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PNNL-38892

Developing a Framework for Valuation of Grid Services

January 2026

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U.S. DEPARTMENT of ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Abstract

The electric system is rapidly evolving and growing, raising new questions about how to define and value grid services delivered by a diverse set of resources, including customer-owned assets. This report advances a service–parameter–value framework that links what a grid service does to why it matters, and how its benefits are evidenced. We build upon prior efforts (Bender et al. 2021) and extend them to include value categories (reliability, resilience, cost & access, and security) with primary and secondary tiers, service-specific value streams that explain how benefits materialize, and metrics that make valuation traceable and comparable. We apply the framework to the six core grid services defined in (Kolln et al. 2023): Frequency Response, Regulation, Reserves, Energy, Voltage Management, and Blackstart and demonstrate it on three use cases to highlight the adaptability of these value streams. Further, we outline how the framework integrates with existing tools such as asset optimization, hosting capacity and cost-benefit analysis, and propose a path to portable qualifications and consistent stacking rules for use in tariffs and filings. Finally, we identify future pathways for research and application research needs, including user weighting, frequency-domain characterizations, and proxy metrics for non-monetary value to support standardization and decision-ready comparisons across services, assets, and architectures.

Summary

This report builds on prior work to refine and extend how grid services are characterized and valued using the Pacific Northwest National Laboratory's (PNNL) Transactive Systems Program (TSP) valuation methodology (Bender et al. 2021). Our objectives are fourfold:

- Consolidate and update the understanding of grid services and their valuation
- Develop a consistent taxonomy for service value
- Structure the service–parameter–value relationship in a way that is usable for grid modeling, and
- Identify trade-offs, synergies, and differences in value across services and between distribution and wholesale contexts.

The findings are intended for distribution and bulk-system planners and operators, regulators and policymakers, customers, and aggregators who need a traceable, comparable, and portable basis for valuing grid services. This framework helps each of these users move from ad-hoc or technology-specific assessments to a unified service-focused structure. With a standardized value framework, users can reduce ambiguity in calculating value, improve alignment between technical performance and compensation, and use transparent evidence for planning, procurement, and policy design.

We advance existing frameworks by parameterizing a value-based optimization view of grid services and aligning terminology with Department of Energy's Distribution Grid Transformation Program, the Grid Modernization Initiative (GMI) Energy Services Interface (ESI) effort (Hammerstrom et al. 2024), and TSP valuation methodology (Bender et al. 2021). The National Energy Standards Board (NAESB) WEQ-025 and REQ-030 grid service definitions (Kolln et al. 2023) anchor our service definitions with electrical and timing attributes and performance determinations. The TSP valuation methodology broadens the valuation lens beyond distribution and stakeholder-focused value to cross-level service-focused coordination. GMI's valuation efforts inform our value definitions and taxonomy. Taken together, these sources provide the baseline we fit valuation into. In addition, they highlight three key elements to consider for our framework development:

- A stable, technology-agnostic attribute set for meaningful, comparable valuation
- Non-monetary dimensions (e.g., resilience, security, access) alongside monetary measures, with explicit trade-offs to capture the multi-dimensional nature of value, and
- Cross-level value flows and distribution-level sourcing to change who benefits, where, and when.

This is illustrated in Figure 1 below:

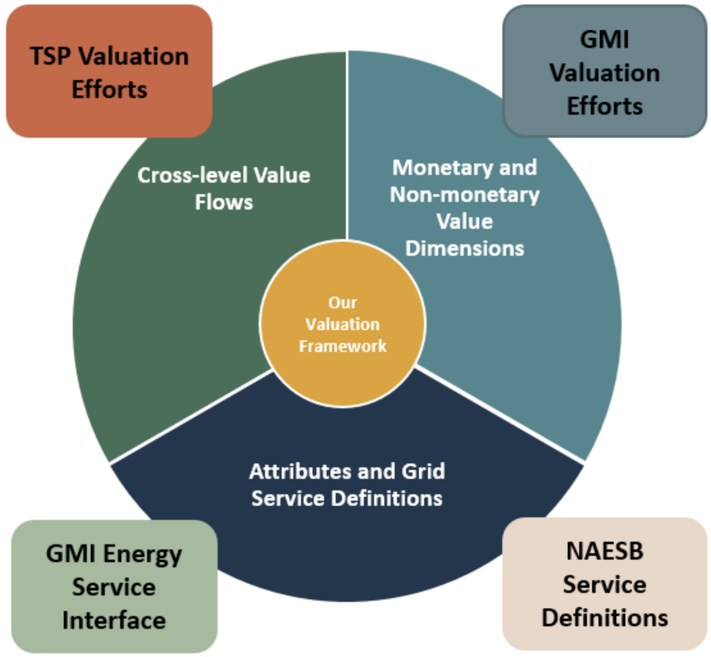

Figure 1. Conceptual connections between existing frameworks and past work that inform our valuation framework.

We propose a layered framework that links *what* a service delivers to *why* it matters and *how* benefits are evidenced. This framework is illustrated in Figure 2. Each grid service is defined by its electrical and temporal attributes. These services and their attributes map to value categories that describe why the service matters for grid objectives. The value categories, in turn, encompass value streams that explain how the service generates value, while metrics provide observable and auditable evidence of that value. Together these layers create a traceable chain from definition to observed value. It is important to note that these metrics are broad in scope, meaning that their direct measurement does not inherently convey the value of a service. Rather, the explicit contribution is realized only by comparing the metric with the service in place against its baseline without the service. The direction and magnitude of the resulting change provide evidence of whether, and to what extent, the service delivered value.

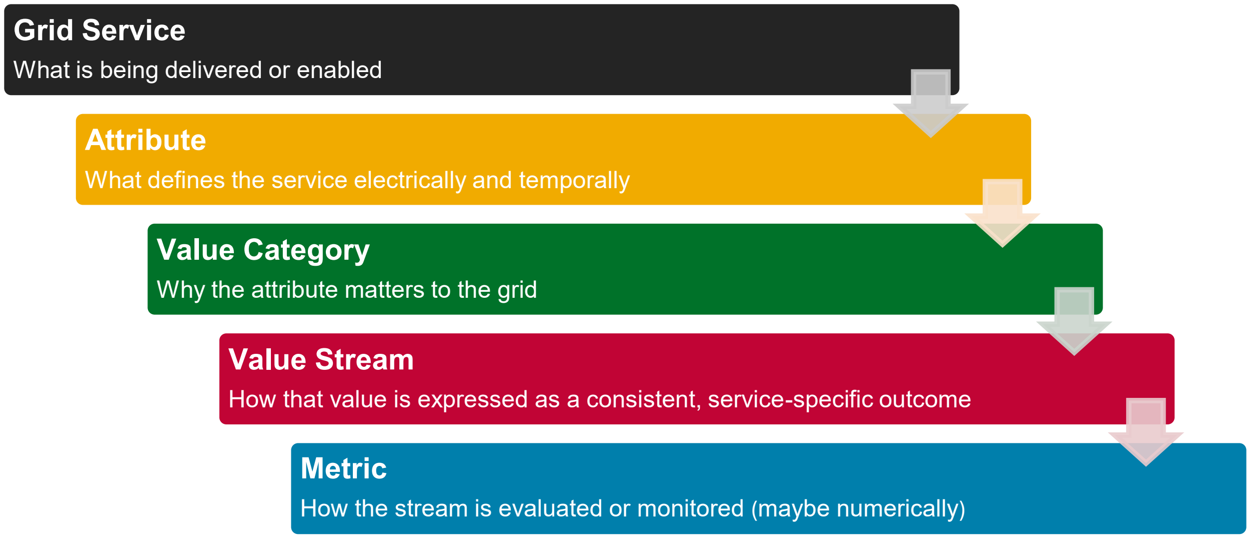

Figure 2. Service-Parameter-Value framework that utilizes metrics to convey how grid service benefits are evidenced.

For visualization, we build layered component diagrams of the completed framework for each service. Attributes are technology-agnostic but performance-specific, enabling different assets to qualify if they meet the same thresholds. Value categories are labeled as primary and secondary to clarify what is required for qualification versus what is co-delivered. To keep the diagrams readable and application-agnostic, we do not show value streams in the figures; some attribute–metric links remain to be finalized as part of future work as value activity diagrams. The layered component diagram visualized in Figure 3 is shown here as an example.

