewable energy integration and decarbonization pathways	Gielen et al. (2019); Yang et al. (2024)	Supports sustainability dimension development	Gielen et al. (2019); Yang et al. (2024); Behera et al. (2024); Kilinc-Ata & Proskuryakova (2024)

Table 2. Thematic Clusters of Studies Included

The thematic clustering reveals the multidisciplinary nature of Energy Trilemma literature and the growing convergence between sustainability assessment, energy transition analysis, and composite index methodologies. The dominance of Energy Trilemma assessment studies shows that balancing energy security, affordability, and environmental sustainability has become a central concern in contemporary energy policy research. At the same time, the strong emphasis on composite energy sustainability indices reflects increasing scholarly preference for integrated frameworks capable of synthesizing multiple indicators into unified performance measures. However, methodological inconsistencies in weighting procedures, normalization methods, and indicator selection remain evident across studies, reinforcing the need for a transparent and provincially adaptable PETI framework.

The localized energy systems and sustainability transition clusters further strengthen the rationale for localized Energy Trilemma assessment. These studies demonstrate that energy transition outcomes are spatially uneven and heavily influenced by infrastructure conditions, resource availability, and geographical fragmentation, thereby challenging the adequacy of purely national-level indices. Furthermore, recent literature increasingly positions sustainability not only as a measure of current environmental performance but also as an indicator of long-term transition capacity and resilience, particularly through renewable energy integration and decarbonization efforts.

#### Indicator Frequency and Relevance Analysis

Indicator frequency analysis identified recurring indicators consistently utilized across Energy Trilemma studies. These indicators were categorized according to the three core dimensions of energy security, energy equity, and environmental sustainability. Indicators with higher recurrence frequencies were interpreted as possessing stronger conceptual consensus and empirical support within existing literature. The review further examined the provincial applicability and measurability of identified indicators to determine their suitability for localized Energy Trilemma assessment.

Indicator	Frequency	Percentage of Included Studies (%)	Theoretical Relevance	Provincial Data Availability	PETI Applicability	References
Electrification Rate	41	61.19	Measures infrastructure accessibility and supply inclusion	High	Strong	Heffron et al. (2021); Jing et al. (2020); Yap et al. (2021)
Energy Diversification	34	50.75	Reduces vulnerability to supply disruptions	Moderate	Strong	Singh et al. (2019); Wei et al. (2025); Fu et al. (2022)
Supply Reliability	31	46.27	Reflects system stability and reliability	Moderate	Strong	Khan et al. (2022); Jing et al. (2020);

Indicator	Frequency	Percentage of Included Studies (%)	Theoretical Relevance	Provincial Data Availability	PETI Applicability	References
Reserve Capacity	24	35.82	Indicates supply adequacy and resilience	Limited	Moderate	Zhao et al. (2024); Shirazi (2022); Fu et al. (2022)
Import Dependency	22	32.84	Measures exposure to external supply shocks	Moderate	Moderate	Heffron et al. (2021); Wei et al. (2025)

Table 3. Frequency and Relevance of Energy Security Indicators

Table 3 reveals that electrification rate is the most dominant energy security indicator within existing Energy Trilemma literature. Its recurrence across a majority of reviewed studies reflects broad scholarly consensus regarding the central role of electricity access in evaluating energy security and infrastructure inclusion, particularly within developing and geographically fragmented regions.

The strong presence of energy diversification and supply reliability indicators further demonstrates the increasingly multidimensional conceptualization of energy security, extending beyond mere supply availability toward resilience, redundancy, and system adaptability. The studies also emphasize that diversified energy portfolios enhance long-term stability by reducing dependence on single energy sources and mitigating vulnerability to price volatility and external supply disruptions, while supply reliability indicators capture the operational performance and continuity of energy systems, especially within island and decentralized contexts. Although reserve capacity and import dependency remain conceptually relevant within Energy Trilemma assessment, their relatively lower recurrence may reflect difficulties in localized operationalization and limitations in subnational data availability. In contrast, highly recurrent indicators such as electrification rate, supply reliability, and energy diversification demonstrate strong provincial applicability due to the availability of measurable datasets from institutions such as the and These findings reinforce the argument that provincial energy security conditions cannot be adequately represented through national-level indicators alone, as infrastructure quality, service reliability, and electrification disparities vary substantially across provinces and island systems, thereby strengthening the justification for localized assessment frameworks such as PETI.

