

Designing Energy-Storage Policy for Renewable-Rich Power Systems: A Comparative Review of the United States, China, Australia, and Algeria

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ABSTRACT

Energy storage is central to integrating variable renewable energy, but deployment alone does not establish system value. This review examines policy combinations and sequences that enable financeable storage services and measurable public benefits, and design functions transferable to Algeria. A structured narrative review and comparative policy analysis assessed 50 scholarly and institutional records for the United States, China, Australia, and Algeria against seven dimensions: legal status, grid and market access, revenue adequacy, investment support, targets and procurement, technical and environmental governance, and system planning and data transparency.

Five mechanisms guided interpretation: access, competition, valuation, risk reduction, and accountability. The comparison identifies three mature, non-equivalent configurations: market access with fiscal support in the United States; planning- and target-led expansion with evolving remuneration in China; and bidirectional market integration with competitive revenue underwriting in Australia. Algeria's renewable expansion lacks a comparably explicit storage-specific legal, remuneration, procurement, or reporting framework in the reviewed record. The article contributes an evidence-linked readiness matrix and a conditional three-stage pathway for Algeria: legal clarification, needs assessment, standards, and differentiated pilots; service-based tenders and regulated revenue contracts; and broader revenue stacking, carbon-aware operation, and circularity after demonstrated performance.

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تصميم سياسات تخزين الطاقة لنظم الكهرباء الغنية بالطاقة المتجددة: مراجعة مقارنة للولايات المتحدة والصين وأستراليا والجزائر

ملخص: أصبح تخزين الطاقة عنصراً محورياً على نحو متزايد في دمج الطاقة المتجددة المتغيرة، إلا أن نشر مرافق التخزين وحده لا يثبت قيمتها للنظام الكهربائي. تبحث هذه المراجعة في توليفات أدوات السياسات وتسلسل تطبيقها التي تمكن التخزين من تقديم خدمات قابلة للتمويل ومنافع عامة قابلة للقياس، وفي الوظائف التصميمية التي يمكن نقلها إلى الجزائر. أجريت مراجعة سردية منظمّة وتحليل مقارنة للسياسات في الولايات المتحدة والصين وأستراليا والجزائر. وقيمت خمسون وثيقة علمية ومؤسسية وفق سبعة أبعاد: الوضع القانوني، والوصول إلى الشبكة والسوق، وكفاية الإيرادات، ودعم الاستثمار، والأهداف والمشتريات، والحوكمة التقنية والبيئية، وتخطيط النظام وشفافية البيانات. وفُسرّت الأدلة من خلال خمس آليات: إتاحة الوصول، والمنافسة، وتقييم القيمة، وخفض المخاطر، والمساءلة. وتحدد المقارنة ثلاثة أنماط ناضجة ولكن غير متكافئة: إتاحة الوصول إلى السوق مقرونة بالدعم المالي في الولايات المتحدة، والتوسع الموجه بالتخطيط والأهداف مع تطور آليات التعويض في الصين؛ ودمج الموارد ثنائية الاتجاه في السوق مقروناً بضمانات للإيرادات تُمنح تنافسياً في أستراليا. وفي الجزائر، تظهر الوثائق التي شملتها المراجعة توسعاً في الطاقة المتجددة من دون إطار مماثل في وضوحه يخص الوضع القانوني للتخزين أو تعويضه أو مشترياته أو الإبلاغ عن أدائه. وتقدم المقالة مصفوفة للجاهزية مرتبطة بالأدلة ومساراً مشروطاً من ثلاث مراحل للجزائر. ويبدأ المسار بتوضيح الوضع القانوني، وتقييم احتياجات النظام، ووضع المعايير، وتنفيذ مشروعات تجريبية متميزة؛ ثم ينتقل إلى المناقشات القائمة على الخدمات وعقود الإيرادات المنظمة؛ ولا يُدخل توسيع الجمع بين مصادر الإيرادات والتشغيل المراعي للانبعاثات وتطبيق مبادئ الاقتصاد الدائري إلا بعد إثبات الأداء. ويحدد التحليل أنماطاً ممكنة، ولا يقدر آثاراً سببية. وتتمثل دلالاته الأساسية في أن السياسة الفعالة للتخزين يجب أن تعترف بالأصل، وتقيم خدماته، وتتعاقد على أداء قابل للتحقق، وألا تتوسع إلا عندما تدعم الأدلة التشغيلية ذلك.

الكلمات المفتاحية: سياسات تخزين الطاقة؛ دمج الطاقة المتجددة؛ تصميم سوق الكهرباء؛ التحليل المقارن للسياسات؛ تسلسل السياسات؛ الجزائر.

1. INTRODUCTION

Variable renewable energy (VRE), particularly solar photovoltaic and wind generation, changes when and where electricity is produced. As its share rises, system operators must balance larger and faster variations in net demand while maintaining frequency, voltage, adequacy, and network security. Flexibility therefore becomes a core planning requirement rather than an ancillary concern. Storage can provide sub-second response, intraday shifting, reserve, congestion relief, black-start capability, and in some configurations multi-hour or longer-duration adequacy support [1–4]. The value of a project, however, depends on its duration, lo-

cation, availability, cycling duty, and dispatch. Nameplate capacity alone says little about the service actually delivered.

Storage also challenges electricity-sector categories. A battery withdraws electricity while charging, injects while discharging, and may provide capacity, ancillary services, network support, or resilience at other times. Rules designed for separate generators, networks, and consumers can therefore expose the same asset to duplicated network charges, uncertain licensing, inappropriate connection procedures, or exclusion from markets for services that it is technically capable of providing [5–7]. Legal recognition and practical participation rules are necessary foundations, but they do not by themselves make a project bankable.

The investment problem is equally important. Storage is capital intensive, whereas many revenues are short term, volatile, and jointly determined by electricity prices, scarcity, market design, competing flexibility resources, and the rate at which additional storage erodes profitable spreads. Benefits such as deferred network reinforcement, resilience, avoided renewable curtailment, and reduced peak-fuel use may accrue to actors other than the project owner or remain outside market settlement. A facility can consequently reduce total system cost and still fail to recover its private cost [8–10]. This divergence explains the diversity of public interventions: legal classification, tariff reform, market access rules, tax credits, grants, deployment targets, competitive procurement, capacity remuneration, and long-term revenue contracts.

These instruments are not substitutes. A capital credit reduces upfront cost; it does not establish dispatch rights. A target coordinates scale; it does not ensure utilization. A participation rule opens a market; it does not guarantee durable revenue. An availability contract can improve financeability, but poor calibration may transfer excessive risk to consumers. The analytical task is therefore to identify the barrier addressed by each instrument, the mechanism through which it operates, and the institutional conditions required for implementation. Sequence matters: procurement before workable interconnection can create stranded commitments, while support paid solely on installed megawatts can reward equipment without securing useful service.

The environmental case for storage also requires qualification. Storage shifts electricity; it is not intrinsically a zero-emission source. Net emissions depend on charging and discharging intervals, round-trip losses, the marginal generators affected, network constraints, and the carbon content of the system [11], [12]. The same battery can reduce renewable curtailment in one operating pattern and increase fossil generation in another. Policy evaluation must therefore extend beyond deployment to utilization, reliability contribution, consumer cost, marginal emissions, safety, and end-of-life outcomes [3], [12–15].

The literature is extensive but fragmented across technology reviews, market-design studies, legal analyses, project-finance research, and jurisdiction-specific policy assessments. Three gaps are especially consequential. First, measures described collectively as incentives are rarely separated by causal function. Second, national cases are often compared using capacity statistics that are based on incompatible technologies, dates, and geographic boundaries. Third, policy sequencing receives less attention than instrument inventories. These limitations are acute in emerging markets, where wholesale-market depth, regulatory capacity, access to finance, utility structure, and data availability differ from the settings in which many storage policies were developed [5], [16–18].