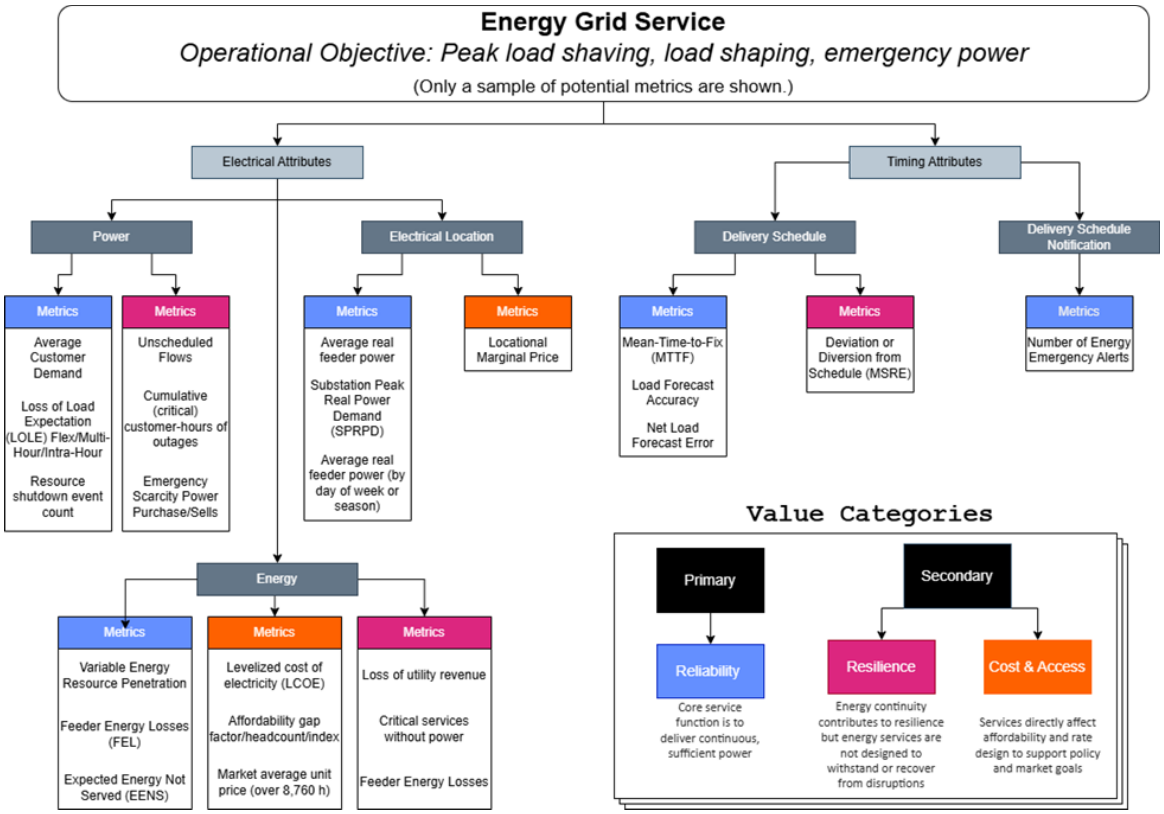

Figure 3. Example of a layered component diagram for Energy service used to illustrate example metrics in the service-parameter-value framework.

We demonstrate the framework on three use-cases to show how it performs under real constraints and to stress-test portability: rural distribution co-ops, generation & transmission (G&T) co-ops, and customers with grid assets. For rural distribution co-ops, the framework makes visible how local services like Voltage Management, Regulation from aggregated customer assets, Reserves, and Energy reduce peak charges and improve member reliability, while highlighting that deliverability depends on feeder topology, sparse telemetry, and priority rules for shared headroom. For G&T co-ops, the framework clarifies how Reserves, Regulation, Energy, and Frequency Response shape adequacy and portfolio costs, with deliverability bounded by tie-line limits, congestion, and unit-commitment constraints; standardized metrics help separate economic effects from reliability outcomes. For customers with grid assets, the framework shows how household-level assets provide contributions when aggregated, creating both direct bill savings and system stability benefits, while requiring stacking rules (e.g., voltage-first) to avoid double counting limited inverter capacity. Overall, the same service-parameter-value chain produces audit-ready results at each scale while making value deliverability explicit.

Across all three cases, the framework demonstrates that a single service–parameter–value chain can generate traceable, audit-ready outputs regardless of scale or asset type. This consistent value basis encourages value deliverability, stacking limits, and trade-offs to be surfaced explicitly rather than buried inside modeling assumptions.

We also look ahead to standardization and future work and consider how the framework will serve its target audience. To apply the framework to modeling practice, we recommend:

- Treating attributes as constraints or variables

- Representing value streams as time-series or event data labeled by service, location, time resolution, and value category, and
- Defining metrics as audited, reportable outcomes.

This way, planning studies, asset optimization, hosting-capacity and avoided-cost tools, and transmission-distribution co-simulation all produce comparable, decision-ready results. Value categories can receive weighting for multi-criteria comparisons, with location and time of service as drivers of value deliverability.

Future work will explore alternative analyses (e.g., frequency-domain for regulation effort) to characterize value, and where data are sparse, use proxies and machine learning surrogates with stated uncertainty to stand in as metrics. The path to standardization is to keep valuations traceable and portable across technologies, programs, and jurisdictions. Adding clear stacking rules (priority, opportunity-cost accounting, anti-double-counting) will enable a bridge to policy and tariff use. By making valuation traceable, comparable, and portable, the framework lays the foundation for more resilient, reliable, and affordable future grid operations and will be validated in future work.

Acronyms and Abbreviations

ACE	Area Control Error
AGC	automatic generation control
BA	balancing authorities
co-op	cooperative
DSO	distribution system operator
G&T	generation & transmission
GMI	Grid Modernization Initiative
GMLC	Grid Modernization Lab Consortium
ISO	independent system operator
M&V	measurement and verification
NAESB	National Energy Standards Board
NERC	North American Electric Reliability Corporation
PNNL	Pacific Northwest National Laboratory
TSP	Transactive Systems Program
UML	Unified Modeling Language

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1.0 Introduction

As the power system evolves, regulators and markets are reconsidering how to maintain grid objectives such as resilience and reliability. Distributed architecture with declining synchronous inertia, a growing number of inverter-based resources, and expanded electrified loads are key elements to consider in the evolving grid. One emerging response is the use of service-oriented, performance-based mechanisms that offer a way to align end user behavior with grid objectives. At the core of these mechanisms is the grid service interface, a bi-directional, service-oriented layer that translates system needs into actionable commitments between those who require grid services and those resources capable of providing them (Hammerstrom et al. 2024). Prior work advanced the standardization of grid service mechanisms and their attributes across wholesale and retail contexts with the intention of differentiating operational goals and physical performance (Kolln et al. 2023; Liu et al. 2022). But critical gaps remain in linking specific services to the value they can provide for interpretability.

This work introduces a framework designed to address that gap by shifting focus away from purely supply-side-centric planning toward a more balanced, service-based approach. The framework provides a structured way to compare how grid services contribute to system objectives, placing both technical and economic value on a common footing. In doing so, it helps mesh formal technical standards with the policy and regulatory language needed to guide implementation, enabling consistent interpretation across planning, market design, and policy contexts.

To operationalize this framework, we employ the valuation methodology developed under the Transactive Systems Program (TSP) at Pacific Northwest National Laboratory (Bender 2021). Valuation provides the structure for linking grid services to measurable forms of value and quantifying how agreements at the grid service interface translate into outcomes. Valuation is an iterative process of assessing the value generated by systems at the grid service interface (Bender et al. 2021). It involves first identifying value exchanges among relevant actors, then selecting appropriate metrics and the data to calculate them and finally modeling value exchanges within the system operations (Bender 2021).

Valuation begins by studying the system to understand the valuation goals. This establishes the scope of analysis, including what decisions the valuation will inform. The next step identifies value exchanges to understand what stakeholder perspectives should be considered. The third step identifies the system actors involved in value exchange. Each actor’s roles, responsibilities, and incentives are clarified to determine where value is created, transferred, or consumed. The fourth step defines metrics to outline what should be measured and calculated for valuation. The fifth step looks more closely at metrics to define data streams and collect relevant data. Lastly, study objectives get refined before the full valuation model is created to explore whether discrepancies between the model and research goals exist. Figure 4 summarizes these six steps.

