Consume better, integrate more renewables: a critical framework for assessing energy synergy

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Abstract

The combination of renewable energy and energy efficiency is often described as synergistic, although its benefits are evaluated using indicators and references that are not always equivalent. This article develops a critical framework for assessing that interaction through a targeted integrative review of verified scientific literature and technical documents, emphasizing recent publications. The synthesis compares mechanisms, analytical boundaries, operating conditions, and the scope of the evidence without estimating an aggregate effect or conducting a bibliometric analysis. The findings distinguish reduced energy per service, electricity supply substitution, temporal flexibility, and consumer responses. Based on this differentiation, the Integrated Energy Synergy Model (MISE, its Spanish acronym) is reformulated as a conceptual proposal connecting renewables, efficiency, enablers, optimization decisions, and sustainability outcomes. A comparison is proposed between a reference and standalone efficiency, standalone renewables, and joint implementation scenarios, maintaining service equivalence and assessment conditions. The framework identifies favorable, zero, or unfavorable interactions for each indicator and avoids interpreting reduced electricity purchases as automatic evidence of total savings. The discussion explains why consumption timing, rebound, financing, and implementation constraints condition benefits. It concludes that synergy should be treated as a testable hypothesis rather than an inherent attribute of technological combination. MISE requires empirical validation or calibrated simulations before local benefits can be estimated or specific configurations recommended.

Keywords: energy efficiency; renewable energy; demand management; energy synergy; measurement and verification; MISE

I Introduction

Deploying renewable generation and improving energy efficiency address related but distinct problems. The former changes the source of electricity; the latter seeks to reduce the energy required to provide a service. A photovoltaic installation can reduce grid purchases without changing equipment consumption, whereas an air-conditioning improvement can reduce that consumption without changing installed renewable capacity. Recognizing this distinction is essential to interpreting projects that combine both interventions and to avoiding the use of bill reductions alone as evidence of energy savings [1], [2].

Integration becomes particularly important when renewable availability and users' needs do not coincide in time. Reducing demand, shifting it to other hours, and supplying it through local generation are different decisions that can reinforce one another or compete for the same benefit. Flexibility allows certain loads to respond to system conditions but does not necessarily mean consuming less. Storage also introduces conversion losses and capacity constraints. Consequently, a solution that improves solar utilization need not simultaneously deliver the greatest reductions in energy use, contracted power, and emissions [3].

The term synergy often expresses the desirability of coordinating technologies. To make it an evaluable category, however, the outcome that improves, the reference against which it is assessed, and the applicable conditions must be specified. A combination outperforming the initial scenario does not demonstrate that its benefit exceeds the sum of the separate interventions. Nor is observing a higher renewable share sufficient: that proportion can increase because clean generation rises, because the consumption denominator falls, or

through both mechanisms. Interpretation requires explicit physical flows, units, system boundaries, and the service received by users.

Studies of energy retrofits and photovoltaic generation provide a concrete setting for examining these interactions. Research on a university building in Recife combines a calibrated model with building improvement and photovoltaic sizing decisions, demonstrating the relevance of jointly addressing choices that affect demand and local supply [4]. Its relevance to this review does not lie in transferring a design solution to any building, but in recognizing that the appropriate generation system size depends on the consumption profile remaining after the efficiency intervention.

Behavior introduces another difficulty. Beppler, Matisoff, and Oliver examine consumption changes following solar adoption, an issue that requires distinguishing electricity drawn from the grid from total household consumption [5]. More recently, Delic and Bucksteeg incorporate empirical solar rebound profiles into a European electricity system optimization model [6]. These contributions enable discussion of both the magnitude and timing of additional consumption without assuming that their estimates represent other markets. User responses can modify expected benefits while redistributing them among private savings, flexibility, and system performance.

Economic assessment likewise cannot be reduced to a single electricity bill. Kerby and colleagues compare measures to reduce household energy burdens, distinguishing weatherization, efficiency, storage, and solar generation alternatives [7]. Such assessments are useful because expenditure reductions depend on tariff rules and investment financing as well as technical performance. A technology can produce aggregate benefits while remaining inaccessible to households facing liquidity constraints. Integrated design must make explicit who bears the costs, who controls the assets, and who receives service improvements.

These questions are relevant to Ecuador, although they do not authorize automatic extrapolation. Research on barriers to renewable expansion in the country identifies institutional and economic dimensions that any implementation assessment should consider [8]. Transferring international experience requires checking use conditions, available infrastructure, maintenance, data, and operating rules. In university buildings, productive facilities, or communities, the value of a common framework lies in organizing these checks, not replacing them with results obtained elsewhere.

This article addresses that need through a targeted critical integrative review and the reformulation of the Integrated Energy Synergy Model (MISE, its Spanish acronym) as an evaluable conceptual proposal. The contribution is neither an aggregate savings percentage nor a bibliometric classification of the field. It links mechanisms, indicators, and counterfactual comparisons to distinguish complementarity, favorable interaction, and trade-offs among objectives. The organizing question is under what conditions the combination of efficiency and renewable generation can be considered synergistic, and what evidence would establish this. The framework guides comparisons of intervention packages and identifies information needed before investment without presenting territorial transfer as an achieved result. The objective is to develop a critical framework for evaluating energy synergy that connects the selected evidence on renewables, efficiency, and demand management with criteria for comparison at equivalent service levels.