Algeria provides a policy-relevant case. Its solar resource, rising electricity demand, re-

mote systems, hot-climate operating conditions, and renewable energy program create a growing need for flexibility [19–22]. Yet a policy architecture suitable for Algeria cannot be obtained by copying the institutional form of the United States, China, or Australia. The relevant question is which functions—legal recognition, credible procurement, service valuation, risk allocation, verification, and learning—can be adapted to a predominantly state-led electricity sector, and in what order.

The central research question is therefore:

Which combinations and sequencing of policy instruments establish the institutional and investment conditions under which energy storage can support VRE integration, and which underlying design functions are transferable to Algeria?

Three subsidiary questions guide the analysis:

1. How do the four cases differ in the legal, market, financial, technical, and planning conditions governing stationary electricity storage?
2. Which mechanisms address investment and operational barriers while directing storage toward observable system benefits?
3. What staged policy and research agenda is appropriate for Algeria as renewable capacity expands?

The article makes four contributions. It first operationalizes storage policy readiness through seven dimensions that can be applied across contrasting electricity-sector structures. It then connects instruments to five mechanisms—access, competition, valuation, risk reduction, and accountability—so that measures serving different purposes are not treated as equivalent. Third, it presents an evidence-linked cross-country matrix and source-defined deployment snapshots without converting unlike administrative statistics into a spurious ranking. Finally, it translates the comparative findings into a conditional three-stage pathway for Algeria. The proposed pathway is a design proposition to be tested through legal review, system modeling, procurement experience, and measured field performance; it is not a forecast of capacity or a causal estimate of policy impact.

The remainder of the article proceeds as follows. Section 2 explains the review design, evidence update, coding, and transferability assessment. Section 3 develops the mechanism-based framework. Section 4 examines the four cases. Section 5 presents the cross-case synthesis. Section 6 proposes the Algerian pathway, Section 7 sets out limitations and a research agenda, and Section 8 concludes.

2. METHODOLOGY

2.1 Review design, scope, and case logic

The study uses a structured narrative review combined with comparative policy analysis. This design is appropriate because the evidence base includes peer-reviewed research alongside legislation, regulatory orders, market rules, system-operator documents, government programs, national statistics, and institutional reports. The method is more transparent than an unstructured overview, but it does not claim the exhaustiveness, protocol registration, or formal risk-of-bias assessment of a systematic review.

The unit of analysis is the documented policy and regulatory architecture governing stationary electricity storage at national level or, where necessary, within the principal electric-

ity market. Batteries receive particular attention because they account for most recent non-pumped-hydro additions, but the analytical dimensions are technology-neutral. Electric vehicles, portable devices, hydrogen production not reconverted to electricity, and storage studies without a policy, regulatory, market, planning, or public-value connection were outside scope.

The cases were selected purposively for institutional contrast. The United States represents a multilevel model in which federal wholesale-market regulation and fiscal policy interact with state procurement and planning. China represents planning and target-led expansion with evolving remuneration. Australia combines an energy-only wholesale market, explicit bidirectional resource participation, integrated planning, and competitive revenue underwriting. Algeria is the transfer case: a state-led electricity system with substantial renewable potential but, in the reviewed record, a less developed storage-specific enabling framework. The sample is analytical rather than statistically representative.

2.2 Source identification, verification, and eligibility

An exploratory search yielded 115 documents, of which 50 were retained based on their relevance, authority, and evidentiary contribution to the analysis. Bibliographic details for scholarly publications were verified against Crossref and publisher metadata, while institutional claims were substantiated using documents issued by ministries, regulatory authorities, system operators, statistical agencies, and international organizations. The search strategy combined the terms “energy storage” and “battery storage” with the name of each country and keywords related to policy, regulation, market design, market participation, tariffs, procurement, tenders, capacity, investment, safety, recycling, planning, and utilization. Backward citation tracing was also undertaken to identify foundational contributions to the literature on legal frameworks and electricity-market design.

No lower publication-year threshold was imposed. Recent evidence was prioritized when examining current policy arrangements, administrative measures, and deployment trends. Earlier studies and policy documents were retained when they remained relevant to the interpretation of regulatory mechanisms, market structures, or established empirical relationships. The final selection included two records identified during the concluding update: the World Bank/ESMAP guidance on storage regulation in developing power systems [18] and an empirical market-equilibrium analysis of battery investment and renewable generation [23]. Where administrative values had been superseded, the most recent authoritative figures were used. Earlier documents were nevertheless retained when required to reconstruct the introduction, original design, or subsequent evolution of a policy instrument.

Sources were eligible for inclusion when they addressed at least one of the following dimensions: legal classification; ownership and licensing; grid connection; market participation; revenue mechanisms; investment support; deployment targets and procurement; technical, safety, or environmental governance; system planning; installed capacity; utilization; or wider system effects. Duplicate records, unverifiable citations, studies concerned exclusively with technical components without a discernible policy dimension, non-stationary storage applications, and commentary lacking traceable supporting evidence were excluded. English-language sources were considered alongside relevant official documents published in French or Chinese, provided that their institutional provenance and operative meaning could be reliably established.

The evidentiary requirements were differentiated according to the nature of each claim. Legislation, regulatory decisions, official program documentation, market rules, and system-operator statistics provided the primary basis for statements concerning legal provisions, implementation status, and administrative or deployment figures. Peer-reviewed studies were given priority when interpreting policy mechanisms, investment behavior, system-level effects, and emissions outcomes. Industry reports were used selectively where comparable public evidence was unavailable, but they were not considered sufficient on their own to support causal conclusions. DOI-bearing references were checked against registered metadata, and institutional sources were examined for provenance and continuing accessibility.

2.3 Extraction and coding

Each record was coded in a source-by-dimension matrix containing jurisdiction, instrument, institutional level, implementation date and status, scope, barrier addressed, mechanism, and claim supported. This structure separates policy announcement from operational implementation. A legal entitlement, tender target, or technical standard was treated as implemented only when the reviewed record identified an operative rule, procedure, contract, or enforcement arrangement.

Seven dimensions organize the comparison: (1) legal recognition and asset status; (2) grid and market access; (3) revenue adequacy and bankability; (4) investment and innovation support; (5) targets and competitive procurement; (6) standards, safety, and environmental governance; and (7) system planning and data transparency. Documentary maturity was classified on an ordinal 0–2 scale. A score of 0 means that no storage-specific instrument was identified within the reviewed record; 1 denotes an indirect, subnational, pilot, developing, or incompletely implemented instrument; and 2 denotes an explicit instrument operating at national level or in the principal electricity market. Borderline cases received the lower score unless implementation was documented directly.

The scores are descriptive judgments, not measurements of policy effectiveness. They do not imply equal intervals, and they are not summed into a league table. A zero is evidence of non-identification within the review boundary, not proof of institutional absence. Coding was not performed independently by multiple reviewers, so no inter-rater statistic is reported. Traceable cell citations, conservative scoring, and explicit interpretation rules are used to make the judgments auditable.

2.4 Synthesis and transferability

The synthesis proceeded in three steps. First, each case was analyzed against the same seven dimensions. Second, recurring combinations of instruments were interpreted through five mechanisms: access, competition, valuation, risk reduction, and accountability. Third, policy functions were assessed for transferability to Algeria. Transferability was evaluated at the level of function rather than legal form. A design function was considered more robust when it appeared in more than one case or was supported by convergent analytical literature; its Algerian relevance was then assessed against sector structure, regulatory capacity, fiscal exposure, data availability, climatic conditions, and the maturity of market institutions.

The approach is configurational and interpretive. It can identify coherent packages, omissions, and plausible sequences, but it cannot isolate the causal effect of a particular policy from

battery cost decline, renewable additions, interest rates, supply chains, network constraints, fuel prices, or demand growth. These boundaries govern the language of the results: the article reports enabling conditions and observable implementation tests rather than policy-effect estimates.