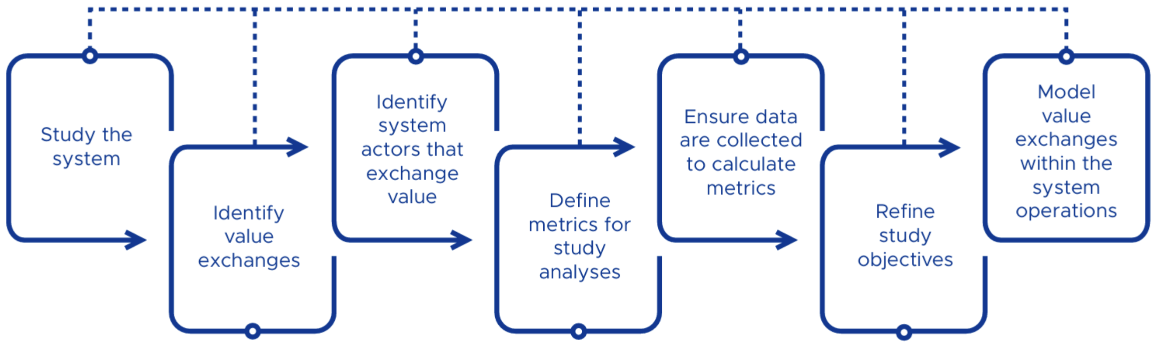

Figure 4. Valuation methodology for the TSP at PNNL that provides a foundation for the service-parameter-value framework in this report (Bender et al. 2021).

The valuation methodology brings a structured, system-level understanding of value to grid services. In retail settings, the approach clarifies the value streams between end users and service providers, which supports the development of fair pricing mechanisms, customer incentives, fair business models for customer owned assets, and demand response programs. In wholesale contexts, it provides a framework for assessing how grid-support services contribute to grid objectives. Valuation also creates opportunities for alignment of technical, financial, and societal dimensions, helping decision-makers and grid operators provide grid services that are not only operationally sound but also viable and scalable.

Agreements play a critical role in defining value exchanged at the grid service interface. Each Agreement specifies the terms, conditions, and guarantees under which a service is requested, delivered, and compensated (Hammerstrom et al. 2024). Functionally, it acts as a contract between a service requestor and a service provider, codifying expectations for service performance, value measurement, and compliance while preserving each party's operational privacy (Hammerstrom et al. 2024). For valuation, an Agreement is the unit of analysis for value since it captures the interactions where value is created or transferred. Agreements also specify rules for value priority and double counting. Double counting refers to attributing the same physical service capability, such as ramp capability, to multiple services simultaneously, which inflates value beyond what the grid can actually use. Priority rules specify how limited capabilities are allocated when services compete for the same resource. These rules help ensure valuation is operationally feasible and transparent.

The scope of valuation at the grid service interface is expanding to encompass distribution level and nonmonetary benefits (DeMartini et al. 2024), cross level coordination informed by value flow analyses (Reeve et al. 2021), and evaluation along the grid service agreement structure to qualify value across dimensions (Hammerstrom et al. 2024). However, existing work stops short of a full, operational characterization of value across the grid service interface with metrics. Value is essential to define the underlying, normative significance of the service, and with metrics we are able to measure the value. In particular, there is not yet a unified parameterization across services that maps metrics to value in a way that can inform future valuation models.

In this work, we extend prior research on grid services and valuation to develop a layered framework that maps grid services to value categories and metrics. This involves developing a taxonomy to illustrate the **service-parameter-value** relationship, the structured relationship between

(a) The electrical and temporal attributes that define a grid service,

(b) The operational parameters that govern how that service performs under real system constraints, and

(c) The measurable outcomes that demonstrate the service's value.

The framework creates a traceable, consistent chain from service definitions to valuation by linking attributes to operational behavior and measurable impacts. This structure also allows different technologies, models, and stakeholders to assess value on comparable terms.

The resulting characterization will inform models that capture how grid service mechanisms and their parameters shape value. In addition, the framework supports comparing centralized and distributed system architectures, clarifying how the provision of grid services and the resulting value differs across resource types. Value within this work is inclusive of monetary and non-monetary (e.g., resilience, reliability, security) values. By clarifying these relationships, the framework offers regulators, operators, and other grid decision-makers with a common basis for assessing and comparing the value of grid services.

The report is structured as follows: Section 2.0 reviews relevant existing work; Section 3.0 explains the framework we developed to structure the service-parameter-value relationship; Section 4.0 applies this framework to each grid service; Section 5.0 demonstrates the framework through three use cases; Section 6.0 discusses future applications of the framework; and Section 7.0 concludes.

2.0 Review of Existing Work

We examined foundational and recent work on grid services, distribution-level coordination, and valuation frameworks (Kolln et al. 2023; Reeve et al. 2021; Hammerstrom et al. 2024; Alam et al. 2021; Boero et al. 2018; DeMartini et al. 2024; Bender 2021; Markel et al. 2019; Kintner-Meyer et al. 2017). Together, these sources span service definitions and attributes, transactive coordination, contract-based service agreements, and multi-dimensional value frameworks that incorporate both monetary and non-monetary value.

2.1 Key Contributions by Concepts

2.1.1 Grid Service Definitions

Recent work has advanced a more standardized, interoperable understanding of grid services by clarifying their electrical and temporal attributes, sourcing requirements, and observable metrics. The National Energy Standards Board (NAESB) WEQ-025 and REQ-030 grid service definitions (Kolln et al. 2023) provide a comprehensive baseline of six grid services across transmission and distribution: **Energy, Reserve, Regulation, Frequency Response, Voltage Management, and Blackstart**. Their work standardizes electrical and temporal attributes and clarifies measurement requirements, advancing a performance-based, service-oriented viewpoint and improving interoperability for asset participation. This work establishes the service + attribute foundation our valuation builds upon but leaves the attribute-to-value mapping only partially developed. Building on this foundation, (Hammerstrom et al. 2024) operationalizes grid-service definitions through standardized, machine-readable service agreements between requestors and providers. The architecture shows how value can be framed along terms, guarantees, status levels, and constraints, creating a pathway for measurable, contract-grade performance and settlement. This work leaves open the question of how these parameters connect via metrics, to higher order outcomes such as resilience, affordability, or security.

Earlier frameworks also outline key elements needed for service characterization. (Kintner-Meyer et al. 2017) articulates attempt to establish a structured framework for identifying and quantifying the value of services provided by customer assets. The report emphasizes that while assets like electric vehicles, smart thermostats, batteries and water heaters can deliver a range of grid services, the methods used to value these services vary significantly across jurisdictions, often leading to inconsistent results and challenges in comparability. The authors provide a conceptual framework to distinguish between services delivered, the methods for quantifying them, and the institutional mechanisms for sourcing and compensating them. This work also notes that locational and temporal granularity are critical for accurate valuation, since the same asset's service can have very different system impacts depending on where and when it is provided. This framework served as a critical foundational approach on which the current valuation study was conducted, and parameters were considered while mapping services to the value categories. Collectively, these studies define grid services and attributes but stop short of linking these attributes to multi-dimensional value categories and measurable metrics in a unified framework.

2.1.2 Foundational Valuation Frameworks

Complementing the service-definition literature, a second set of works introduces structured methodologies for valuing grid technologies, actor interactions, and systemwide impacts.

(Bender et al. 2021) provide a structural valuation methodology designed to integrate economic analysis into the early design phases of complex energy systems. The report introduces a visual modelling approach using UML diagrams to map value exchanges, actor[1] interactions and economic flows. The methodology strengthens decision-making by evaluating systemwide economic outcomes while also quantifying impacts on individual actors. The report emphasizes early intervention of economic considerations into technical research design. The study lays out a step-by step process of implementing the valuation methodology beginning with system understanding, actor identification, value exchange mapping, metric definition, data collection and refinement of research objectives. The report also demonstrates a practical example through use case diagrams and value activity diagrams to visually and quantitatively represent the application of the proposed framework. The valuation methodology presented in this report directly applies to the context of this framework for characterizing and mapping across grid services through visual modelling that aligns with deriving value from both at an actor level and at a system level.