II Methods

A Review design and scope

A targeted critical integrative review was conducted to examine the relationships among renewable energy, energy efficiency and demand management, and translate those relationships into evaluable criteria. The unit of analysis was the technical claim supported by a study or institutional document, rather than the number of publications mentioning a technology. The design follows the alignment between purpose, selection and synthesis described by Snyder [9]. The study distinguishes three outputs: a synthesis of published evidence, interpretation of mechanisms and formulation of the Integrated Energy Synergy Model (MISE, its Spanish acronym). The latter remains a conceptual proposal; no original simulation or intervention in electrical installations was conducted.

The documentary antecedent is the degree thesis that formulated MISE. Its architecture served as a conceptual starting point, while external claims in the article were checked against verifiable sources. The review is not presented as a bibliometric census, a meta-analysis or an exhaustive systematic review. Consequently, it does not estimate publication growth rates, country rankings or pooled effects. This delimitation prevents an explanatory synthesis from adopting a level of statistical precision that its procedure cannot support.

The guiding question was which conditions distinguish a useful technological combination from an energy interaction that exceeds the sum of its separate effects. The scope includes buildings, households and electricity systems where studies identify renewable generation, demand, efficiency measures or coordination mechanisms. Macroeconomic studies inform the discussion of institutional conditions, but their associations are not directly transferred to the physical behavior of an installation. Figure 1 summarizes the review and conceptual-development sequence.

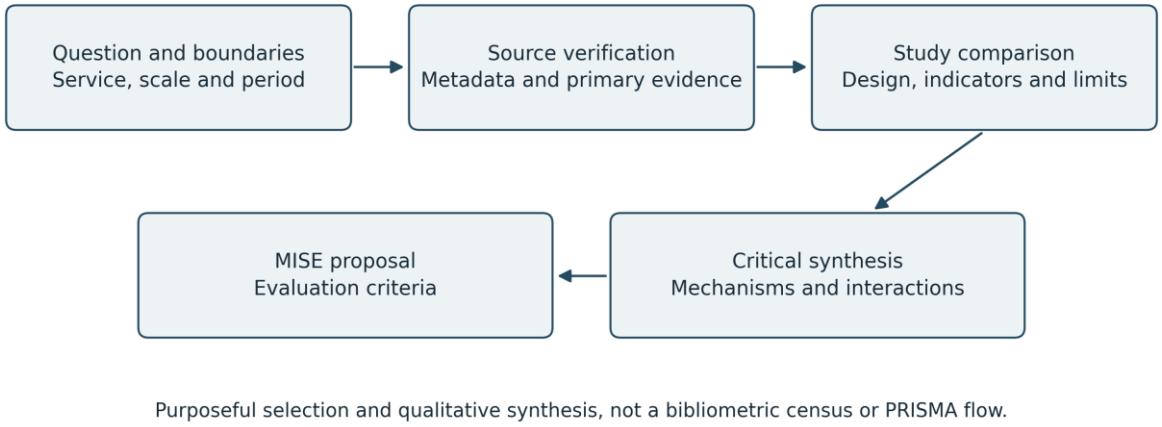


Fig. 1. Purposeful critical integrative review procedure. Conceptual illustration; it does not represent measured or simulated results.

B Source retrieval and verification

The documentary update was undertaken on October 29, 2026, through targeted searches and consultation of publisher pages, DOIs, energy organizations and repositories of the authors' institutions. Literature from 2022–2026 was prioritized; earlier sources were retained only where they provided a definition or procedure that was difficult to replace. Search themes combined the terms energy efficiency, renewable energy, photovoltaic retrofit, demand flexibility, solar rebound, energy burden, and measurement and verification. Relevant studies identified in consulted references were also verified by title or DOI.

Relevance was assessed through connection with at least one of four problems: joint efficiency and generation design; the distinction between electricity consumption and imports; temporal coordination and service constraints; or verification of savings and environmental performance. Original research was preferred for analyzing mechanisms and official documents for contextualizing policies and procedures. A reference was not included solely because it contained the word synergy. Sources without sufficient information to support a specific claim were not used as evidence of that result.

Verification distinguished bibliographic metadata, accessible content and the scope of inference. Where only an abstract or institutional record could be examined, the synthesis was restricted to the design and findings described there, without attributing unobservable procedures. The reference list constitutes the cited documentary set, not an eligibility denominator or a representative sample of worldwide research. Targeted searching favors thematic depth but retains risks of omission and selection; this limitation is addressed in the discussion.

C Extraction and critical comparison

For sources used in the comparison, the scale, intervention, outcome variable, method, treatment of behavior and transferability limit were identified. Table I presents the rules used to distinguish concepts that are often grouped together. Critical reading focused particularly on whether a study measured total consumption or grid purchases, whether it compared standalone technologies with a combination, and whether equivalent service conditions were maintained. No CASP, JBI or AMSTAR quality scores were assigned, and independent duplicate assessment was not claimed.

Table I. Concepts and interpretation rules

Concept	Variable or unit	Does not establish
Efficiency	kWh per service unit as an indicator	Technical savings from reduced activity.
Renewable generation	Net kWh generated	Lower end-use consumption.
Electricity imports	kWh purchased from the grid	Total consumption when self-consumption occurs.
Flexibility	Available kW and duration	Net kWh reduction without checking recovery.
Renewable fraction	Percentage with explicit denominator	Absolute savings or hourly adequacy.
Cost and emissions	USD; kg CO_2e, separately	Equivalence between bills, energy and carbon.