3. ANALYTICAL FRAMEWORK: FROM STORAGE CAPABILITY TO PUBLIC VALUE

Energy storage does not generate public value merely because it is installed. Its contribution depends on where it is connected, how it is operated, which services it provides, and whether those services generate measurable benefits for the electricity system and society. The analytical framework developed in this review therefore traces a causal chain from the policy barrier to the instrument adopted, the mechanism activated, its effective implementation, and the resulting system outcome. Five mechanisms are considered: access, competition, valuation, risk reduction, and accountability. This approach distinguishes the formal adoption of a policy from its practical ability to support efficient, financeable, and socially beneficial storage deployment.

3.1 Why a policy package is required

Energy storage deployment is constrained by several interrelated regulatory, market, and institutional failures. The first is a regulatory-classification failure: storage alternates between electricity consumption and injection, yet existing rules may treat it exclusively as either load or generation. This ambiguity can result in inappropriate licensing requirements, duplicated network charges, or uncertain interconnection rights. The second is a valuation failure. Existing market products may compensate only a limited portion of the services that storage can provide, while benefits such as network-investment deferral, resilience, congestion relief, avoided curtailment, and emissions reduction often remain only partially valued or entirely unremunerated. The third is a coordination failure. Storage location, duration, and operating strategy can simultaneously affect generation, transmission, distribution, and consumers, whereas planning and procurement decisions are frequently made within separate institutional structures. A fourth barrier concerns investment risk. Storage projects generally require substantial upfront expenditure, while their financing depends on multiple revenue streams that may be volatile, correlated, and potentially self-cannibalizing as deployment increases. Finally, storage can generate environmental and safety externalities related to charging emissions, land and mineral use, fire hazards, and end-of-life management. No single policy instrument can address all these barriers. Capital subsidies can reduce initial investment costs but cannot remove restrictive market rules or ensure efficient dispatch. Deployment targets can create a visible project pipeline but may favor short-duration systems if energy capacity, availability, and performance requirements are not specified. Energy-market arbitrage rewards operational flexibility, but it may not provide sufficiently stable revenue or ensure that charging and discharging reduce system costs and emissions. Similarly, safety standards can limit operational risks but cannot, by themselves, establish a viable business case. Effective storage policy therefore requires a coordinated package of mutually reinforcing instruments. The sequence of implementation is equally important. Procurement introduced before clear interconnection rules may create projects that cannot connect on time, while market access without adequate valuation may make participation legally possible but financially unattractive. Likewise, public support without performance verification risks rewarding installed capacity rather than deliv-

ered system services. Figure 1 summarizes the mechanism-based sequence applied in this review: recognize storage, enable access, value its services, procure bankable performance, verify outcomes, and scale deployment only when the evidence supports expansion.

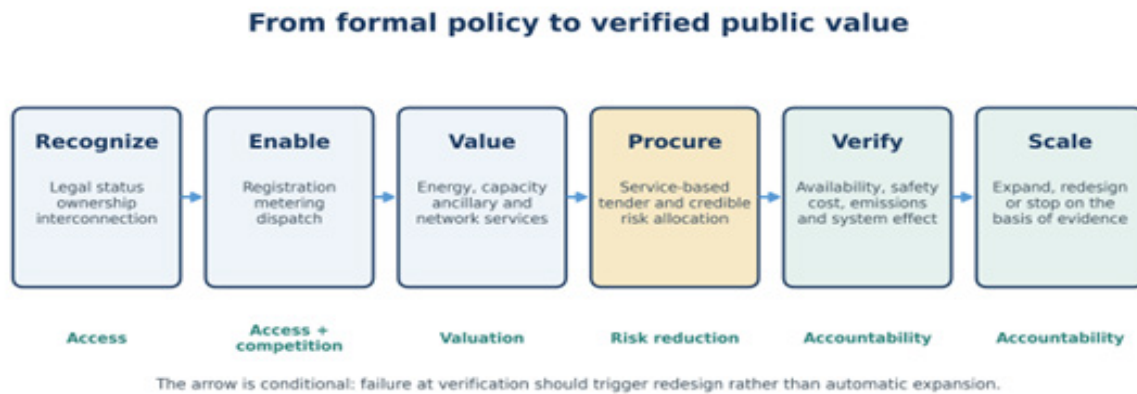


Figure 1. Mechanism-based sequence from formal recognition to verified public value. The sequence is conditional: implementation evidence determines whether an instrument should be expanded, revised, or discontinued.

3.2 Policy instruments and causal mechanisms

Table 1 organizes the principal energy-storage policy instruments according to the mechanisms through which they are expected to influence investment, deployment, and operation. The taxonomy begins with the barrier that each policy family is intended to remove and then identifies the mechanism through which the intervention may produce change. It also includes an observable implementation test, since the formal adoption of a law, market rule, or support scheme does not necessarily demonstrate that storage projects can use it in practice. The final dimension considers the principal design risk associated with each instrument, acknowledging that poorly calibrated policies may create new distortions even when they address a legitimate constraint. This structure provides a common analytical basis for comparing national policy frameworks and for distinguishing the existence of a policy instrument from its practical effectiveness.

The taxonomy demonstrates why policies commonly grouped under the broad label of incentives can produce fundamentally different outcomes. A tax credit primarily reduces capital costs, whereas a market-participation rule enables access. A contract for difference or capacity agreement addresses revenue risk, while a deployment target primarily addresses scale and coordination. Treating these instruments as equivalent obscures their causal functions and can lead to policy recommendations that do not address the underlying barrier [8–10]. The framework also separates policy announcement from effective implementation. The existence of a market rule, procurement target, or technical standard is insufficient unless the corresponding procedures, contractual arrangements, institutional responsibilities, and enforcement mechanisms are operational. The observable tests in Table 1 are therefore used in the comparative analysis to assess not only whether an instrument has been adopted, but also whether it can produce the intended outcome.

Table 1. Mechanism-based taxonomy of energy-storage policy instruments

Policy family	Principal barrier addressed	Mechanism activated	Observable implementation test	Main design risk
Legal definition and interconnection	Ambiguous asset status, duplicated treatment, and uncertain connection rights	Access: recognizes storage as a bidirectional resource and defines its rights and responsibilities	Storage can register, connect, charge, and discharge through explicit and consistent procedures	Technology-specific definitions or inconsistent treatment across network levels
Market-access reform	Exclusion from energy, capacity, or ancillary-service markets	Access and competition: allows technically capable resources to compete and combine multiple services	Participation models, bidding rules, metering, aggregation, dispatch, and settlement arrangements are operational	Formal eligibility without workable telemetry, baseline, aggregation, or settlement rules
Tariff and price reform	Distorted charging costs and inadequate temporal or locational signals	Valuation: aligns charges and remuneration with time, location, congestion, and system-service value	Unjustified double charging is avoided, and time-varying or service-based compensation is available	Retail arbitrage may redistribute costs without producing equivalent system value
Capital support and innovation funding	High upfront costs and technology, demonstration, or manufacturing risks	Risk reduction: lowers initial expenditure and supports technological learning	Tax credits, grants, concessional finance, demonstrations, and R&D awards include transparent eligibility conditions	Subsidizing nameplate capacity without regard to location, duration, performance, or additionality
Targets and competitive procurement	Coordination barriers, limited project pipelines, and weak cost discovery	Competition and risk reduction: creates predictable demand while revealing costs through competitive allocation	Requirements specify MW and MWh, duration, availability, delivery dates, performance obligations, and penalties	Politically determined volumes, weak additionality, or premature technological lock-in
Revenue underwriting and capacity remuneration	Volatile merchant revenues and limited project bankability	Risk reduction: converts uncertain service value into a more predictable revenue structure	Long-term contracts, floor-and-cap arrangements, capacity payments, or availability payments are operational	Overcompensation, asymmetric risk transfer, or excessive reduction of market incentives
Standards, safety, and circularity	Fire, electrical, interoperability, and end-of-life externalities	Accountability: establishes minimum technical, environmental, and safety requirements	Codes, testing procedures, incident reporting, recycling obligations, and producer-responsibility rules are enforced	Compliance requirements that exceed institutional monitoring and enforcement capacity
Integrated planning and public data	Fragmented decision-making and information asymmetry	Valuation and accountability: coordinates storage with generation, networks, and demand while enabling policy evaluation	System plans explicitly model storage, and public datasets report MW, MWh, duration, location, use, and performance	Planning models may undervalue resilience, distribution-level benefits, or long-duration services