(Boero et al. 2018) similarly articulates a roadmap for developing a standardized, broadly accepted framework for valuing grid technologies and services. The framework emphasizes three pillars: (1) a taxonomy and glossary of services, technologies, and relevant metrics; (2) a formal deconstruction of valuation as a process linking methods, metrics, and stakeholder perspectives; and (3) stakeholder-vetted guidelines prescribing minimum requirements for conducting and documenting valuation studies. It establishes a stakeholder-neutral framing for six non-monetary system metrics (i.e., affordability, reliability, resilience, flexibility, sustainability, security) with guidance to monetize when data support it, or to score qualitatively when they do not. It emphasizes explicit trade-offs (e.g., ratepayer burden vs. utility capex deferral), which we echo in our value-stream and metric mapping.

(Anderson et al., 2017) on the other hand catalogs and evaluates a wide array of existing and emerging metrics relevant to grid modernization, providing a structured foundation for assessing the grid service attributes such as reliability, resiliency, flexibility, sustainability, security, and affordability. Similar to previous frameworks, this document identifies base and composite metrics, highlights methodological challenges in quantification of qualitative metrics. This report supports the hierarchical organization of the metrics, from fundamental state variables or measurements to composite indicators. This source was instrumental in bridging the definitions of attributes to measurable expressions that are later linked to its composite metric, and this approach was drawn in our valuation study.

Finally, (Markel et al. 2019) offers a systematic, transparent valuation process across both quantitative and qualitative dimensions. The framework introduces a 11-step process organized into four phases – from defining scope, framing valuation criteria to presenting results that explicitly incorporates stakeholder engagement, multi-criteria integration through a scorecard approach by documenting trade-offs, and uncertainty treatment. The framework also distinguishes between base and composite metrics, offering a hierarchical structure that allows flexibility for future modifications. This method has been adopted to keep our framework extensible and auditable. While serving as a foundational guide for multi-dimensional valuation, this study highlights ongoing challenges in operationalizing qualitative dimensions and ensure compatibility across studies. These foundational frameworks provide methodological rigor but lack on integrated mapping between standardized service attributes, value categories, and metrics, an integration this study aims to provide.

[1] Within UML, “actors” refer to stakeholders within the system considered for valuation.

2.1.3 Distribution-Level Coordination

A parallel body of literature focuses on how distribution-connected assets are coordinated and how their services manifest as system-level value.

(Reeve et al. 2021) represents one of the most rigorous investigations into distribution-level flexibility and transactive coordination valuation. The study centers on large-scale simulations of the ERCOT system, comparing business-as-usual conditions with scenarios that incorporate flexible loads, and behind-the-meter batteries coordinated through a transactive energy framework. Its stakeholder-centric value-flow diagrams make the distribution and pathways of value explicit, beyond avoided-cost heuristics. The resulting value flow diagrams extend the characterization of demand coordination beyond the distribution level pointing to additional value streams such as peak shaving, volatility reduction, and improved operational efficiency that are relevant across bulk system as well. The report provides a reference point for future models that seek to value grid service contributions across various contexts.

Similarly, (Alam et al. 2021) evaluated the feasibility of a double-auction based transactive energy system to coordinate the reactive power capabilities of photovoltaic plant inverters for distribution-level voltage management. This study highlighted how buyers of the services value them by supplying demand curves to reflect the marginal benefit attained, i.e. utility's ability to pay for services vs opportunity cost for the supplier. For example, a reduction on transformer tap changes can be achieved through the voltage service, reducing asset stress and extending its lifetime. Importantly, the study frames value not only in monetary terms but also through secondary and complementary streams, such as improved asset lifetimes, operational efficiency, and energy savings, offering a structured way to classify value beyond primary grid service provision. This led to the development of hierarchical importance of value categories as primary and secondary in our framework.

(DeMartini et al. 2024) further expands this view by developing a comprehensive framework for valuing and sourcing distribution level services from customer assets, emphasizing both monetary and non-monetary dimensions. It underscores sourcing differences between independent system operator (ISO)-level and distribution system operator (DSO)-level services, the importance of locational and temporal targeting, shared-risk models, and scalable participation. The report advocates to balance ratepayer value certainty with provider and retail customer financial viability to mitigate risks in long-term participation. This analysis underscores the importance of value streams such as reliability assurance, risk reduction, and resilience which are often less acknowledged in current frameworks. The highlight of this report is the techno-econometric decision model that offers a structured pathway to optimize asset portfolios across these dimensions. The framework reveals a critical gap in valuation; sourcing methods remain fragmented in how service value is linked to higher order outcomes like resilience or affordability. Collectively, these studies illustrate the operational and economic pathways by which distribution-level coordination produces value, though they stop short of integrating these pathways into a unified, attribute-driven valuation structure.

2.2 Summary of Findings

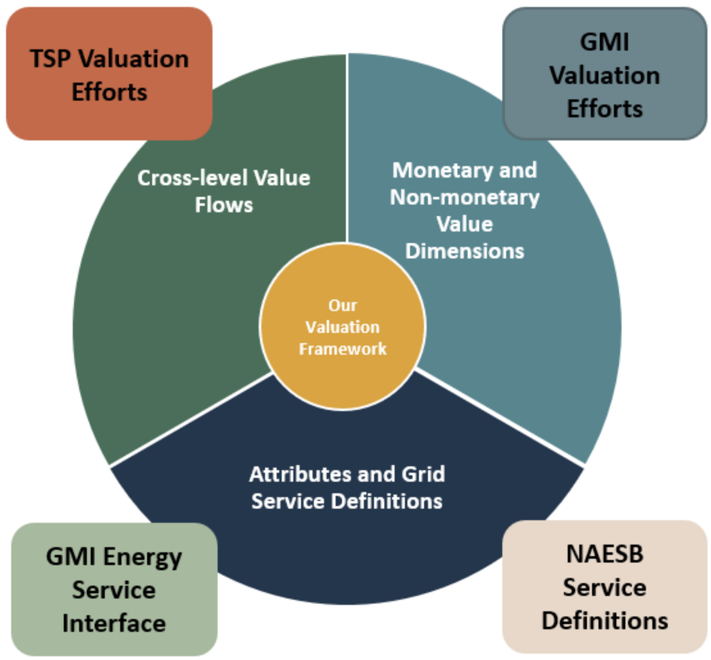

Figure 5. Conceptual connections between existing frameworks and past work that inform our valuation framework.

The conceptual connections between past work and existing frameworks (Figure 5) highlight the necessary themes to address in our development of a service-parameter-value interplay. The first theme is common language; a stable, technology-agnostic attribute set for services is a prerequisite for meaningful valuation. Standardization of electrical and temporal attributes in (Kolln et al. 2023) provides a strong baseline for this language. A second theme is that value is multi-dimensional. Non-monetary dimensions must sit alongside monetary measures with explicit trade-offs so that value is communicated appropriately for different audiences using the framework. Third, coordination across system levels matters. As services are increasingly sourced from the distribution system, the flow of value no longer follows traditional top-down pathways. This means that benefits may accrue in different points of the system. For instance, a distribution-system located resource providing a grid service might primarily support local reliability while also contributing to transmission-level stability. These cross-level value flows change who benefits, where, and when and impact how value is counted. Finally, value depends on location and time. Even with effective coordination, technical constraints will influence the available value of a service. Lastly, a future model should directly inform grid operations, planning, and policy at multiple scales. This requires service-specific, measurable, and model-ready parameters that capture how value manifests in practice. Value should be expressed in relative and proportional terms across services to communicate comparative potential and guide prioritization.

Despite progress, gaps remain. Parameter taxonomy is inconsistent across sources, making it difficult to compare capabilities[1]. Attribute-to-value traceability is incomplete; most work stops short of a full chain from attributes to metrics to value categories/streams to stakeholder outcomes. Differing approaches to baselines, causality, and opportunity-cost accounting make value stacking rules uneven. Finally, distribution deliverability is underspecified in many valuations, with limited treatment of locational feasibility and DSO constraints.