Note: operational distinctions used in this review; service and boundaries must remain explicit.

The synthesis was organized around mechanisms rather than a chronological sequence of authors. Electricity-balance boundaries were examined first, followed by interactions among sizing, timing and behavior, and finally verification and transferability requirements. Simulation findings were treated as conditional on their assumptions, observational studies as evidence of associations or effects under their identification strategy, and institutional reports as technical guidance. Heterogeneous objectives and units precluded a meaningful average of savings.

D Development of an evaluable framework

The formulation of MISE linked each component to observable variables and a validation question. The consistency criterion required that no improvement be inferred solely from the presence of solar panels, batteries or digital tools. A factorial comparison was proposed between the absence and presence of efficiency and renewables, using the same boundary, period and service level. This is a design for subsequent research, not an experiment conducted in this review.

The procedure separates three tests that are not equivalent: checking the physical balance, comparing a model against measurements and estimating the effect attributable to an intervention. The literature on residential baseline forecasting compares algorithms and aggregation scales, but improved prediction does not automatically identify the causal effect of a measure [10]. A model may satisfy energy conservation while still misrepresenting occupancy schedules or user responses. Similarly, an accurate consumption forecast does not, by itself, identify how much consumption would have changed without the intervention. This distinction determines which future findings could support, refute or revise the proposed relationships.

III Results

A The measurement boundary changes the interpretation of improvement

The synthesis first establishes that efficiency, self-consumption and flexibility are not interchangeable names for the same outcome. Efficiency relates energy to service; renewable generation changes the source of supply; flexibility changes when electricity is consumed or exported. Table I identifies the variable corresponding to each claim. An installation may import less electricity without reducing final demand, and may shift load toward favorable hours without reducing kilowatt-hours over the period.

To make this distinction explicit, Figure 2 represents an installation without storage, with energy quantities in kWh measured over the same interval. L denotes final electricity consumption, I imports from the grid, G net photovoltaic generation at the inverter output, and C the portion of that generation consumed locally. X denotes exports. Under this simplified boundary, the balance is:

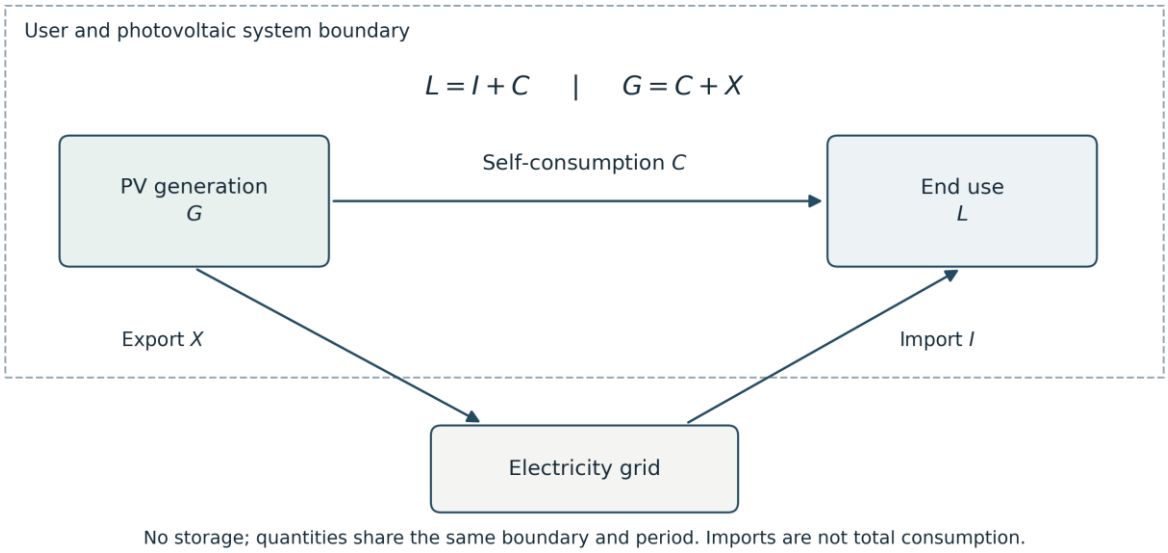


Fig. 2. Conceptual electricity balance without storage. Conceptual illustration; it does not represent measured or simulated results.

$$L = I + C \quad ; \quad G = C + X \quad (1)$$

This identity has an immediate methodological implication: a decrease in I does not demonstrate a decrease in L. When local generation is installed, C can replace some previously purchased electricity even if services and equipment remain unchanged. Analyzing consumption changes after solar adoption requires reconstructing total demand, as illustrated by Beppler, Matisoff and Oliver [5]. Confusing the two quantities would attribute a supply-substitution outcome to efficiency.

The balance must be extended where batteries are present. Charging, discharging, losses and changes in stored energy must then be recorded, and the charging source—grid or local generation—specified. Simply adding discharge to renewable generation is insufficient and may count the same unit of energy twice. Nor is all discharge renewable by definition. Transition models with different spatial resolutions and sector-coupling options also show that the boundary changes the comparison of alternatives [11]. Selecting an alternating-current or direct-current boundary must be accompanied by consistent treatment of conversion losses; changing boundaries between scenarios invalidates apparently precise comparisons.