3.3 Evaluation criteria beyond installed power

Installed power, expressed in megawatts, is an important deployment indicator, but it is not an adequate measure of policy effectiveness. Energy capacity in megawatt-hours and discharge duration determine how long a storage system can sustain its rated output. Availability, response time, round-trip efficiency, degradation, utilization, charging profile, and location further determine its operational contribution. Evaluation should therefore extend from asset

characteristics to system-level outcomes. Relevant indicators include avoided renewable energy curtailment, reliability contribution, congestion relief, deferred network investment, consumer costs, net marginal emissions, safety incidents, and end-of-life material recovery. These outcomes should be assessed against an explicit counterfactual because the same installed capacity can produce markedly different benefits under different renewable energy shares, network constraints, market arrangements, and charging patterns [3], [11–15]. Policy design should consequently specify the services and outcomes expected from storage rather than assume that a particular technology or capacity target will automatically deliver them. Competitive procurement can remain technology neutral while defining requirements for discharge duration, ramping capability, availability, grid-forming performance, environmental operating conditions, safety, and delivery location. Similarly, operating incentives can be linked to measured service delivery rather than to equipment installation alone. The analytical distinction is therefore between three successive levels: asset deployment, demonstrated by installed MW and MWh; service delivery, established through verified operational performance; and public value, demonstrated by measurable system and societal benefits relative to a credible counterfactual. This distinction underpins the cross-country comparison developed in the following sections.

4. COMPARATIVE CASE ANALYSIS: FROM DEPLOYMENT TO PUBLIC VALUE

4.1 United States: market access and fiscal support

The United States illustrates a layered policy architecture in which federal wholesale market rules, federal fiscal support, and state-level planning or procurement interact. The architecture is comparatively strong in market access and investment support but less uniform in long-term revenue certainty and national deployment targets.

The principal market-access reform is Federal Energy Regulatory Commission (FERC) Order No. 841. Issued in 2018, it required regional transmission organizations and independent system operators to establish participation models that recognize the physical and operational characteristics of electric storage. Eligible storage must be able to provide all capacity, energy, and ancillary services that it is technically capable of providing, buy energy at wholesale prices when charging for resale, self-manage state of charge, and participate subject to a minimum-size requirement not exceeding 100 kW [24]. FERC Order No. 2222 subsequently required organized wholesale markets to enable aggregated distributed energy resources, creating a pathway for smaller batteries and other flexible resources to participate collectively [25]. These orders address the access barrier, although implementation differs across regional markets and distribution-level interconnection remains largely under state jurisdiction.

Federal fiscal policy substantially changed the investment case for storage. For qualified energy-storage technology placed in service after 31 December 2024, the Clean Electricity Investment Credit under Internal Revenue Code Section 48E provides a base credit of 6% and up to 30% when prevailing-wage and apprenticeship requirements are met, with possible domestic-content and energy-community bonuses [26]. Unlike the pre-2022 framework, eligibility is not restricted to storage charged by a co-located renewable generator. This reduces capital cost and allows project configuration to follow system needs more closely. However, tax eligibility does not guarantee efficient siting, sufficient duration, or low-carbon operation; those outcomes depend on planning, market prices, and complementary procurement.

Deployment has accelerated. The U.S. Energy Information Administration reported 43.6 GW of operational battery storage at the end of 2025 and nearly 52 GW by the end of June 2026 [27]. The speed of growth is consistent with a stronger enabling environment, but causality cannot be assigned to one measure because cost declines, renewable additions, state mandates, resource-adequacy needs, and interconnection conditions changed simultaneously. Moreover, the large interconnection queue shows both investment interest and a continuing administrative bottleneck.

State policies add heterogeneity and experimentation. California and other states have used procurement requirements, integrated resource planning, rebates, and market reforms, while federal and state research programs support demonstration and manufacturing. Comparative studies of North American storage policy show that state innovation and regional market design have been important in developing stationary storage [28]. Empirical and modeling work also indicates that competition, tax support, and procurement can increase capacity while producing different distributions of risk and public value [12], [29–32].

The U.S. case therefore demonstrates a central principle: capital support becomes more effective when market-access barriers have already been reduced. Its main unresolved issue is not simple access but revenue durability and system alignment. Merchant revenue may decline as storage penetration increases and price spreads are arbitrated away, a market-equilibrium effect now documented empirically [23]. A project may also optimize private revenue without minimizing emissions or addressing the most valuable network constraint. Greater transparency on operating duty, degradation, marginal emissions, and stacked revenues is therefore needed to evaluate additionality and public value.

4.2 China: target-led scale with market remuneration under development

China represents a planning-led pathway in which national targets, provincial implementation, manufacturing capacity, demonstration programs, and evolving power markets jointly support rapid deployment. In 2021, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) set the objective of more than 30 GW of “new-type” storage by 2025 and full market-oriented development by 2030. The guidance recognized independent storage as a market participant and called for participation in medium- and long-term energy transactions, spot markets, and ancillary services, together with research on capacity-price and transmission-tariff mechanisms [33].

The target provided a strong and visible signal. By the end of 2025, the NEA reported 136 GW/351 GWh of commissioned new-type storage, with an average duration of 2.58 h. Power capacity had increased by 84% relative to the end of 2024 and substantially exceeded the initial 2025 target [34]. This expansion is consistent with the combined influence of targets, provincial requirements, industrial policy, and supply-chain capability. It also illustrates why deployment power must be reported together with energy capacity and duration: rapid MW growth does not by itself establish whether the portfolio can address multi-hour or multi-day flexibility needs.

China's policy emphasis is shifting from construction toward utilization, standardization, and market participation. The 2025-2027 special action plan promotes broader applications, improved dispatch and utilization, technical innovation, standards, participation in energy and ancillary-service markets, and development of pricing mechanisms [35]. In 2026, the NEA

described continuing work on independent-storage capacity pricing, provincial spot-market coverage, ancillary-service prices, and equal market status for new operating entities, including storage [36]. The same official series reported 1,195 equivalent utilization hours in 2025 and an average duration of 2.58 h, underscoring that construction, duration, dispatch, and settlement must be assessed together [34]. These reforms acknowledge a central tension: administratively driven expansion can deliver scale before a stable and nationally consistent revenue model is fully developed.

Research on Chinese storage investment confirms that policy uncertainty, subsidy changes, technology cost, and market rules affect the timing and value of investment [37]—mandatory renewable-plus-storage configurations can accelerate capacity, but they may also lead to low utilization when dispatch rights, compensation, and operational responsibilities are unclear. Provincial variation in peak-valley tariffs, capacity leasing, ancillary-service markets, and renewable integration further limits the meaning of a single national description.

The China case demonstrates the strength of target-led coordination and industrial learning, while highlighting the need to complete the transition from capacity mandates to service-based remuneration. The next policy test is whether storage is dispatched where and when it creates system value and whether revenues remain sufficient without perpetuating administratively required but underused assets. Transparent reporting of utilization, curtailment reduction, service revenue, duration, degradation, and safety performance would make this transition measurable.

4.3 Australia: bidirectional market integration and competitive revenue underwriting

Australia combines wholesale-market reform, long-term system planning, state and federal support, and competitive revenue underwriting. This package addresses both operational access and financing risk more directly than a capital subsidy alone.

The National Electricity Market (NEM) was historically designed around separate generation and load registrations. The Integrating Energy Storage Systems reform introduced an integrated resource-provider category and bidirectional-unit arrangements, allowing batteries and hybrid facilities to register, bid, and dispatch within a framework that better reflects their two-way operation. The principal implementation was completed in June 2024, followed by an industry transition period [38]. This change reduced a structural barrier and made market participation more consistent with storage physics.