Indicator	Frequency	Percentage of Included Studies (%)	Theoretical Relevance	Provincial Data Availability	PETI Applicability	References
Electricity Affordability	39	58.21	Measures equitable access to electricity services	High	Strong	Khan et al. (2022); Fu et al. (2022); Song et al. (2023)
Energy Access	35	52.24	Reflects inclusiveness of electricity provision	High	Strong	Heffron et al. (2021); Yap et al. (2021)
Household Energy Burden	27	40.3	Captures affordability pressure on households	Moderate	Strong	Song et al. (2023); Zhao et al. (2024)
Energy Poverty	21	31.34	Indicates deprivation in energy access	Moderate	Moderate	Shirazi (2022); Khan et al. (2022)
Rural Electrification	18	26.87	Measures inclusion of remote communities	High	Strong	Lacea et al. (2021); Yap et al. (2021)

Table 4. Frequency and Relevance of Energy Equity Indicators

The analysis shows that electricity affordability remains one of the most dominant indicators within the energy equity dimension of Energy Trilemma literature. Its strong recurrence across reviewed studies reflects increasing scholarly recognition that sustainable energy transitions must remain socially inclusive and economically accessible, particularly within developing economies where rising electricity costs may intensify household vulnerability and energy exclusion.

Energy access likewise emerged as a highly recurrent indicator, reinforcing the close conceptual relationship between energy equity and inclusiveness.

The studies consistently emphasize that sustainable energy systems should ensure equitable access to reliable and modern energy services alongside infrastructure resilience and environmental sustainability. In addition, the growing use of household energy burden indicators demonstrates a broader shift toward socially grounded sustainability assessment, wherein scholars increasingly evaluate the proportion of household income allocated to energy expenditures as a measure of affordability-related vulnerability and localized energy inequality.

Although energy poverty indicators remain moderately represented, their lower recurrence may be attributed to methodological inconsistencies in operational definitions and measurement thresholds across studies. Meanwhile, the inclusion of rural electrification indicators is particularly relevant within the Philippine and island context, where geographically isolated communities often experience lower electrification coverage, weaker infrastructure conditions, and higher electricity costs relative to urban centers.

The findings strengthen the suitability of affordability, access, household burden, and rural inclusion indicators for integration within the proposed PETI framework and reinforce the importance of localized Energy Trilemma assessment in capturing spatial disparities and inequities in energy provision.

Indicator	Frequency	Percentage of Included Studies (%)	Theoretical Relevance	Provincial Data Availability	PETI Applicability	Key Supporting References
Renewable Energy Share	46	68.66	Indicates sustainability transition performance	High	Strong	Heffron et al. (2021); Shirazi (2022); Yang et al. (2024)
Carbon Emissions	38	56.72	Measures environmental impact of energy systems	Moderate	Moderate	Song et al. (2023); Gielen et al. (2019)
Energy Efficiency	29	43.28	Reflects efficient energy utilization	Moderate	Strong	Fu et al. (2022); Yang et al. (2024)
Energy Intensity	24	35.82	Measures energy consumption relative to output	Moderate	Moderate	Davtyan et al. (2023); Wu et al. (2024)
Clean Energy Adoption	20	29.85	Indicates low-carbon transition capacity	Moderate	Moderate	Behera et al. (2024); Kilinc-Ata & Proskuryakova (2024)