The renewable share, in turn, is a ratio requiring an explicit denominator and period. It may rise because renewable supply increases, total consumption decreases, or both. The percentage alone does not indicate avoided energy or hourly coincidence with demand. For this reason, MISE uses separate indicators rather than a single improvement percentage combining physical and economic quantities.

B Evidence of complementarity and transferability limits

Table II brings together studies examining relationships among technologies, behavior and performance at different scales. It does not seek to rank countries or select a universal solution. Its comparison shows why joint design deserves attention, but also why a local advantage does not establish a general law of synergy. The study of retrofits and photovoltaics in a university building in Recife analyzes integrated solutions using a calibrated model; its contribution is to link intervention and sizing decisions, not to demonstrate that every combination retains the same performance in another climate [4].

Table II. Compared studies and transfer limits

Study and setting	Design and contribution	Interpretation limit
Munguba et al. [4] Recife, Brazil	Calibrated university-building model integrates retrofit and PV sizing.	Modeled results, not observed post-intervention savings. Climate and costs require local adaptation.
Beppler et al. [5] Households with PV	Matched observational comparison distinguishes total consumption from grid purchases.	Do not transfer rebound magnitude or causal certainty across populations. Matching does not eliminate all unobserved confounding.
Delic and Bucksteeg [6] Europe	Sectoral scenarios incorporate solar-rebound magnitude and timing.	Prospective consequences, not an Ecuadorian behavioral coefficient. Concurrent electrification must be distinguished from behavioral rebound.
Kerby et al. [7] Modeled households	GridLAB-D compares efficiency, weatherization, PV and storage.	Energy burden, consumption and resilience are not interchangeable outcomes. Building characteristics condition the choice of measures.
Afroz et al. [12] Australia	Calibrated building models characterize flexibility by timing and temperature.	Extrapolated potential, not metered national flexibility. Building type changes its operational availability.
Nambiar et al. [13] Cordova, Alaska	Occupant-centered assessment links events, comfort and participation.	Preferences and thermal recovery are location-dependent. Thermal service is part of the outcome, not only load.
Menniti et al. [14] Calabria, Italy	Interaction tool using aggregated residential hourly data.	January–August 2020 window does not represent a full year. Local profiles limit transferability of availability.
Barnes et al. [15] California and New England	PyPSA-USA compares separate and joint electrical and thermal demand response.	Scenarios for 2030, not realized savings. Pricing structure conditions economically optimal shifting.

Note: purposeful comparative selection; PV: photovoltaic. This is neither a quality ranking nor a meta-analysis.

Retrofitting changes the demand that generation must subsequently supply. If a photovoltaic system is sized using consumption before the improvement, its eventual surplus may differ from expectations. However, reducing daytime demand may also reduce the self-consumption of an existing solar installation. This outcome does not invalidate efficiency; it shows that valuation criteria matter. Increased exports may be acceptable for the electricity system and less favorable for the user, or vice versa, depending on operational and economic conditions. The answer requires evaluating the complete project rather than independently maximizing a self-consumption rate.

The comparison of energy-burden reduction measures by Kerby and colleagues distinguishes efficiency, weatherization and distributed technologies through simulation [7]. Its value for MISE lies in separating bills from energy. Monetary savings depend on prices, charges and exchange rules; they are not a physical unit transferable across territories. A distributional assessment should therefore report who bears the investment, who receives the expenditure reduction and which services are obtained, alongside the energy balance.

User behavior introduces another distinction between technical potential and observed effects. Beppler and colleagues examine consumption changes associated with solar adoption [5]. Delic and Bucksteeg incorporate empirical consumption-response profiles into European system modeling, demonstrating the importance of considering both the magnitude and timing of changes [6]. These studies do not provide a rebound coefficient applicable to Ecuador. They do justify recording post-intervention uses rather than assuming that service demand remains unchanged.

An integrative review must preserve these methodological differences. The calibrated building allows alternatives to be examined under controlled assumptions; household evidence informs adoption and use; system modeling evaluates aggregate consequences within a planning structure. None replaces the others. Their convergence lies in the need to represent interactions, not in a savings figure transferable without recalibration.

C Temporal coordination and operating conditions

The integration of variable generation depends on its relationship with demand and the resources available to balance the system [2]. At an installation, two alternatives with identical annual balances may impose different maximum imports or surpluses. The annual period is therefore useful for summarizing energy but insufficient for describing power constraints, solar coincidence or load recovery. MISE proposes retaining temporal resolution consistent with the phenomenon: a monthly average does not verify a short-duration peak reduction.

The framework developed by Satchwell and colleagues distinguishes complementary and competing relationships between efficiency and demand response [16]. Menniti and colleagues propose an interaction tool linked to reliability and apply it to aggregated hourly records from residential users in Calabria [14]. Their observation window and profiles are specific; the methodological interest lies in evaluating interaction rather than assuming that every load reduction preserves the same response availability. The multisector modeling by Barnes and colleagues compares electrical and thermal response separately and jointly in California and New England [15]. These antecedents support explicit comparisons but do not validate the MISE contrast or its future applications.

Flexibility adds decisions concerning the timing and duration of consumption [3]. An air-conditioning controller may bring forward part of a load, but its assessment must record temperature, occupancy and subsequent recovery. If the load avoided during an event returns afterward, the outcome may remain useful for a time-specific constraint without representing net savings. The control function is therefore specified before its success is judged: reducing energy, shifting demand and responding to a system signal are related but distinct objectives.