The Capacity Investment Scheme (CIS) adds a risk-allocation instrument. It uses competitive tenders and revenue-underwriting agreements to accelerate renewable generation and clean dispatchable capacity. The scheme's target was expanded in 2025 to 40 GW by 2030, including 14 GW of clean dispatchable capacity [39]—tender outcomes specify both power and energy capacity. For example, the NEM dispatchable tender announced in September 2025 selected 16 projects totaling 4.13 GW and 15.37 GWh [39]. By providing downside protection while retaining competitive selection and exposure to market incentives, the CIS addresses the financing difficulty created by volatile and multi-source storage revenues.

Long-term planning complements the procurement mechanism. The Australian Energy Market Operator's 2026 Integrated System Plan identifies an optimal development path for generation, networks, storage, and consumer-energy resources to 2050 [40]. Operational evidence indicates that batteries are increasingly shifting daytime renewable energy into evening

peaks. AEMO reported that, between the second quarters of 2025 and 2026, battery projects totaling 4,640 MW/12,353 MWh began commissioning in the NEM. Installed battery power exceeded 9 GW, including both fully commissioned facilities and projects still being commissioned. Average battery discharge reached 476 MW, and battery charging and discharging together set spot prices in 36% of dispatch intervals, evidence that their role had progressed from installation to material market operation [41]. The Clean Energy Council separately reported record commissioning and financial commitments in 2025 [42].

The Australian literature nevertheless identifies risks. Storage revenue and emissions depend on dispatch and market conditions; price arbitrage does not always align with decarbonization [43]. State schemes, network rules, consumer-battery coordination, connection studies, and community acceptance remain important. Policy must also avoid transferring excessive price risk to consumers through poorly calibrated underwriting contracts.

Australia's distinguishing feature is the sequence market integration → integrated planning → competitive procurement with revenue underwriting. This architecture does not eliminate competition; it uses a competitively allocated contract to make investment financeable while preserving performance and market exposure. It offers a particularly relevant lesson for emerging markets that cannot initially rely on deep ancillary-service and energy-only markets to finance storage.

4.4 Algeria: renewable ambition without a complete storage-specific enabling layer

Algeria has strong solar resources, growing electricity demand, high-temperature operating conditions, and strategic reasons to reduce domestic gas consumption and diversify its energy system [19], [20]. The Ministry of Energy and Renewable Energies reports a national objective of 15,000 MW of renewable capacity by 2035, with a first 3,200 MW solar photovoltaic phase under development [21]. Sonelgaz signed contracts in 2024 for 3,000 MW of photovoltaic plants under the 2,000 MW and Solar 1,000 programs [22]. These additions will increase the value of flexibility, particularly for evening ramps, remote systems, reserve provision, and network-constrained regions.

The electricity sector is governed principally by Law No. 02-01 of 5 February 2002 and its implementing texts. The law created the Commission for Electricity and Gas Regulation (CREG), defined electricity-market actors, and assigned responsibilities for system balance, network operation, concessions, and renewable generation [44]. In the official and scholarly sources reviewed to the cutoff date, however, no national storage-specific legal category, wholesale participation model, remuneration framework, quantitative storage target, or competitive storage-procurement mechanism comparable to those in the other three cases was identified. This statement concerns the reviewed documentary record and should not be interpreted as proof that no pilot, internal utility practice, or project-specific arrangement exists.

Algerian energy transition studies consistently identify a gap between renewable potential and implementation, including financing, institutional coordination, industrial capability, and regulatory adaptation [19], [20]. General renewable targets do not resolve storage-specific questions: whether a storage operator may buy and sell electricity; who may own grid-side storage; how charging energy and network fees are treated; which entity procures flexibility; how capacity, ancillary services, or avoided network costs are valued; and which safety and end-of-life standards apply.

The lack of a mature energy-only or ancillary-service market does not prevent storage deployment, but it changes the appropriate first instrument. International experience in emerging markets shows that early projects often require concessional finance, public procurement, or utility-backed contracts before competitive service markets are sufficiently liquid [16], [17]. Directly copying the U.S. merchant market model would therefore be unsuitable. Australia's competitively tendered revenue underwriting and China's staged movement from planning and demonstration toward market remuneration offer more relevant design elements, provided that governance, transparency, and performance requirements are adapted to Algeria.

Algeria also has case-specific research needs. High ambient temperatures can accelerate battery degradation, increase cooling demand, and impose additional safety requirements. Remote and autonomous systems create different service values from interconnected utility-scale projects. Policy appraisal should therefore incorporate lifetime performance under Algerian climates, local maintenance capacity, cybersecurity, recycling and second-life pathways, and the potential for domestic integration of components and control systems. These factors support a staged, evidence-generating approach rather than an immediate undifferentiated capacity mandate.

5. CROSS-CASE SYNTHESIS AND COMPARATIVE ANALYSIS

5.1 Reading national deployment evidence without false equivalence

Administrative data show that energy storage has moved well beyond the demonstration stage in the three mature cases, although the reported quantities cannot be compared directly. The United States series covers utility-scale battery power capacity, while China reports commissioned “new-type” storage in both power and energy terms. The Australian figure refers specifically to batteries installed within the National Electricity Market (NEM) and does not necessarily capture all installations nationwide. In Algeria, no authoritative national series reporting installed storage capacity was identified by the review cut-off. Differences in technological coverage, geographical scope, minimum project size, measurement units, and observation dates prevent these values from being placed on a common quantitative scale without introducing unsupported assumptions. Figure 2 therefore preserves each indicator as reported by its original source and presents the values as contextual snapshots rather than as a ranking of national performance. In addition to situating the country cases, the figure highlights the importance of consistent public reporting for monitoring deployment and evaluating the practical effects of storage policy.

The figures should be read as jurisdiction-specific implementation signals rather than as a common market-size measure. A defensible cross-country quantitative comparison would require a harmonized dataset reporting, at minimum, technology, power, energy, duration, commissioning status, location, ownership, and reference date. In its absence, converting these values into a single storage rate, market-share percentage, or consumption chart would create precision unsupported by the source data. The comparative analysis that follows therefore uses documented policy architecture, not raw capacity, as its common basis.