Table 5. Frequency and Relevance of Environmental Sustainability Indicators

Table 5 suggests that renewable energy share constitutes the most dominant environmental sustainability indicator within existing Energy Trilemma literature, appearing across a substantial proportion of reviewed studies. This high recurrence reflects strong conceptual convergence regarding the centrality of renewable energy transition in advancing long-term sustainability, resilience, and decarbonization objectives. Contemporary literature increasingly positions renewable energy deployment as a strategic mechanism for reducing fossil fuel dependence, mitigating carbon emissions, and enhancing adaptive energy system capacity. The prominence of renewable energy indicators further illustrates the growing integration of global climate mitigation agendas and low-carbon transition frameworks within Energy Trilemma research, particularly through the linkage between sustainability transition, energy diversification, and long-term system resilience.

In addition, the utilization of carbon emissions, energy efficiency, and energy intensity indicators further indicates that environmental sustainability assessment has evolved beyond conventional environmental performance measurement toward broader transition-oriented evaluation. Existing studies increasingly emphasize efficient resource utilization, consumption optimization, and productivity improvement as essential dimensions of sustainable energy systems. Nevertheless, the findings also reveal methodological and operational limitations associated with localized sustainability assessment, particularly in relation to emissions-related indicators, due to fragmented provincial inventories and inconsistent subnational reporting mechanisms within decentralized and island-based contexts. Meanwhile, the comparatively lower recurrence of clean energy adoption indicators may reflect the emerging and evolving nature of low-carbon technology diffusion, as well as limited availability of localized technological adoption datasets.

Thus, environmental sustainability within Energy Trilemma literature is increasingly conceptualized in terms of transition capacity, adaptive resilience, and long-term sustainability transformation, thereby providing strong analytical justification for the inclusion of renewable energy, efficiency, and emissions-related indicators within the proposed PETI framework.

#### *Cross-Dimensional Interactions within the Energy Trilemma*

The literature revealed that the three dimensions of the Energy Trilemma, energy security, energy equity, and environmental sustainability, are highly interconnected and characterized by complex trade-offs and reinforcing relationships (Heffron et al., 2021; Shirazi, 2022; Singh et al., 2019). The studies consistently emphasize that improvements in one dimension may simultaneously generate positive or negative implications for other dimensions depending on infrastructure readiness, policy design, and local energy conditions. Several studies also observed that renewable energy expansion may strengthen environmental sustainability while improving long-term energy security through diversification of energy sources and reduced fossil fuel dependence (Gielen et al., 2019; Yang et al., 2024). However, renewable integration may also create affordability pressures when infrastructure and transition costs are transferred to consumers through increased electricity rates (Heffron et al., 2021; Khan et al., 2022). Similarly, aggressive decarbonization initiatives may improve sustainability outcomes while potentially affecting supply reliability in regions with limited grid flexibility and reserve capacity (Shirazi, 2022).

The literature further suggests that energy equity frequently intersects with infrastructure and sustainability objectives. Expanding electrification and energy access may improve social inclusion and developmental outcomes, particularly in rural and island communities, yet such expansion often requires substantial infrastructure investments and operational support (Lacea et al., 2021; Yap et al., 2021). These findings demonstrate that Energy Trilemma dimensions should not be treated as isolated policy domains but rather as interconnected components of broader energy system performance. Moreover, localized conditions significantly influence the nature and intensity of Energy Trilemma trade-offs. Provinces with stronger renewable resource potential, more reliable infrastructure, and higher institutional capacity are more likely to achieve balanced Energy Trilemma performance compared to geographically isolated and infrastructure-constrained regions (Jing et al., 2020; Zhao et al., 2024). Consequently, provincial-level assessment becomes essential for identifying localized transition opportunities, vulnerabilities, and sustainability disparities that may not be captured through national-level analyses.

#### *Indicator Selection Criteria for PETI Development*

The inclusion of indicators within the proposed PETI framework was guided by a structured and evidence-based selection process emphasizing theoretical consistency, empirical support, provincial applicability, and operational feasibility. Although numerous indicators were identified within the reviewed literature, not all indicators were considered suitable for localized and provincial-level assessment.