Overall, these past efforts are a blueprint for future quantitative modeling of devices and systems providing grid services. Our work will provide a more comprehensive valuation of grid services, defining "value" beyond financial metrics. This will help justify investments in emerging grid technologies and provide a more holistic evaluation of service trade-offs. Those tradeoffs and synergies will further inform decision-making for grid planning at both the bulk and distribution system level which aids utilities, grid operators, and policymakers in achieving grid objectives.

[1] Each system operator has a unique set of operational manuals, business practices and procedures that makes it difficult to analyze and contrast service requirements. An upcoming PNNL ESI services document detailing common objects and signals is currently under development to close this gap.

3.0 Structuring the Service-Parameter-Value Relationship

We propose a service-parameter-value framework to link what a grid service delivers to why it matters and how its benefits are evidenced (Figure 6). The top layer is the grid service itself, which is the capability being delivered or enabled. Beneath that, attributes define the service electrically and temporally (e.g., power, energy, response speed, duration, location). Value categories explain why those attributes matter to the grid by tying them to intended system outcomes. Value streams on the next layer then specify how value is realized for a given service, describing the service-specific outcome and its net effect (positive/negative) on a coherent grouping of metrics. Finally, metrics provide an observable, auditable basis for evaluation; they are granular, unitized, and can be mapped to grid objectives (Anderson et al. 2017). Together these layers create a traceable chain from service definition to observed value.

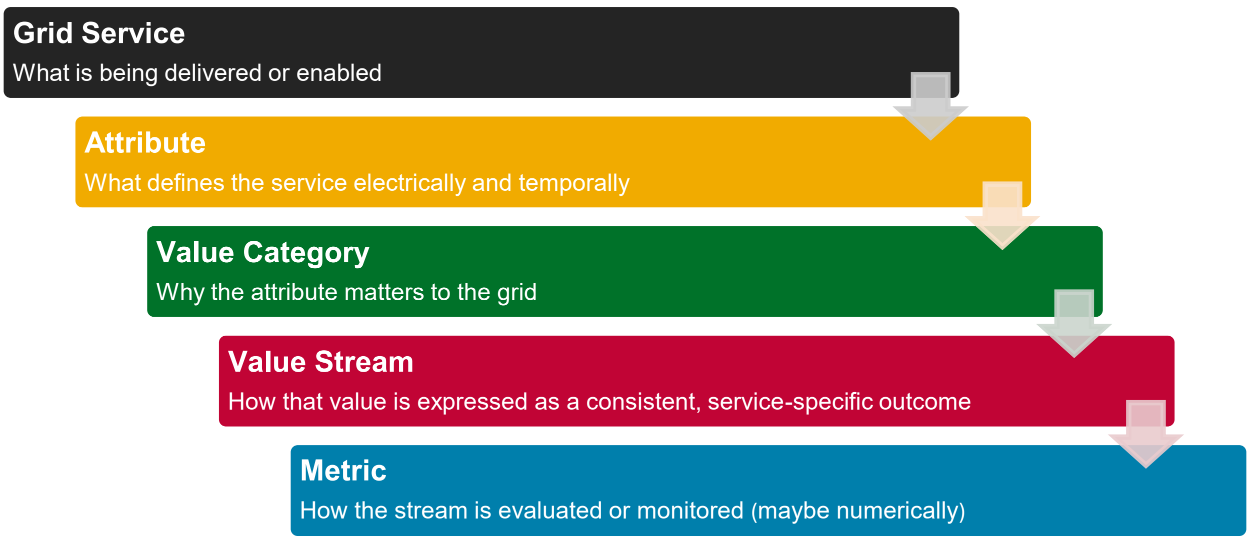

Figure 6. Grid Service-Value framework mapping service attributes to value categories, value streams, and metrics.

3.1 Grid Service Definitions and Attributes

Building upon prior foundational work (Kolln et al. 2023; Liu et al. 2022), we characterize each grid service by a set of electrical and timing attributes that are technology-agnostic but performance-specific. Figure 7 illustrates this characterization and includes the performance determinations which are quantifiable metrics whose acceptable values are typically set by the service requestor and influenced by asset type and measurement approach (e.g., interval measurements, baselines, and telemetry requirements). Services can be valued in two ways: why the service is needed (the outcome it supports) and how it is provided (the mechanism and attributes that make it deliverable). Thus, the performance determinations aid valuation framing by surfacing trade-offs; for example, how a particular asset's response profile might shift monetary value versus resilience benefits. Further, the grid service definitions and attributes are device- and spatially agnostic. So, within the framework, we can explicitly incorporate modifiers for asset type and location, capturing how feeder constraints, topology, or communications capabilities shape value deliverability. For instance, a battery located on a constrained rural feeder may provide high levels of local reliability values compared to the same device on an unconstrained urban feeder, even if their technical attributes are identical. In this case, the same speed-of-response requirement for Reserve service is interpreted differently, since the battery's dispatch strategy shifts with system priorities.

Grid Service	Electrical Attributes	Timing Attributes	Performance Determinations
ENERGY	energy (quantity); power (level); electrical location	delivery schedule; delivery schedule notice	agreements specify: a) measurement equipment and location, b) measurement units and frequency, and c) calculations of estimating methods. Examples: revenue grade energy interval meters or periodic power measurements to estimate energy.
RESERVE	energy (quantity); power (level); electrical location	delivery schedule; delivery schedule notice; speed of response	agreements specify how performances is quantified such as energy interval meters and time-stamped power measurements.
REGULATION	power (level); power regulation range; power mileage; electrical location	delivery schedule; delivery schedule notice; speed of response; signal periodicity	agreements specify how real power increase or decrease is measured. A performance score or index mechanism may be applied.
FREQ RESPONSE	percent droop; deadband; electrical location	delivery schedule; delivery schedule notice	agreements specify how performance is quantified with frequency response measurements.
VOLTAGE MGMT	target voltage/range; electrical location	delivery schedule; delivery schedule notice; signal periodicity	agreements specify how performance is quantified.
BLACKSTART	power (level); power regulation range; electrical location	delivery schedule; delivery schedule notice; speed of response	agreements specify how performance is quantified.

Figure 7. Sample of grid services and their electrical and timing attributes (Kolln et al. 2023; Liu et al. 2022).

3.2 Value Categories

Value categories are grounded in established grid objectives and represent intended system outcomes (Anderson et al. 2017; Markel et al. 2019). We use four final categories:

- **Reliability:** maintaining continuous, high-quality power delivery through stable, coordinated operations.
- **Resilience:** withstanding, adapting to, and rapidly recovering from external disturbances.
- **Cost & Access:** improving system costs or financial efficiency, including affordability and deferral of infrastructure upgrades.
- **Security:** protecting the grid against physical, cyber, and operational threats that could destabilize the system.

These four categories were selected from the broader GMLC framework (Anderson et al. 2017) because they most directly reflect the operational and planning outcomes that grid services deliver. Flexibility was not retained as a separate category because it functions as a mechanism through which services create value across all categories, rather than a distinct outcome. Sustainability and affordability (reflected here as cost & access) are captured as specific value streams within the categories where their impacts materialize; These value categories are most often cost & access, and in some cases reliability (e.g., adequacy or emissions-constrained operations).

Not every category applies meaningfully to every service; therefore, for each service we introduce primary and secondary category designations to make it clear what outcomes a service primarily delivers versus what it may provide incidentally. Figure 8 illustrates these primary and secondary designations for each grid service. The primary value category describes the main outcome the service is procured to deliver. The majority of realized value under normal conditions falls into this category because the service's core attributes are designed to fulfill the primary value category's objective. Secondary value categories describe a meaningful co-delivered benefit that arises from meeting the primary objective but is not the reason for procurement. It can often be enhanced with operational choices without compromising the primary objective. This tiering is not fixed: stakeholders interpret value differently so a service that is "primary" for a system operator (e.g., operational guarantees) may only be "secondary" for a regulator focused on affordability. Section 5.0's framework use-cases demonstrate how the primary and secondary tiering can change.