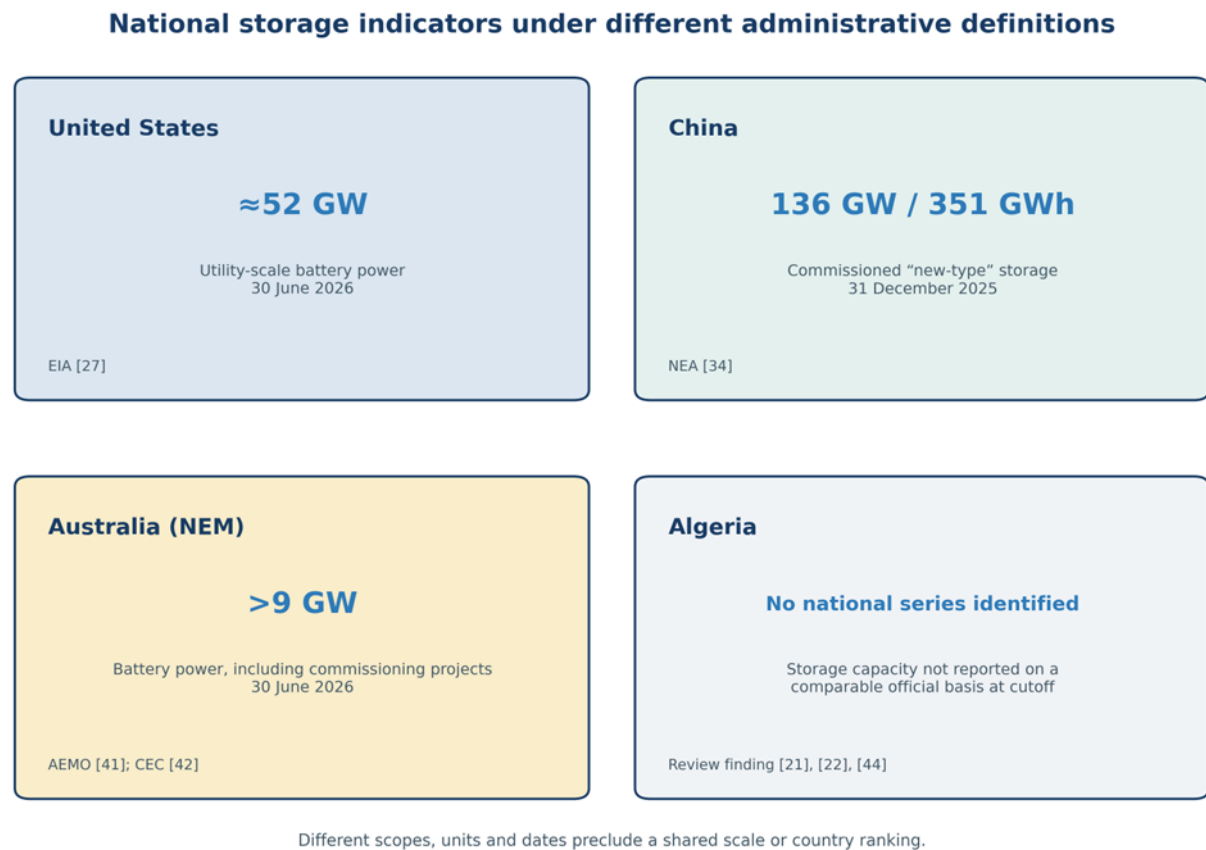


Figure 2. Source-defined administrative snapshots of storage deployment. Values differ in technology scope, geographic coverage, unit, and reference date; they are intentionally not plotted on a shared axis. Sources: [21], [22], [27], [34], [41], [42], [44]. The Australian total includes projects still being commissioned.

5.2 Policy-readiness matrix

Policy readiness is assessed here through the maturity of the documented institutional architecture governing energy storage, rather than through deployment outcomes or presumed policy effectiveness. Seven dimensions were evaluated using a three-level ordinal scale that distinguishes between instruments not identified in the reviewed record, arrangements that remain partial or under development, and provisions that are both explicit and operational. Figure 3 summarizes the resulting pattern, while Table 2 reports the underlying scores and supporting references. The comparison reveals three relatively developed but distinct policy configurations. Australia shows explicit and operational arrangements across most dimensions, whereas the United States and China retain areas of partial development, particularly in relation to revenue adequacy and bankability. For Algeria, the reviewed evidence indicates limited recognition of storage within planning and public data, but no clearly documented storage-specific framework across the remaining dimensions. These scores should therefore be interpreted as indicators of documentary and institutional maturity, not as proof of policy effectiveness, deployment performance, or the absence of project-specific initiatives outside the reviewed record.

Documented maturity of storage-policy architecture				
	United States	China	Australia	Algeria
Legal recognition	2	2	2	0
Grid and market access	2	1	2	0
Revenue adequacy	1	1	2	0
Investment support	2	2	2	0
Targets and procurement	1	2	2	0
Safety and environmental governance	1	2	1	0
Planning and data transparency	2	2	2	1

0 = not identified; 1 = partial/developing; 2 = explicit and operational. Scores are not effectiveness rankings.

Figure 3. Cross-country comparison of the documented maturity of national energy-storage policy architectures.

Table 2. Evidence-linked documentary maturity of national energy-storage policy architectures as of 16 August 2026

Dimension	United States	China	Australia	Algeria
Legal recognition and asset status	2 [24], [25]	2 [33]	2 [38]	0 [21], [22], [44]
Grid and market access	2 [24], [25]	1 [33], [36]	2 [38]	0 [44]
Revenue adequacy and bankability	1 [26], [28–32]	1 [33], [36], [37]	2 [39]	0 [16], [17], [44]
Investment and innovation support	2 [26], [28–32]	2 [33–37]	2 [39], [42]	0 [16], [17], [19–22], [44]
Targets and competitive procurement	1 [28–32]	2 [33–35]	2 [39]	0 [21], [22], [44]
Standards, safety, and environmental governance	1 [28]	2 [35]	1 [38–40]	0 [44]
System planning and data transparency	2 [24–28]	2 [33–36]	2 [39–42]	1 [21], [22], [44]

Note: 0 = no storage-specific instrument identified in the reviewed record; 1 = partial, indirect, subnational, pilot, developing, or incompletely implemented; 2 = explicit and operational at national level or in the principal electricity market. Scores describe documentary maturity, not causal effectiveness. A score of 0 is not proof that no pilot, utility practice, or project-specific arrangement exists.

The matrix reveals distinct profiles rather than a single hierarchy. The United States is

strongest in wholesale-market access and fiscal support, while procurement, safety governance, and long-term revenue certainty remain fragmented across states and markets. China combines national targets, planning, standards, and innovation support, but access and remuneration remain heterogeneous. Australia combines bidirectional participation, integrated planning, competitive tenders, and revenue underwriting. Algeria's profile reflects limited storage-specific documentation in the reviewed record, not a judgment on renewable resources, technical competence, or the existence of unreported pilots. For this reason, the analysis relies on the pattern across dimensions and does not interpret small score differences as meaningful performance gaps.

5.3 Comparative policy configurations

The cases can be summarized as four comparative policy configurations. These configurations describe recurring combinations of instruments and institutional functions; they are not universal stages or estimates of policy effectiveness:

1. Market-enabling plus fiscal support (United States): access reforms permit competition across multiple services, while tax incentives reduce capital cost. The configuration's strengths are innovation and rapid deployment; its principal limitations are fragmented procurement, uneven state coverage, and exposure to volatile merchant revenues.
2. Target- and planning-led scale (China): national and provincial targets, industrial policy, and demonstrations mobilize deployment and learning. The configuration's strengths are coordination and scale; its principal limitations are heterogeneous market access, evolving remuneration, and the risk that installed capacity outpaces effective utilization.
3. Market integration plus competitively allocated underwriting (Australia): tenders that reduce revenue risk complement bidirectional participation and integrated planning. The configuration's strengths are transparent procurement and bankability; its principal limitations concern contract calibration, system-cost allocation, and the emissions consequences of dispatch.
4. Renewable expansion without a storage-specific enabling layer (Algeria): renewable projects advance under general electricity-sector institutions, while the reviewed record does not yet identify an equally explicit storage-specific legal, remuneration, target, or procurement framework. This configuration creates an opportunity to generate evidence through differentiated pilots before committing to large-scale support.

5.4 Mechanism-level findings

Five findings emerge from the cross-case comparison.

First, sequencing matters. Legal recognition, interconnection, metering, and dispatch rules are foundational. Financial support provided before these conditions are clarified can create installed assets that cannot access the services needed for economic operation. The U.S. and Australian cases show that market-participation reform expands the set of monetizable services; the China case shows that rapid target-led construction increases pressure to complete remuneration and dispatch reform.

Second, access and bankability are different policy problems. Allowing participation

does not ensure sufficient or financeable revenue. Storage revenues are volatile, may come from several products, and can decline as competing storage suppresses price spreads. Australia's competitive underwriting addresses this problem directly. In contrast, tax credits primarily reduce capital expenditure, and targets primarily create a pipeline. A mature policy package should identify which risk is borne by investors, consumers, utilities, and government [8–10].

Third, procurement should specify service, duration, and performance—not only MW. China's experience demonstrates the power of a capacity target, while Australian tenders illustrate the added information contained in MW and MWh requirements. Procurement should define availability windows, discharge duration, response, cycling expectations, degradation accountability, interconnection milestones, safety, and delivery penalties. Technology neutrality is compatible with rigorous service specifications.

Fourth, storage policy should be emissions-aware. Evidence from the United States and Australia shows that revenue-maximizing operation can increase emissions when price and marginal emissions are misaligned [11], [12], [43]. Public support should therefore be evaluated against avoided curtailment, marginal emissions, and system need. Options include carbon pricing, emissions-aware dispatch signals, clean-charging conditions where justified, or performance reporting that reveals the charging mix without prescribing a single operating rule.