Criterion	Description	Importance to PETI Development	Supporting Literature
Theoretical Relevance	Alignment with Energy Trilemma dimensions	Ensures conceptual consistency	Heffron et al. (2021); Singh et al. (2019)
Frequency in Literature	Recurrence across reviewed studies	Strengthens empirical support	Fu et al. (2022); Shirazi (2022)
Provincial Measurability	Availability of provincial-level data	Supports operational feasibility	Yap et al. (2021); Lacea et al. (2021)
Comparability	Consistency across provinces	Enables benchmarking and ranking	Wu et al. (2024); Wang et al. (2023)

Policy Relevance	Applicability to energy planning and sustainability policy	Enhances practical utility	Khan et al. (2022); Song et al. (2023)
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Table 6. Criteria for PETI Indicator Inclusion

The indicator selection criteria in Table 6 reflect the study’s effort to balance conceptual rigor with operational feasibility. Although existing Energy Trilemma literature presents numerous theoretically relevant indicators, many remain difficult to operationalize at the provincial level due to fragmented reporting systems, inconsistent datasets, and limited subnational data availability. Consequently, the selection process prioritized indicators that are conceptually grounded, empirically recurrent, provincially measurable, and suitable for comparative assessment. Theoretical relevance was emphasized to ensure alignment with the core dimensions of energy security, energy equity, and environmental sustainability, thereby strengthening the conceptual coherence of PETI and minimizing overlap across dimensions. Frequency in the literature was likewise considered important because recurring indicators generally reflect stronger methodological legitimacy and scholarly consensus. However, indicator inclusion was not based solely on recurrence, as indicators were further evaluated according to their suitability for localized operationalization and provincial benchmarking.

Provincial measurability emerged as a critical consideration within the selection process. PETI therefore prioritizes indicators that can realistically be measured using publicly accessible and replicable provincial datasets. Comparability across provinces was also emphasized to support transparent benchmarking and cross-provincial evaluation, leading to the prioritization of standardized and consistently measurable indicators.

Finally, policy relevance was incorporated to strengthen the practical utility of PETI beyond academic assessment. The framework is intended to support evidence-based provincial energy planning, sustainability monitoring, renewable energy integration, and localized transition assessment. Consequently, indicators lacking clear policy applicability were assigned lower priority within the final selection process.

*Proposed Provincial Energy Trilemma Index (PETI) Framework*

Based on the synthesis of the reviewed literature, the study proposes a Provincial Energy Trilemma Index (PETI) structured around the three core dimensions of:

- energy security,
- energy equity,
- and environmental sustainability.

The proposed framework prioritizes indicators demonstrating strong theoretical grounding, high recurrence within existing Energy Trilemma literature, provincial measurability, and policy relevance. The resulting structure is intended to provide a localized and systematic framework capable of evaluating provincial energy performance across diverse energy system conditions. Unlike existing national-level Energy Trilemma indices, PETI emphasizes localized energy realities and provincial disparities. The framework therefore seeks to operationalize Energy Trilemma assessment within decentralized and geographically heterogeneous contexts, particularly relevant to developing and archipelagic countries such as the Philippines.

Dimension	Indicator	Operational Definition	Unit of Measurement	Rationale	Potential Provincial Data Source	Key Supporting References
Energy Security	Electrification Rate	Proportion of households with electricity access	% of households	Measures accessibility and infrastructure reach	Department of Energy (DOE) / Philippine Statistics Authority (PSA)	Heffron et al. (2021); Yap et al. (2021)
Energy Security	Supply Reliability	Frequency and duration of outages	System Average Interruption Frequency Index (SAIFI) / System Average Interruption	Reflects stability of electricity supply	National Electrification Administration (NEA) / Distribution Utilities	Jing et al. (2020); Zhao et al. (2024)