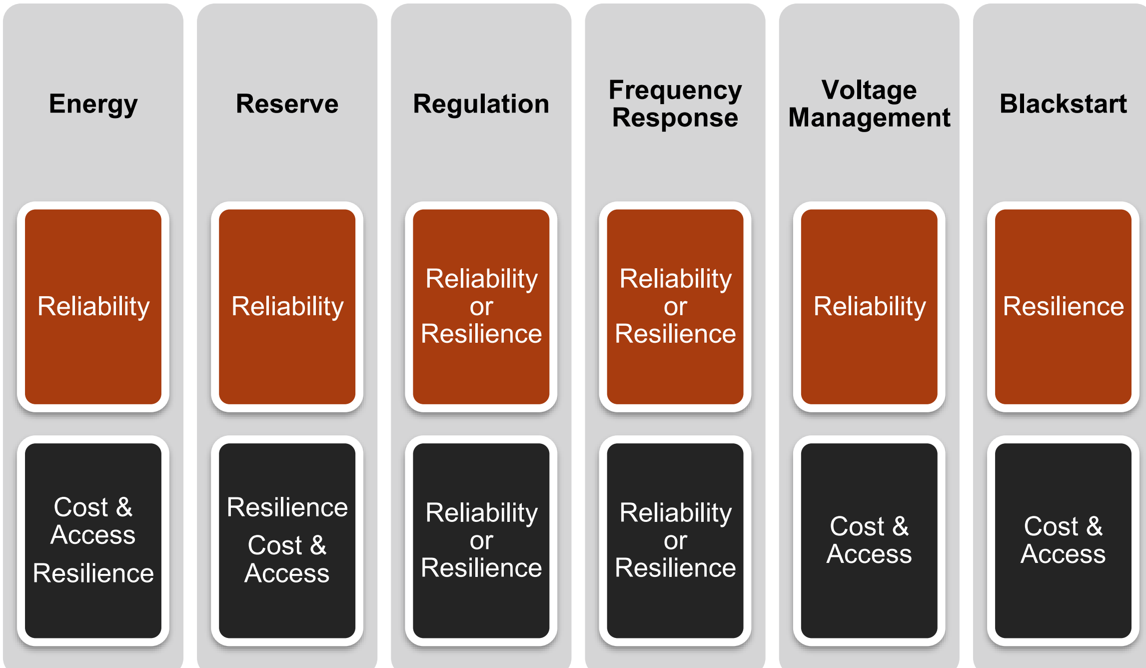

Figure 8. Primary and secondary value categories for each grid service. The first row (brown) indicates primary categories, while the second row (black) shows secondary categories.

3.3 Value Streams

A value stream is a specific mechanism, pathway, or outcome through which a grid service creates value for a given category. Its purpose is to describe how a particular service contributes to that category in practice. Value streams are detailed, service-specific, and often directly measurable. Examples include Outage Impact Reduction (for Blackstart under resilience) and Upgrade Deferral (for Voltage Management under cost & access). Conceptually, streams group related metrics and can be used to assess net direction of impact (e.g., + for minimizing time without power; – for increasing equipment wear). Value streams are audience-dependent and not prescriptive; Section 5.0 illustrates how these streams are constructed for specific use cases.

3.4 Metrics

Metrics provide a measurable basis for monitoring and evaluating value streams (Bender et al. 2021). Prior Grid Modernization Initiative (GMI) efforts (Anderson et al. 2017; Markel et al. 2019) mapped many metrics to grid objectives; we adopt and extend that work. Metrics can be qualitative, Boolean, or numeric, but in all cases, they should be granular, directional and comparable (clearly indicating better or worse). Metrics can be tied to service providers, service types, operating windows, or locational attributes as needed. They should align with practical measurement and verification (M&V) to ensure data is available to compute them. The framework accommodates metrics that are retrospective, forward-looking, or scenario-based to adapt to the service and framework use case. Within the framework, metrics close the loop: they tell how value streams are tracked and verified and provide a consistent basis for stacking analyses and comparison across services. The full metrics catalog and definitions appear in Appendix A.

4.0 Visual Framework

Understanding the layered relationships in the framework (Figure 6) can be challenging to convey through text alone. Visual diagrams make these mappings explicit by showing how each grid service connects to each layer of the framework in a structured way. UML notation applied to e3 value modeling principles has been used within valuation methodology (Huemer et al. 2008), and previous PNNL TSP valuation work follows this approach using value activity diagrams (Bender et al. 2021). Because our framework helps identify value exchanges, we built layered component diagrams to visualize the results of the proposed framework. A component diagram is a UML representation that organizes a system into discrete building blocks and shows how those blocks interact (Object Management Group 2017). It highlights structure rather than process, making it ideal for depicting how services, attributes, and value elements fit together. Further, the layered component diagrams complement e3 value activity diagrams described in (Bender 2021) by outlining the value exchanges to consider for each actor.

The component diagram for each grid service presents the framework starting with the grid service (*what* is delivered/enabled), then it's electrical and temporal attributes, followed by the value categories (*why* it matters), and example metrics that can be used for monitoring, measurement, and verification (*how* to track it). Attributes are technology-agnostic but performance-specific, allowing different assets to qualify if they meet the same thresholds. Value categories are designated by primary and secondary labels. We assume security is an inherent value category across all grid services because maintaining the integrity, availability, and confidentiality of the electrical system is foundational to delivering every other grid service. This tiering clarifies what is required for qualification versus what is co-delivered by a service. These designations are applied generically across services in this work, and framework users can adapt or refine primary and secondary designations to reflect their specific priorities.

While these diagrams present the framework in a uniform format, practical implementation will also depend on technical and contextual factors. The use-cases in Section 5.0 highlight how factors such as asset capabilities, local grid conditions, and data availability influence the deliverability of value. Section 5.0 also notes approaches for handling double counting through priority rules to ensure consistency across services. Because of this, the framework demonstration in Section 4.0 also does not include value streams because they are application specific and we aim to maintain presentability of the diagrams. Further, it is important to note that captured metrics are intended to be illustrative, rather than prescriptive, and that individual metrics may be applicable to one or more service attributes and may yield value across multiple value categories. A more comprehensive metrics list is in Appendix A.

4.1 Energy Service

The energy service is procured to balance production and consumption. In practice, the operator schedules blocks of energy generation (MWh) at specific nodes and feeders via market dispatch or bilateral arrangements, subject to network deliverability and scarcity conditions. Delivery terms are typically defined by the electrical attributes of power (MW) and energy (MWh), and electrical location (node/feeder). Additionally, timing attributes may be used to define the delivery schedules (e.g., day-ahead to intra-hour) and how these must be announced (i.e., delivery schedule notifications). An energy service agreement specifies the delivery point and measurement for settlement (Hammerstrom et al. 2024).[1]

Figure 9 maps each Energy service attribute to value categories. These attributes yield primary value in reliability (meeting energy balance at the point of need), secondary value in cost & access (affordability, rate design, participation) and resilience (continuity for critical loads and support to secure operations).The component diagram makes these relationships explicit by showing how the Energy service decomposes into its four attributes, and how each one contributes differently to reliability, resilience, and cost outcomes. The color-coded metric blocks illustrate examples of what operators, planners, or aggregators would measure to verify value delivery at the feeder, substation, or system level. For Energy service, metrics span operational adequacy (e.g., loss of load expectation, feeder demand, emergency purchases), customer impact (e.g., outages, affordability indicators), and economic performance (e.g., local marginal prices, energy losses). Further, the value categories span multiple attributes. This reflects Energy service's multi-dimensional impact and value.