Fifth, transparent data are a policy instrument. Public reporting of power, energy, duration, location, availability, utilization, services, incidents, degradation, and public support enables regulators to correct design errors and researchers to evaluate outcomes. Installed-capacity announcements alone cannot reveal underutilization, congestion value, reliability contribution, or emissions. For emerging markets, data obligations attached to pilots can create the evidence base needed for later competitive procurement.

5.5 Transferability to Algeria

Transfer does not mean copying institutional form. FERC participation rules presume organized wholesale markets; China's mandates presume strong planning and provincial implementation capacity; Australia's underwriting operates within the NEM and a mature tender framework. Algeria requires functional equivalents suited to a vertically coordinated and state-led system.

The transferable functions are nevertheless clear: define storage as a bidirectional flexibility resource; establish interconnection and dispatch rights; identify a creditworthy buyer of storage services; use transparent competitive procurement; specify performance in both MW and MWh; collect operational data; and integrate safety, climate resilience, and end-of-life requirements. These functions can initially be implemented through regulated utility procurement and later opened to broader market participation as institutional capacity develops.

6. A STAGED POLICY ROADMAP FOR ALGERIA

The comparative evidence supports an evidence-informed three-stage pathway for Algeria. It is a proposed sequencing framework, not a forecast, a binding legal prescription, or a claim that the same instruments will produce identical effects across jurisdictions. The stages may overlap, but each is designed to reduce a different uncertainty: institutional and technical feasibility, procurement and revenue adequacy, and finally scalable market integration. Progression should therefore depend on evidence generated during the preceding stage rather

than on a capacity target set independently of quantified system needs.

6.1 Stage I (institutional foundation and evidence-generating pilots)

The first stage should establish the legal and technical basis for storage. A regulatory text under the existing electricity law should define electrical energy storage as a bidirectional resource, clarify permissible ownership models, and assign responsibilities for connection, metering, dispatch, and settlement. CREG, the system operator, Sonelgaz entities, research institutions, civil protection, standards bodies, and environmental authorities should jointly prepare interconnection, fire-safety, cybersecurity, environmental, and end-of-life requirements.

A national flexibility-needs assessment should then quantify use cases by location and time scale: isolated southern systems, renewable smoothing, evening peak supply, operating reserves, transmission and distribution constraints, black start, and critical-load resilience. The assessment should distinguish power (MW), energy (MWh), duration, response time, availability, and climate requirements. Open methods and public assumptions would allow independent review.

Two or more competitively selected pilots should test distinct services rather than repeat the same configuration. Candidate pilots include a solar-plus-storage plant supporting the interconnected system; a high-temperature autonomous or weak-grid installation in southern Algeria; and a distribution-level project testing peak relief or critical-service resilience. Contracts should require publication of non-confidential data on charge and discharge energy, state of charge, availability, efficiency, degradation, temperature, incidents, curtailment, service delivery, and lifecycle cost.

6.2 Stage II (competitive procurement and regulated remuneration)

Once pilot and planning data define the need, Algeria can procure storage services competitively. Tenders should specify the required service and location, together with MW, MWh, minimum duration, availability windows, response, grid-forming or black-start capability where required, environmental operating range, safety certification, commissioning deadlines, and performance penalties. Qualification should remain technology-neutral where technically possible.

Because a liquid merchant market is not yet the appropriate financing basis, an initial regulated revenue model is required. Options include an availability payment, a capacity-service agreement, or a competitively determined floor-and-cap contract. The selected structure should expose developers to performance and operational incentives while preventing the public purchaser from bearing unlimited downside risk while allowing developers to retain all upside gains. Competitive tenders, transparent evaluation, bid bonds, delivery milestones, and independent verification can reduce procurement risk.

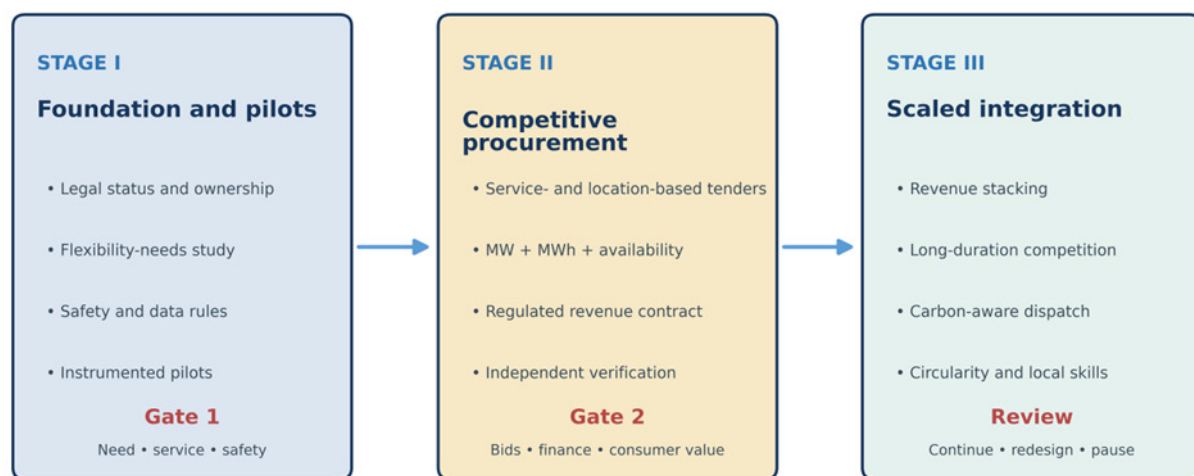
Tariff reform should prevent double charging and establish time- and service-differentiated compensation. Storage used as a network alternative should be evaluated against conventional reinforcement using consistent cost and reliability criteria. Behind-the-meter and community pilots can be introduced through time-of-use tariffs and aggregation rules, but only with consumer protection, metering, and rules that prevent cost shifting.

6.3 Stage III (scaled integration, revenue stacking, and circularity)

The comparative findings indicate that storage-policy development in Algeria should fol-

low a sequenced, evidence-led pathway rather than replicate instruments adopted in more mature markets. As outlined in Figure 4, the immediate priority is to establish legal, technical, and safety foundations and generate reliable evidence through well-instrumented pilot projects. Competitive procurement and more advanced market arrangements should be introduced only when system needs, project performance, financing conditions, and consumer value have been adequately demonstrated. The stages are not tied to a fixed timetable; progression depends on evidence, institutional readiness, and periodic review.

Conditional policy pathway for Algeria



Progress is evidence-dependent; stages may overlap, but later instruments should not substitute for missing foundations.

Figure 4. Proposed conditional pathway for storage-policy development in Algeria. Progression depends on explicit decision gates and may be paused or redesigned when evidence is insufficient.

The staged pathway presented in Figure 4 is translated into an operational roadmap in Table 3. For each stage, the table links priority policy actions to the institutional functions required for implementation and to the evidence that should be available before storage deployment is expanded. This structure is intended to prevent premature scaling: legal and technical foundations are established first, procurement follows once pilot evidence is sufficiently robust, and advanced market integration is introduced only when system performance and public-value outcomes can be assessed. The proposed institutional roles remain indicative and would require formal assignment following legal and institutional review.

This roadmap is consistent with evidence from emerging and transitioning markets, where legal clarity, creditworthy procurement, system-value assessment, and institutional coordination precede broad merchant participation [5], [16–18], [45–50]. Its central safeguard is conditional scaling. Advancement from Stage I should require verified service delivery, a defensible locational need, acceptable safety performance, and a lifecycle-cost benchmark. Advancement from Stage II should additionally require competitive bid tension, auditable availability, evidence of consumer value, and a financing structure that does not place unlimited downside risk on the public purchaser. Each stage is therefore a decision gate, not merely a calendar

period.