Dimension	Indicator	Operational Definition	Unit of Measurement	Rationale	Potential Provincial Data Source	Key Supporting References
			Duration Index (SAIDI)			
Energy Security	Energy Diversification	Diversity of generation sources	Diversity Index	Reduces vulnerability to single-source dependence	DOE	Singh et al. (2019); Wei et al. (2025)
Energy Equity	Electricity Affordability	Household electricity expenditure burden	% of household income	Captures affordability and equitable access	Energy Regulatory Commission / PSA	Khan et al. (2022); Song et al. (2023)
Energy Equity	Energy Access	Population with access to electricity services	% population served	Measures inclusiveness of energy provision	DOE	Heffron et al. (2021); Fu et al. (2022)
Energy Equity	Rural Electrification	Electrification coverage in rural communities	% barangays electrified	Reflects rural energy inclusion	NEA	Lacea et al. (2021); Yap et al. (2021)
Environmental Sustainability	Renewable Energy Share	Share of renewable energy in provincial energy mix	% generation	Indicates sustainability transition capacity	DOE	Shirazi (2022); Yang et al. (2024)
Environmental Sustainability	Carbon Emissions	Emissions associated with provincial energy systems	Tons CO <sub>2</sub>	Measures environmental impact	Department of Environment and Natural Resources (DENR) / DOE	Gielen et al. (2019); Song et al. (2023)
Environmental Sustainability	Energy Efficiency	Energy use relative to economic output	Energy Intensity Ratio	Reflects efficient energy utilization	DOE / PSA	Fu et al. (2022); Davtyan et al. (2023)

Table 7. Proposed Operational Framework for the Provincial Energy Trilemma Index (PETI)

The proposed PETI framework operationalizes the Energy Trilemma within a provincial and subnational context by integrating infrastructural, socio-economic, and environmental dimensions into a unified assessment structure. In contrast to existing national-level Energy Trilemma indices, PETI emphasizes localized energy realities and provincial disparities, addressing the limited availability of subnational and provincially adaptable Energy Trilemma frameworks identified in the literature. The inclusion of electrification rate and supply reliability indicators reflects the continuing importance of infrastructure accessibility and system resilience within provincial energy systems. While national electrification statistics often suggest broad energy access, localized disparities in service quality, reliability, and infrastructure stability remain significant, particularly across remote and island provinces. The integration of reliability indicators therefore extends assessment beyond basic connectivity by capturing operational performance and energy system resilience.

Energy diversification was incorporated because diversified energy portfolios enhance adaptive capacity and reduce vulnerability to supply disruptions, fuel price volatility, and external dependency. This is particularly relevant within decentralized and island systems where dependence on imported fuels and isolated generation systems remains substantial. Diversification also strengthens long-term transition capacity by supporting renewable energy integration and reducing structural reliance on conventional energy sources. Within the energy equity dimension, affordability and accessibility indicators capture the socio-economic dimensions of energy sustainability. The framework recognizes that electrification alone does not necessarily translate into equitable energy access when electricity costs remain financially burdensome or unevenly distributed across communities. The inclusion of affordability and rural electrification indicators therefore strengthens PETI's capacity to evaluate social inclusiveness, energy vulnerability, and spatial inequality within provincial energy systems.

The environmental sustainability dimension prioritizes renewable energy share, carbon emissions, and energy efficiency as core indicators of sustainability transition performance. Renewable energy share emerged as the most recurrent indicator across reviewed studies, highlighting its central role in decarbonization and long-term energy resilience. Meanwhile, energy efficiency indicators emphasize that sustainability transitions require not only cleaner energy sources but also improvements in resource utilization and system productivity. Although carbon emissions remain important for assessing environmental impact, the review also revealed potential limitations in localized emissions reporting, indicating the need for methodological flexibility in provincial application. Overall, the PETI framework contributes conceptually and methodologically to existing Energy Trilemma scholarship by localizing multidimensional energy sustainability assessment for provincial application. By integrating measurable and policy-relevant indicators across the three core dimensions, the framework establishes a systematic foundation for provincial benchmarking, sustainability monitoring, and localized energy transition analysis.