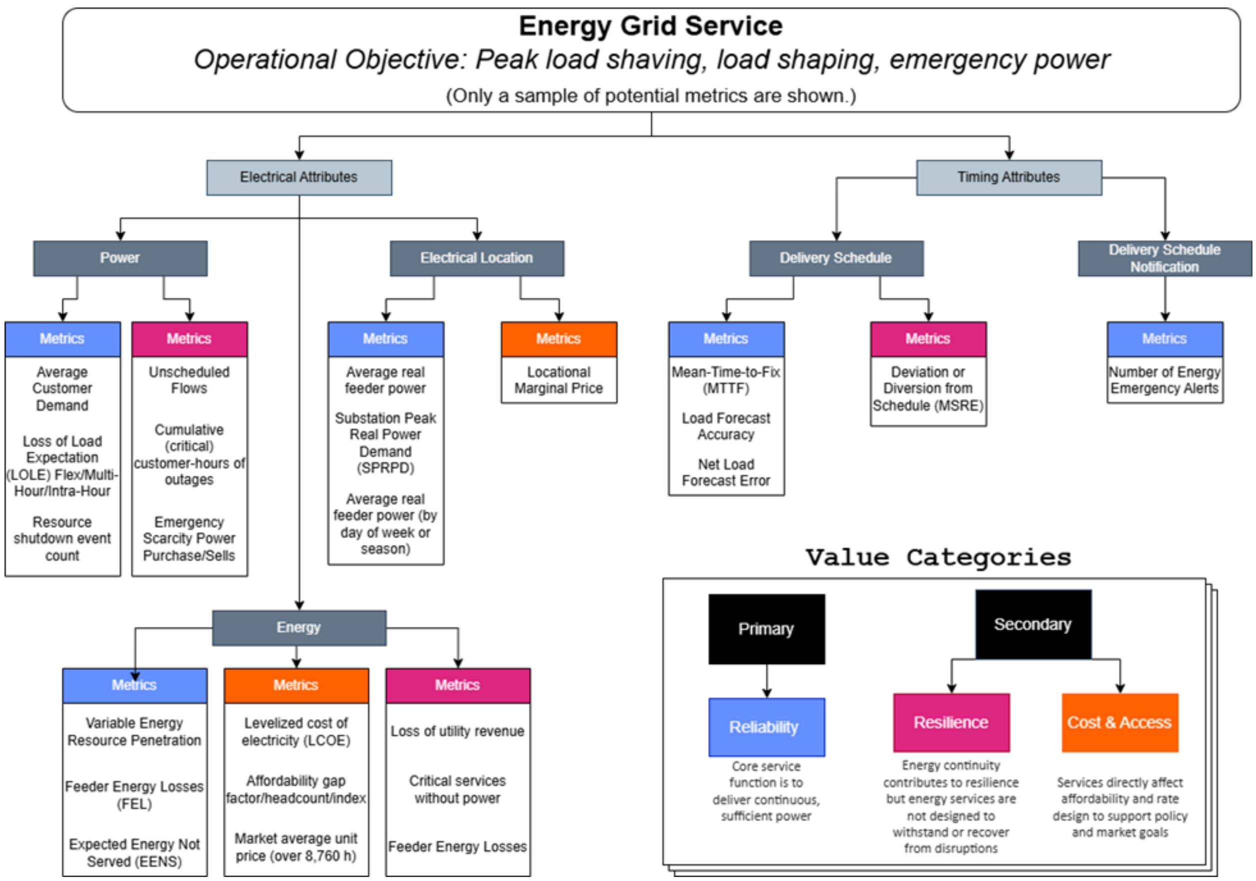

Figure 9. Energy service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: reliability; secondary: cost & access, and resilience) to sample metrics.

[1] Settlement is entered after a service requestor and service provider have agreed on a set of collected measurements and exchanged rewards and penalties for the service event as specified by a service agreement (Hammerstrom et al. 2024).

4.2 Reserve Service

The reserve service is a callable capacity held to sustain adequacy, cover contingencies, and manage net-load ramps when conditions deviate from plan. In practice, providers commit reserve capacity ahead of time by signing into dedicated programs (e.g., via a contract or tariff). Once committed, they remain on standby and must deliver energy when called upon. Participants are paid for availability and, if deployed, for delivered energy, with non-performance penalties per the service agreement. Delivery service characteristics may be defined by power (MW), energy (MWh), electrical location (zone/feeder/node), and may include a delivery schedule (day-ahead/hour-ahead/intra-hour), definition on when and how the schedule or signal can change (e.g., the delivery schedule notification), and the speed of response (MW/min, minimum/maximum duration). Speed of response is pivotal; faster categories serve immediate contingencies, and slower classes serve replenishment and adequacy. A reserve service agreement specifies how performance is measured.

Figure 10 shows how the Reserve service links its electrical and timing attributes to multiple value categories through diverse operational pathways. The primary value is reliability: Reserves preserve operational reliability in real time and support planning adequacy when forecast deviations or contingencies occur. Metrics such as planned reserve margin, net demand ramping variability, balancing variability, and local reserve sufficiency show how Reserves provide a quantifiable buffer between expected system needs and the capability available to respond.

Resilience is a secondary value category because callable capacity during extreme or prolonged events is important for sustaining critical operations and recovery. Metrics like customers benefited, energy not served, and reserve duration capture how Reserves support continuity of service and enable system recovery when normal operations are disrupted. Although Reserves are not chiefly procured for resilience, the diagram shows that the delivery schedule and power attributes activate resilience benefits in specific operating conditions.

Cost & access is also mapped as a secondary value category. Attributes tied to power, energy, and speed of response can create cost benefits through avoided emergency procurement, deferred capacity additions, or favorable participation in ancillary service markets. Metrics such as operational cost savings, market value of ancillary services, and deferred costs from loss of load illustrate these value streams. While these economic effects are meaningful, they are usually co-delivered outcomes rather than the main reason Reserves are procured, which is why they sit in the secondary tier.

Similar to Energy service, the diagram shows that each value category draws from multiple attributes, underscoring that Reserve value is multi-dimensional. No single attribute determines a value contribution; instead, a combination of attributes delivers value.

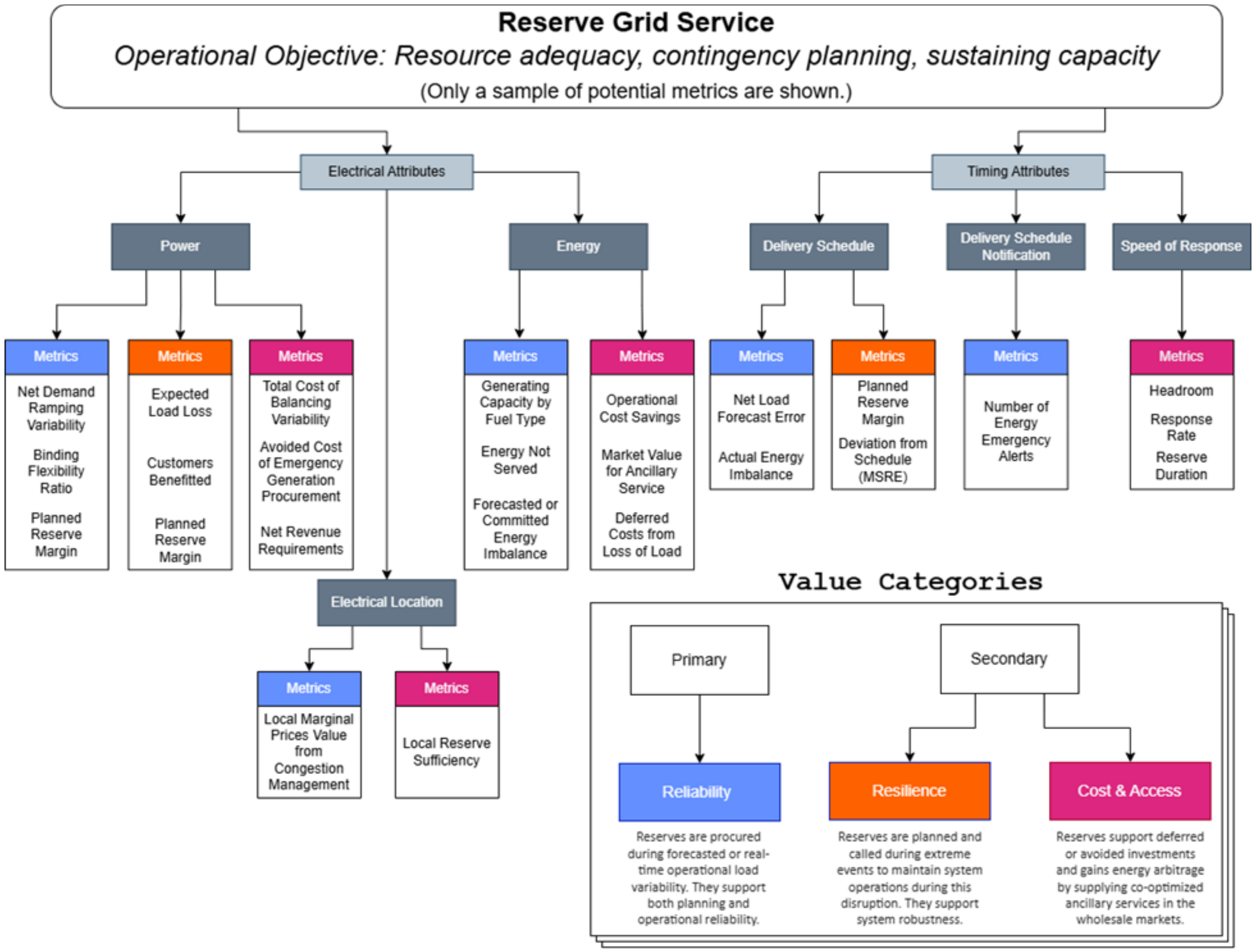

Figure 10. Reserve service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: reliability and secondary: resilience and cost & access) to representative metrics.