Afroz and colleagues characterize flexibility in Australian commercial buildings using calibrated physical models and parametric analysis [12]. The study of price-responsive office flexibility under cooling-dominated conditions likewise places performance within specific usage conditions and economic signals [17]. Residential coordination of distributed resources, examined using high-resolution records and rolling-horizon scheduling, provides another way of representing temporal mismatches [18]. The synthesis does not combine their findings into a common rate: their loads, assets and objective functions differ.

Storage extends coordination options without eliminating these distinctions. A battery may reduce imports during one period and increase them during another because of charging and losses. A measure may reduce bills under a particular tariff while increasing total electricity consumption. Environmental assessment also requires knowing the origin and timing of displaced electricity. Benefits are therefore neither assumed from installed capacity nor mechanically added to efficiency savings.

Digital tools are treated as enablers conditional on an operational need. Metering can detect deviations; an energy management system can coordinate equipment; an algorithm can improve a decision if it has adequate information and outperforms a relevant benchmark. None of these functions automatically makes an installation efficient. The design requires comparing the proposed controller with simple rules, recording communication failures and assessing operating costs. Complexity should be justified by a problem that cannot be solved more robustly with fewer resources. The OpenADR 3.0 communication architecture studied for continuous flexibility clarifies this enabling role: exchanging price or capacity signals does not, by itself, demonstrate net savings [19].

D Proposed operational architecture for MISE

Figure 3 reorganizes MISE into four levels while retaining its five conceptual components: renewables, efficiency, enablers, optimization and sustainability. The first level defines physical interventions and service

demand. The second identifies metering, control and coordination resources. The third establishes sizing and operating decisions under constraints. The fourth records verifiable outcomes and feeds information back to the preceding levels. The connections express relationships proposed for examination, not estimated causal coefficients.

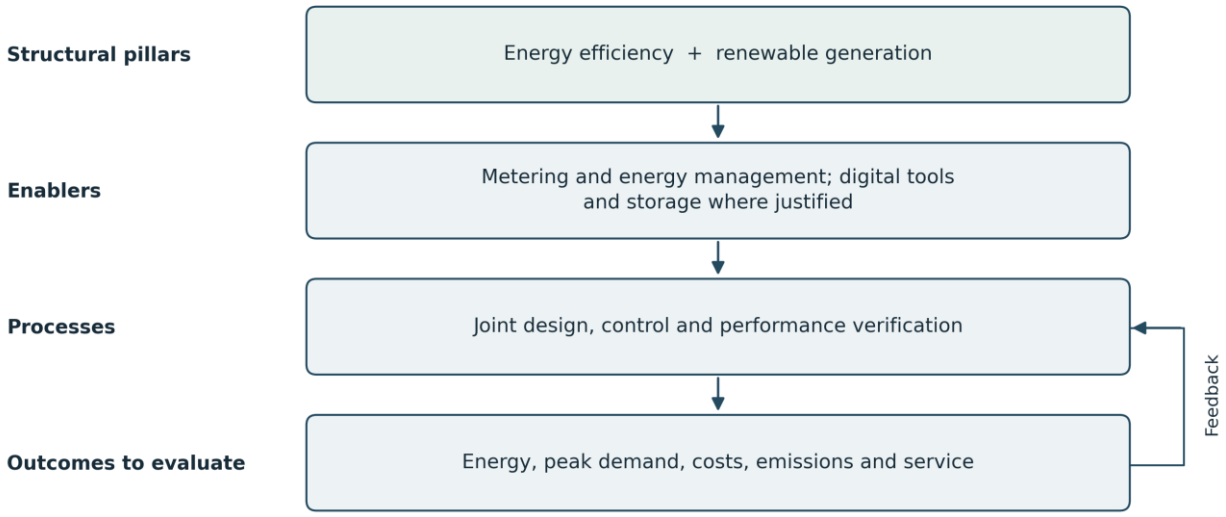


Fig. 3. Conceptual architecture of the Integrated Energy Synergy Model MISE. Conceptual illustration; it does not represent measured or simulated results.

Table III translates this architecture into evaluation questions. The contribution is not to add a list of technologies, but to require each technology to have a function, a variable and a failure condition. If the objective is to reduce the energy required for cooling, thermal service and consumption must be measured; if it is to reduce a peak in imports, the demand interval must be defined; if it is to reduce emissions, the calculation method and boundary must be specified. This correspondence prevents an unachieved outcome from being replaced with a more favorable indicator after the data have been observed.

Table III. MISE components and evaluable questions

Component	Observable variable	Validation question
Renewables	Net generation and surplus	Does supply coincide with demand?
Efficiency	Energy per service	Does improvement persist at equivalent service?
Enablers	Data, availability and failures	Does coordination outperform a simple rule?
Optimization	Outcomes and constraints	Does the solution remain feasible under disturbances?
Sustainability	Emissions, cost and service	Do benefits avoid shifting burdens to other users?

Note: proposed operationalization; these relationships have not been validated in this article.

MISE is expressed as a set of outcomes and constraints, not a global score. Final energy, maximum power, cost, emissions and service may move in different directions. Their weighting would be a normative decision requiring disclosure of user or operator preferences, rather than a physical property of the installation. Where two alternatives present competing advantages, a legitimate result may be a set of nondominated options accompanied by their opportunity costs, instead of an artificially unique winner.