#### *Provincial Operational Challenges and Framework Limitations*

The review identified several operational and methodological challenges associated with provincial-level Energy Trilemma assessment. Although localized assessment provides important analytical and policy advantages, implementation at the provincial level remains constrained by fragmented datasets, inconsistent reporting systems, and varying institutional capacities (Jing et al., 2020; Yap et al., 2021). One of the major limitations involves the availability and standardization of provincial energy data. Subnational energy information is often dispersed across multiple institutions, including energy agencies, distribution utilities, local government units, and electrification administrations. As a result, provincial datasets may remain incomplete, inconsistently updated, or difficult to harmonize for comparative assessment. Similar challenges also apply to localized carbon emissions measurement, where provincial emissions inventories are not always systematically reported, potentially requiring the use of estimation procedures or proxy indicators (Shirazi, 2022).

The review further revealed that decentralized and island systems frequently exhibit operational conditions not fully reflected in national-level statistics. Provinces may differ substantially in terms of infrastructure quality, renewable resource availability, grid interconnectivity, fuel dependence, and electrification conditions, thereby complicating direct comparability across regions (Lacea et al., 2021; Pojadas & Abundo, 2021). These variations highlight the need for contextual interpretation when applying PETI within geographically heterogeneous environments. Institutional capacity also emerged as an important operational consideration. Provinces with stronger planning systems, technical expertise, and energy infrastructure may possess more reliable monitoring and reporting mechanisms than less developed regions. Consequently, implementation of PETI may require phased adaptation, methodological flexibility, and capacity-building support to ensure consistency and reliability across provincial applications.

Despite these limitations, this paper indicates that sufficient indicators and publicly accessible datasets exist to support the development of a localized Energy Trilemma framework. Rather than undermining the feasibility of PETI, these challenges emphasize the importance of methodological transparency, adaptive implementation strategies, and continued improvement in provincial energy data systems.

#### *Research Gaps, Theoretical Contribution, and Methodological Contribution*

This review identified several major gaps within existing Energy Trilemma literature. Most reviewed studies remain concentrated at the national or cross-country level, limiting the ability to capture localized disparities and decentralized energy conditions. Relatively few studies operationalize integrated Energy Trilemma assessment frameworks suitable for provincial or island systems. This also revealed substantial methodological inconsistency across existing studies, particularly in relation to indicator selection, weighting procedures, normalization methods, and aggregation techniques. These inconsistencies reduce comparability across studies and highlight the absence of standardized localized assessment frameworks.

Identified Literature Gap	Evidence from Reviewed Literature	Proposed PETI Contribution	Supporting References
National-level dominance	Majority of studies focus on cross-country comparisons	Provincial-level Energy Trilemma assessment	Heffron et al. (2021); Fu et al. (2022)
Limited subnational frameworks	Few studies operationalize localized systems	PETI localized framework	Jing et al. (2020); Zhao et al. (2024)

Weak representation of island systems	Limited Philippine and decentralized energy studies	Provincial and island applicability	Yap et al. (2021); Lacea et al. (2021)
Methodological inconsistency	Variation in indicators and weighting methods	Structured and transparent PETI framework	Wang et al. (2023); Wu et al. (2024)
Limited provincial operationalization	Absence of measurable localized indicators	Provincially adaptable indicator system	Khan et al. (2022); Shirazi (2022)