Table 3. Proposed storage-policy roadmap for Algeria

Stage	Priority actions	Lead institutional functions	Evidence required before scaling
I. Foundation and pilots	Legal definition; ownership and connection rules; needs assessment; safety and data standards; differentiated pilots	Ministry: policy; CREG: regulation; system operator/Sonelgaz: system requirements and procurement; research and standards bodies: testing and evaluation	Locational flexibility need; MW/MWh/duration; lifecycle cost; high-temperature performance; service verification; safety record
II. Competitive procurement	Service-based tenders; availability or floor-and-cap contracts; tariff reform; independent performance verification	Regulator and public purchaser with transparent tender governance	Competitive bids; financing terms; availability; degradation; curtailment and network impacts; consumer cost
III. Scaled integration	Revenue stacking; periodic planning; aggregation; long-duration competition; carbon-aware dispatch; recycling and second-life regulation	Market/system operator, regulator, utilities, environmental and industrial authorities	Market liquidity; marginal emissions; long-duration need; material flows; distributional and local-industry effects

Note. Stages are conditional decision gates, not fixed calendar periods. Lead functions should be assigned formally following legal and institutional review.

7. LIMITATIONS AND RESEARCH AGENDA

7.1 Limitations

This study has four principal limitations. First, it is a structured narrative review rather than a systematic review. The search scope, eligibility criteria, and update date are disclosed, but the exploratory origin of the initial corpus and reliance on targeted searching mean that exhaustive coverage cannot be guaranteed. The four cases were selected for analytical contrast rather than statistical representativeness; additional European, Asian, Latin American, and African cases could reveal other configurations.

Second, the policy-readiness profiles measure documentary maturity, not policy quality or causal effectiveness. The ordinal categories compress differences among federal, provincial, state, market, and utility arrangements, and the study does not report independent dual coding or inter-rater agreement. Evidence-linked citations and conservative scoring improve traceability but do not eliminate author judgment. A score of 2 does not demonstrate uniform implementation, cost-effectiveness, or equity, while a score of 0 means only that an instrument was not identified within the reviewed record. The matrix should therefore be interpreted dimension by dimension rather than as a precise country ranking.

Third, policy and deployment change rapidly, and the cutoff date must accompany any reuse of the matrix. Fourth, observed deployment cannot be attributed to policy alone: battery prices, renewable additions, interconnection capacity, supply chains, interest rates, fuel prices, demand growth, and industrial policy act simultaneously. The proposed Algerian roadmap is consequently an evidence-informed design proposition that still requires legal review, stakeholder consultation, system modeling, and pilot validation. Future work should use proj-

ect-level and time-series data to separate policy effects from these concurrent drivers.

7.2 Research agenda

The review identifies seven research priorities.

1. **Causal evaluation of policy packages.** Cross-state, cross-province, and cross-country quasi-experimental studies should estimate the additional storage investment, service delivery, and consumer benefit attributable to specific reforms. Difference-in-differences, synthetic-control, and event-study designs could test market-access rules, tax credits, procurement, and capacity payments while controlling for battery prices and renewable growth.
2. **Revenue adequacy and contract design.** Research should compare merchant operation, availability payments, capacity mechanisms, cap-and-floor contracts, and contracts for differences under common assumptions. The relevant outcomes are financing cost, competition, dispatch efficiency, consumer exposure, and technology neutrality—not only project internal rate of return [8–10].
3. **Carbon-aware storage operation.** High-resolution marginal-emissions data should be linked to storage charging and discharging. Studies should determine when price signals align with emissions and assess carbon pricing, clean-charging rules, or reporting requirements without unnecessarily restricting reliability services [11], [12], [43].
4. **Long-duration and multi-timescale value.** Planning models should distinguish sub-hourly reserves, intraday shifting, multi-day adequacy, and seasonal balancing. Common sensitivity analyses are required for weather years, renewable portfolios, transmission expansion, demand flexibility, and firm low-carbon resources.
5. **Safety, degradation, and climate robustness.** For Algeria and other hot-climate regions, field and accelerated-aging studies should connect temperature exposure, cycling duty, state of charge, cooling demand, failure risk, and lifetime cost. Procurement specifications should be validated against measured degradation rather than nominal laboratory performance.
6. **Circularity and second life.** Research should establish state-of-health thresholds, traceability, liability, testing, safety, and economic conditions for reuse. Lifecycle assessment must account for avoided production, additional processing, transport, degradation, and final recycling.
7. **Equity and institutional capacity.** Distributional analysis should identify who pays for storage support and who receives reliability, bill, employment, and environmental benefits. For emerging markets, research should also evaluate procurement capability, data governance, workforce needs, foreign-exchange exposure, and the design of concessional finance.

A research agenda is most useful when its broad priorities are translated into questions that can be investigated with appropriate methods and data. Table 4 makes this connection explicit by linking each research question to a preferred analytical approach, the minimum evidence required, and the policy decision that the results would inform. The proposed structure directs future work toward measurable outcomes, including deployment additionality, financing costs, emissions, storage duration and location, climate-related performance, and

second-life applications, thereby supporting policy decisions based on verified evidence rather than untested assumptions.

Table 4. Priority research questions and decision-relevant evidence

Research question	Preferred analytical approach	Minimum data	Policy decision informed
Which policy package causes additional deployment and service delivery?	Quasi-experimental panel or matched-project analysis	Policy dates, project pipeline, commissioning, prices, renewable additions, interconnection	Selection and continuation of incentives
Which contract minimizes financing cost without over-compensation?	Stochastic cash-flow and auction analysis	Bids, revenues by service, financing terms, availability, penalties	Procurement and risk allocation
Does storage operation reduce marginal emissions?	Chronological dispatch and marginal-emissions analysis	Charge/discharge intervals, generation mix, losses, congestion	Carbon-aware tariffs and reporting
How much duration is required and where?	Capacity-expansion plus production-cost modeling across weather years	Load, VRE, network, outages, resource costs, reliability standard	MW/MWh targets and siting
How does hot climate affect lifecycle value and safety?	Field monitoring plus accelerated aging and thermal modeling	Temperature, SOC, current, cooling, degradation, incidents	Technical specifications and warranty
When is second-life use environmentally and economically justified?	Lifecycle assessment and techno-economic analysis	SOH, use history, repurposing cost, failure rate, recycling yield	Reuse certification and producer responsibility

8. CONCLUSION

This review examined which combinations and sequencing of policy instruments enable storage to support renewable-energy integration and which functions are transferable to Algeria. Its principal contribution is an evidence-linked policy-readiness framework that connects seven institutional dimensions to five mechanisms—access, competition, valuation, risk reduction, and accountability—and then translates the comparison into a staged Algerian pathway. The analysis shows that storage deployment depends on a policy architecture rather than an isolated incentive.

Across the three more mature cases, different configurations perform complementary functions. The United States combines wholesale-market access with strong fiscal support but retains fragmented procurement and merchant-revenue risk. China demonstrates the mobilizing power of national targets, industrial policy, and planning while remuneration and utilization rules continue to evolve. Australia combines bidirectional market integration, integrated planning, and competitively allocated revenue underwriting. These configurations are not interchangeable templates; they reveal functions that must be adapted to the host electricity sector.

In Algeria, renewable expansion creates a growing need for flexibility, but the reviewed record does not yet show a comparably explicit storage-specific legal status, remuneration mechanism, target, or competitive procurement route. The proposed response is conditional sequencing: establish legal and technical foundations, quantify locational and temporal needs, and procure differentiated pilots; use the resulting evidence to design competitive service-based tenders and regulated revenue contracts; and expand revenue stacking, carbon-aware operation, and circularity only as institutions and data mature.

The synthesis therefore yields a practical policy rule: recognize, value, procure, verify, and then scale. This rule is an analytical proposition rather than a causal estimate. Its implementa-

tion requires legal validation, transparent procurement, measured performance under Algerian climatic conditions, and periodic revision as costs, technologies, and system needs evolve. Future research should test policy additionality, revenue adequacy, marginal-emissions effects, long-duration value, climate robustness, safety, circularity, and distributional outcomes.

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