Sustainability includes service continuity and quality alongside energy performance. A subsequent application must distinguish reductions caused by technical improvement from those caused by lower

activity, disconnections or access restrictions. A building consuming less because it is unoccupied does not demonstrate greater efficiency; an installation interrupting essential loads does not establish improved wellbeing. Service equivalence is thus a condition for interpretation rather than a secondary note at the end of the analysis.

E Proposed interaction contrast and verification

Figure 4 presents a factorial comparison of four configurations: a reference without the interventions under analysis, efficiency alone, renewables alone and their combination. The subscript of outcome Y identifies the presence or absence of efficiency and renewables, respectively. For an additive indicator in which lower values represent improvement, the following contrast is proposed:

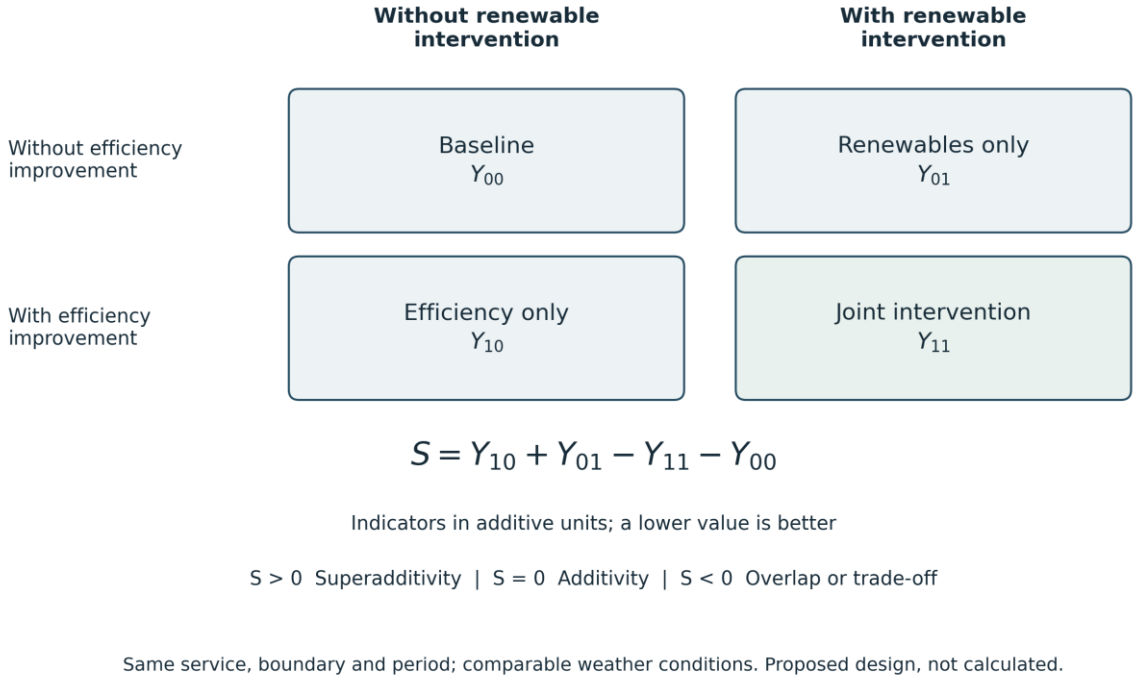


Fig. 4. Proposed factorial comparison to identify interaction between interventions. Conceptual illustration; it does not represent measured or simulated results.

$$S = Y_{10} + Y_{01} - Y_{11} - Y_{00} \quad (2)$$

The term S equals the combined benefit minus the sum of the separate benefits relative to the same reference. A positive value would indicate a reduction exceeding the additive hypothesis; zero would be compatible with additivity; a negative value would indicate overlap or offsetting effects relative to that reference. The latter condition does not imply that the combination is worse than the initial situation. Two measures may both be beneficial while sharing some reduction potential, so adding them without acknowledging that overlap would overestimate the benefit.

The contrast is not a universal index. It must be formulated separately for energy, cost or emissions, always using compatible units and boundaries. It cannot be applied without transformation and justification to bounded percentages, such as the renewable fraction, or to indicators intended for maximization. Physical limits also matter: when one configuration approaches zero imports, the sum of standalone reductions may exceed the available margin. A negative sign may then reflect an indicator constraint rather than deficient coordination.

The four configurations require equivalent climate, occupancy, production and service, or explicit adjustments permitting comparison. A contrast obtained through simulation would represent an interaction within the model; a causal interpretation in actual operation would require justified identification of the counterfactual. A point estimate of S would likewise be insufficient: measurement uncertainty, parameters and behavioral assumptions must be propagated jointly, preserving dependencies between scenarios. If the

resulting range includes zero, the evidence would not support a claim of superadditivity at the assessed precision.

Table IV brings together the minimum indicator set and avoids reducing the analysis to nominal savings. To examine the additional value of coordination, the same combination should be compared, after the basic contrast, under simple and coordinated control. Equipment and capacities must remain unchanged when isolating the control effect. If sizing also changes, the outcome must be attributed to the design-and-operation package rather than exclusively to the algorithm.