Table 8. Identified Research Gaps and PETI Contributions

### Contributions of the Study

This study contributes to the growing body of Energy Trilemma and sustainability assessment literature by developing a localized and provincially adaptable framework for evaluating multidimensional energy system performance. While existing Energy Trilemma studies predominantly focus on national-level and cross-country comparisons, this study extends the analytical scope of Energy Trilemma assessment into the subnational and provincial context through the proposed Provincial Energy Trilemma Index (PETI). By localizing the assessment of energy security, energy equity, and environmental sustainability, the study advances the conceptual understanding of how Energy Trilemma dimensions interact within decentralized and geographically heterogeneous energy systems, particularly within developing and archipelagic contexts such as the Philippines. Furthermore, this study contributes by establishing a structured indicator selection process grounded in theoretical relevance, empirical recurrence, provincial measurability, comparability, and policy applicability. Through this process, the study identified measurable and operationally feasible indicators related to energy security, energy equity, and environmental sustainability, while also providing guidance regarding potential provincial data sources and localized measurement approaches.

In practical and policy terms, the proposed PETI framework provides provincial governments, policymakers, and energy institutions with a localized tool for evaluating energy performance and sustainability conditions. The framework may support evidence-based provincial energy planning, renewable energy transition assessment, electrification monitoring, sustainability benchmarking, and resilience-oriented infrastructure development. It also establishes a foundation for future empirical applications, including provincial benchmarking, comparative sustainability assessment, localized transition monitoring, sensitivity analysis, and evidence-based energy policy development.

## Conclusion and Recommendations

The transition toward sustainable energy systems increasingly requires assessment frameworks that move beyond generalized national indicators and account for the localized realities shaping energy development outcomes. As energy systems become more decentralized, geographically differentiated, and transition-oriented, the need for multidimensional and context-sensitive assessment approaches becomes more critical. Energy sustainability is no longer solely a question of expanding energy supply or increasing renewable deployment, but also of balancing reliability, accessibility, affordability, resilience, and environmental responsibility within diverse local conditions.

This study underscores the importance of localizing Energy Trilemma assessment within provincial and subnational contexts where disparities in infrastructure, resource availability, institutional capacity, and energy accessibility are often most pronounced. The findings suggest that national-level assessments may inadequately capture the complexities and vulnerabilities of decentralized and geographically fragmented energy systems, particularly within archipelagic and developing country settings. Consequently, localized assessment frameworks are essential for understanding how energy transition pathways differ across regions and how sustainability objectives may be shaped by varying provincial conditions.

The proposed Provincial Energy Trilemma Index (PETI) therefore represents a shift toward more context-responsive and operationally grounded energy sustainability assessment. By integrating multidimensional indicators within a provincially adaptable framework, PETI provides a foundation for more inclusive, evidence-based, and spatially sensitive energy governance. Ultimately, the study highlights that achieving sustainable energy transitions requires not only national policy direction but also localized assessment mechanisms capable of identifying regional disparities, transition vulnerabilities, and context-specific opportunities for long-term sustainable development.

### *Policy Implications*

The framework also carries important policy implications by enabling provincial governments and energy institutions to translate PETI indicators into localized and actionable planning questions. Rather than relying solely on generalized national energy statistics, PETI may support evidence-based identification of specific provincial and community-level vulnerabilities. For example, electrification indicators may help determine which barangays or municipalities exhibit the lowest electricity access rates and therefore require priority infrastructure expansion. Supply reliability indicators may identify areas experiencing the highest frequency and duration of power interruptions, while affordability indicators may reveal communities where electricity costs impose the greatest household burden. Similarly, renewable energy and energy diversification indicators may assist policymakers in identifying provinces with strong potential for decentralized renewable deployment or areas highly dependent on imported fuels. Environmental sustainability indicators may also support the identification of provinces with high carbon intensity and low energy efficiency, thereby guiding localized transition and decarbonization strategies. Through these applications, PETI strengthens the capacity of provincial energy planning to become more targeted, spatially responsive, and context-sensitive.

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## **Competing Interests Statement**

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

## **Data Availability Statement**

Data sharing is not applicable to this article as no new data were created or analyzed in this study; all data used were obtained from previously published sources as cited in the reference list.

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## Appendices

No appendices are attached to this study.