Table IV. Minimum indicators and comparison safeguards

Indicator	Unit	Boundary and safeguard
End-use energy	kWh/period	Separate imports, self-consumption and losses.
Peak imports	kW	Fix the interval; check subsequent recovery.
Project cost	Base-year USD	Include investment, operation, replacement and horizon.
Emissions	kg CO_2e/period	State factors, timing and operational or life-cycle boundary.
Service	Relevant functional unit	Record output, comfort or continuity; do not add heterogeneous units.

Note: report indicators separately; monetary reduction does not establish energy savings.

Table V presents a prospective verification pathway. Service is defined and meters audited first; an adjustable baseline is then established, the model checked and configurations compared. Evaluation ends with sensitivity, uncertainty and monitoring of use, rather than identification of a nominally optimal solution. IPMVP provides a reference framework for verifying energy projects [20]; the FEMP guidelines develop the use of adjusted baselines, routine and non-routine adjustments, and uncertainty [21]. These references guide the design without implying certification of compliance. In this article, the pathway is a research proposal: no installations receiving interventions, operational tests or calculated interaction values are reported.

Table V. Prospective pathway for testing MISE

Stage	Required evidence	Condition limiting inference
Baseline	Audited meters, weather, activity and service	Incompatible boundaries or services.
Calibration and testing	Documented calibration and independent temporal testing	Confusing fit with validated prediction.
Counterfactuals	Four configurations with common assumptions	Unidentified simultaneous changes.
Uncertainty	Sensitivity and joint error propagation	Interaction interval compatible with zero.
Monitoring	Service, maintenance and subsequent consumption	Improvement explained by access restrictions or lower activity.

Note: proposal informed by measurement and verification principles [21]; it does not describe completed tests. Superadditivity also requires sufficiently bounded uncertainty and a defensible service comparison; a favorable point estimate is insufficient.

IV Discussion

A Integration as a testable hypothesis

Coordinating efficiency and renewables does not guarantee an advantage over the sum of separate actions. An unfavorable interaction against that additive reference does not mean the technologies are useless or the project worsens the initial situation; it may reflect both measures partly exploiting the same opportunity.

Building retrofits illustrate this issue. If an improvement reduces daytime demand, a photovoltaic installation sized for the previous situation may export a larger fraction of its production. Total building consumption falls, but the solar self-consumption ratio may decline. There is no physical contradiction: the indicators describe different processes. The study integrating retrofits and photovoltaics in Recife is relevant precisely because it addresses sizing decisions linked to building performance [4]. The resulting recommendation is not always to reduce solar capacity, but to reassess the hourly balance and economic conditions when demand changes. This reasoning also requires reconsidering the implementation sequence. Comparing a joint project with two independently designed measures may attribute an advantage to integration that simply results from correcting an initially unsuitable design. For the result to be interpretable, the alternatives must represent technically admissible designs rather than artificially unfavorable references.

Complementarity describes compatible functions; quantified synergy requires an interaction for each indicator. A cost advantage may exist without an energy advantage. Keeping partial results visible allows trade-offs to be discussed with users before selecting a solution.

B Timing and consumer response

Annual balances are useful for describing magnitudes but can conceal when benefits occur. Two alternatives with the same annual consumption may impose different maximum demands or require grid support at different times. Demand management should be analyzed at a resolution appropriate to the decision: a monthly balance does not necessarily identify the peak constraining an installation or the period in which renewable generation is underutilized. Reports on renewable integration and demand flexibility support considering these operational functions rather than accumulated energy alone [2], [3].

Rebound introduces a dimension that cannot be resolved through a universal correction factor. Solar adoption may alter perceptions of electricity use costs and change equipment operation; efficiency improvements may enable previously constrained service levels. Beppler and colleagues empirically examine changes following solar adoption, whereas Delic and Bucksteeg transfer response profiles into a European system assessment [5], [6]. Together, they suggest an important distinction: additional energy and its temporal distribution should be investigated separately because their operational consequences are not necessarily the same.

From a welfare perspective, not every reduction in expected savings constitutes project failure. If a household moves from inadequate thermal conditions to an acceptable service, part of the benefit takes the form of improved habitability rather than measured savings. Assessment should retain that change rather than conceal it within a supposedly equivalent comparison. Research by Nambiar and colleagues on residential thermal flexibility highlights the importance of considering intervention duration and temperature recovery alongside household participation [13]. MISE proposes reporting energy performance and achieved service together. This avoids rewarding interventions that reduce consumption through unwanted restrictions or penalizing improvements that address previously unmet needs.

This approach connects with Creutzig and colleagues' discussion of services and well-being and the IPCC assessment of demand-side mitigation options [22], [23]. Reducing energy is not the only relevant criterion: which needs are met and with what resources also matter. The perspective on material impacts of the transition extends that consideration to equipment and infrastructure requirements [24]. For MISE, this suggests avoiding situations in which an improved operating indicator conceals material burdens beyond its boundary. Those impacts are not quantified here; they are proposed as an assessment dimension when compatible data are available.

C Digital enablers with a defined role

Metering, forecasting, and control systems can connect generation and demand decisions, but their usefulness depends on the function they perform. MISE does not require artificial intelligence, machine learning, and large data volumes to be incorporated simultaneously. A simple control scheme may suffice when schedules are stable and constraints are well defined. Tool selection should begin with the decision need and measurement quality rather than algorithmic complexity.

The proposal distinguishes prediction from control: accurate forecasts do not demonstrate cost or emission reductions. A future implementation should compare the advanced controller with a transparent rule using identical data and constraints, test responses to errors, and account for devices, maintenance, and human intervention. These are protocol conditions, not experimental findings of the article.

Information governance should define access, record retention, and safe operation when automation fails. The framework permits gradual implementation: consistent measurements, operational coordination, and more complex tools only when they demonstrably improve on the simpler alternative.

D Costs and territorial transferability

Investment decisions require distinguishing system costs, user expenditure, and the distribution of benefits. Storage may change the bill without reducing the electricity needed to provide the service; a building envelope improvement may benefit an occupant without maximizing photovoltaic utilization. Kerby and colleagues' comparison of alternatives to reduce household energy burdens provides a basis for addressing these differences [7]. Forrester and colleagues reinforce this distinction through an assessment of energy burdens among solar adopters: payments associated with acquiring the system and other financial flows should be considered alongside the bill [25]. The proposed framework adds the requirement to maintain the same economic perspective when comparing scenarios and separately report investment, operation, replacement, and compensation for exports.

For Ecuador, the barriers identified by Barragán-Escandón and colleagues preclude interpreting adoption as a purely technological decision [8]. A proposed application should examine financing availability, maintenance responsibilities, and institutional capacity to sustain measurements. Results from other countries can guide questions and variable selection but cannot determine the optimum installation size or users' responses. Nor can they establish benefits for Esmeraldas without observing its operating conditions.

The selected Ecuadorian evidence helps clarify different scales of the problem. Moya and colleagues estimate spatially resolved climatic, end-use, and socioeconomic drivers; their products reveal territorial heterogeneity but do not replace measured hourly profiles at a facility [26]. Arévalo, Cano, and Jurado connect ANFIS demand forecasting with national renewable integration scenarios; forecasting supports planning without independently validating an efficiency intervention [27]. Sterl and colleagues, in turn, model the coordination of hydropower and variable renewables under drought conditions, highlighting a relationship among generation, stored water, and temporal adequacy that an annual balance does not represent [28]. These studies do not demonstrate MISE, but they delimit system conditions worth incorporating into its evaluation.

Economic and multicriteria decisions require equally explicit treatment. Heredia Fonseca and Gardumi examine how discount rates modify power expansion scenarios using OSeMOSYS; their findings underscore that technological choices also depend on financing assumptions [29]. Godoy and colleagues consider technical, environmental, and social criteria alongside stakeholder preferences to support planning [30]. For a MISE application, that perspective entails declaring weights and exploring how recommendations change when they vary. The best alternative under one combination of preferences is not a universal optimum, and a favorable ranking does not constitute demonstrated operational performance.

An initial applied study could delimit a building or facility with identifiable uses, document the required service, and compare efficiency, renewables, and joint-operation scenarios. If the four conditions could not be implemented physically, a calibrated simulation could provide counterfactuals, provided these were distinguished from measurements and their uncertainty examined. Case selection should reflect record availability and monitoring capacity, not merely the ease of installing equipment. This is a proposed verification pathway, not a completed pilot.

E Contribution and limitations

Targeted selection may omit relevant experiences and cannot establish publication trends, geographic leadership, or average synergy magnitudes. Heterogeneous scales and designs preclude pooling effects as

observations from one experiment. These limitations restrict inference while allowing explicit assessment criteria to be formulated.

MISE requires applications documenting variables and zero or adverse results. Validation should examine balance consistency and its decision-making usefulness under changes in climate, use, and economic conditions. The contribution makes these requirements testable rather than declaring them satisfied.

V Conclusions

The integration of energy efficiency and renewable generation cannot be assessed using a single consumption indicator or an isolated reduction in grid purchases. The critical review distinguishes mechanisms commonly grouped under the notion of synergy: reduced energy per service, supply substitution, temporal shifting, and behavioral changes. Coordinating them may yield benefits, but these must be established for each objective and analytical boundary.

The reformulated MISE framework organizes five components within a structure connecting resources and interventions, enablers, operating decisions, and sustainability outcomes. Its main contribution is linking that architecture to a comparison among a reference, standalone efficiency, standalone renewables, and joint implementation while maintaining service equivalence. This comparison makes it possible to identify favorable, zero, or unfavorable interactions without confusing good joint performance with superiority over the sum of the separate measures.

Timing and user responses condition outcomes. Self-consumption, peak demand, emissions, and costs can evolve differently; digital enablers should be compared with simple operating alternatives.

Application in Ecuador requires locally grounded measurements and implementation conditions. This work provides neither measured local savings nor experimental validation of MISE; it offers criteria for developing them through traceable studies. The next stage is to test the framework in bounded cases, document uncertainty, and retain negative findings or trade-offs among objectives. Synergy thus ceases to function as a general expectation and becomes a hypothesis that can be evaluated and, where appropriate, refuted.

Alignment with the research line and subline

The article aligns thematically with the research line “Transformation and Use of Matter, Force, Energy, and Computer Systems” (FACI) and the research sub-line “Transformation and Efficient Use of Energy as an Alternative for Eco-sustainable Development” (Electricity). This connection is grounded in an integrated analysis of renewable energy utilization, efficiency, and demand-side management, as well as in the proposal of verifiable criteria to assess their contribution to the sustainable use of electricity.

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