4.3 Regulation Service

The regulation service corrects short-term supply-demand imbalances by continuously adjusting real power around a basepoint to track an automatic generation control (AGC) signal. Success means high-quality signal tracking within the dispatch window, bidirectionally (up and down) and near-continuously. Attributes such as power (MW), power regulation range (a target band around the setpoint), power mileage (sum of up and down power level changes), and electrical location (node/feeder) may define the electrical attributes. Timing attributes may include, delivery schedule (start and end time), delivery schedule notification requirements, signal periodicity (seconds), and speed of response (quality of the resource to adjust its operation).

Figure 11 illustrates how Regulation’s electrical and timing attributes translate into reliability and resilience value through measurable system effects. Regulation’s primary value is typically reliability, because its core function is to continuously correct short-term supply–demand imbalances and maintain frequency targets during normal operations. Metrics such as Area Control Error (ACE), frequency-related compliance factors, mean absolute percentage tracking error, and the number of disturbances per year directly capture the quality of this balancing action. Together, these measures show how well a resource responds to the AGC signal and how effectively it stabilizes frequency in real time.

Resilience is the secondary value category because Regulation inherently helps dampen disturbances and reduce how deeply frequency dips during abnormal events. Metrics like frequency nadir and rate of change of frequency quantify these stabilizing effects. If a program or grid operator explicitly designs Regulation to support disturbance recovery, resilience can become a primary value category.

Across the diagram, the value categories are somewhat multi-dimensional; reliability spans all attributes, but reliance is limited to characteristics of the power regulation range and speed of response. The metrics shown are examples of terms in a Regulation service agreement that specify performance through tracking quality, delivered service, and operability constraints. Most programs pay for capacity (the MW kept available for regulation) and for mileage (the instructed movement), both adjusted by the performance score over each settlement interval to inform value delivery.

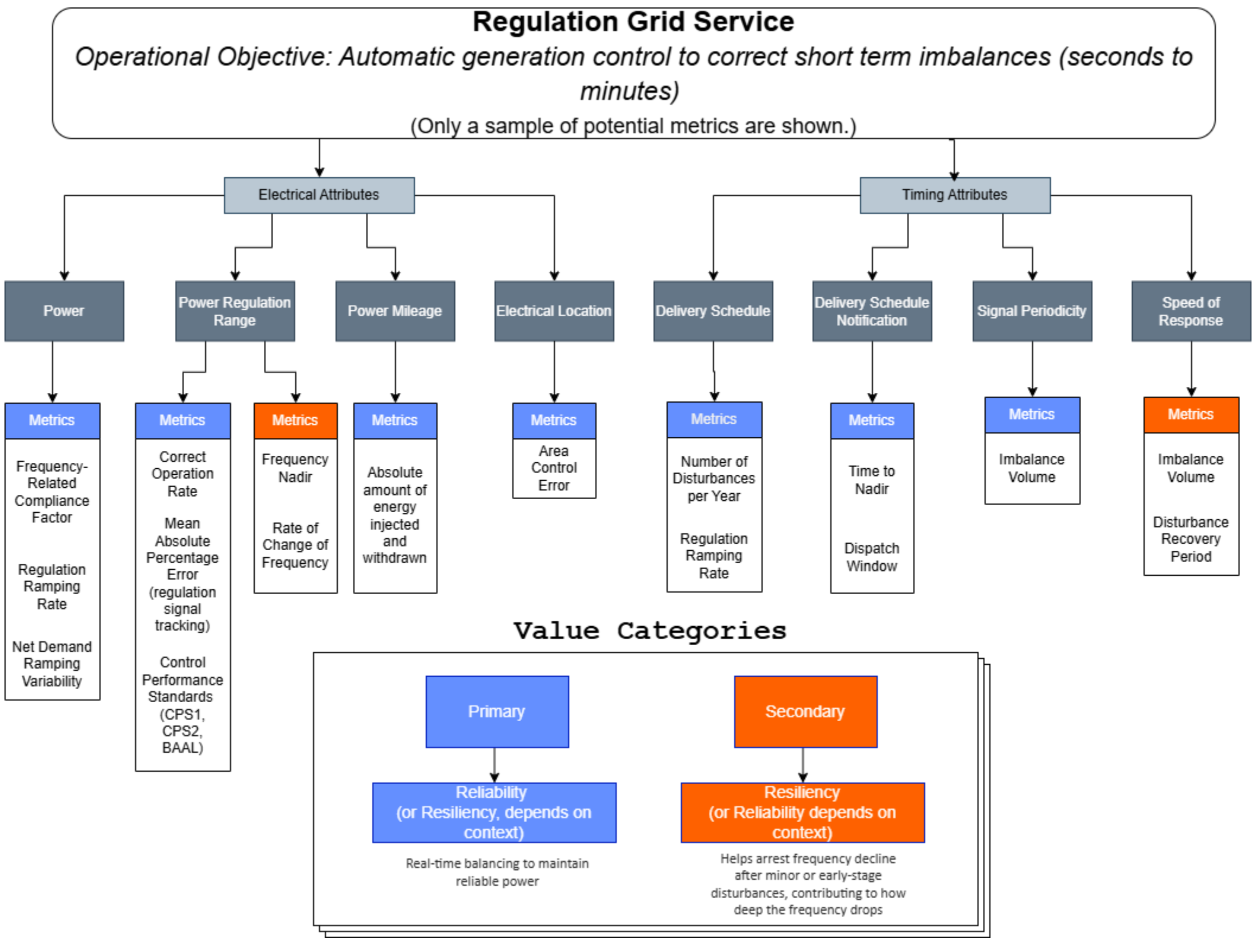

Figure 11. Regulation service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: reliability and secondary: resilience) to representative metrics.

4.4 Frequency Response Service

Frequency response service rapidly stabilizes frequency following sudden changes in generation or load. In practice, this covers sub-second inertial/fast Frequency Response and secondary Frequency Response. It is distinct from Regulation, which acts on longer (multi-second to minute) horizons. Electrical attributes may include percent droop (real power change for a change in frequency), deadband (frequency deviation threshold in Hz), and electrical location (e.g., a balancing area). Delivery schedule[1] (start and end time of the response) and delivery schedule notification are the timing attributes. Frequency Response only has a primary value category because of its primary function to arrest frequency decline.

Figure 12 shows how Frequency Response links its core electrical and timing attributes to a single primary value category. Whether this service is acting before or after an outage will determine if reliability or resilience fits the primary value slot. When operating during normal contingencies, Frequency Response is a reliability service: it arrests frequency decline, improves nadir, and buys time for slower controls such as Regulation and Reserves to engage. During extreme events or system degradation, the same attributes provide resilience by reducing the likelihood and severity of load shedding, islanding, or cascading outages. The diagram makes this duality explicit by assigning Reliability/Resilience as a blended primary category whose interpretation depends on whether the service is acting before, during, or after an outage. Bulk-system operating guidelines specify how frequency response is armed, triggered, measured, and credited so Balancing Authorities (BA), Generator Operators/Owners, and Transmission Operators/Owners can consistently configure droop/deadband, monitor events, and coordinate actions.

The metrics shown in the diagram, such as nadir frequency, rate of change of frequency, deadband width, frequency response sufficiency, and time to nadir, capture the measurable system impacts of Frequency Response. These metrics are not interchangeable: nadir frequency represents how deep the disturbance dips, rate of change of frequency captures how fast it declines, and sufficiency metrics indicate whether enough resources responded in time. Taken together, these metrics quantify how effectively the system absorbed a disturbance and how much stability headroom remains.

[1] This designation is consistent with prior work, though Frequency Response is typically automatic and not scheduled.

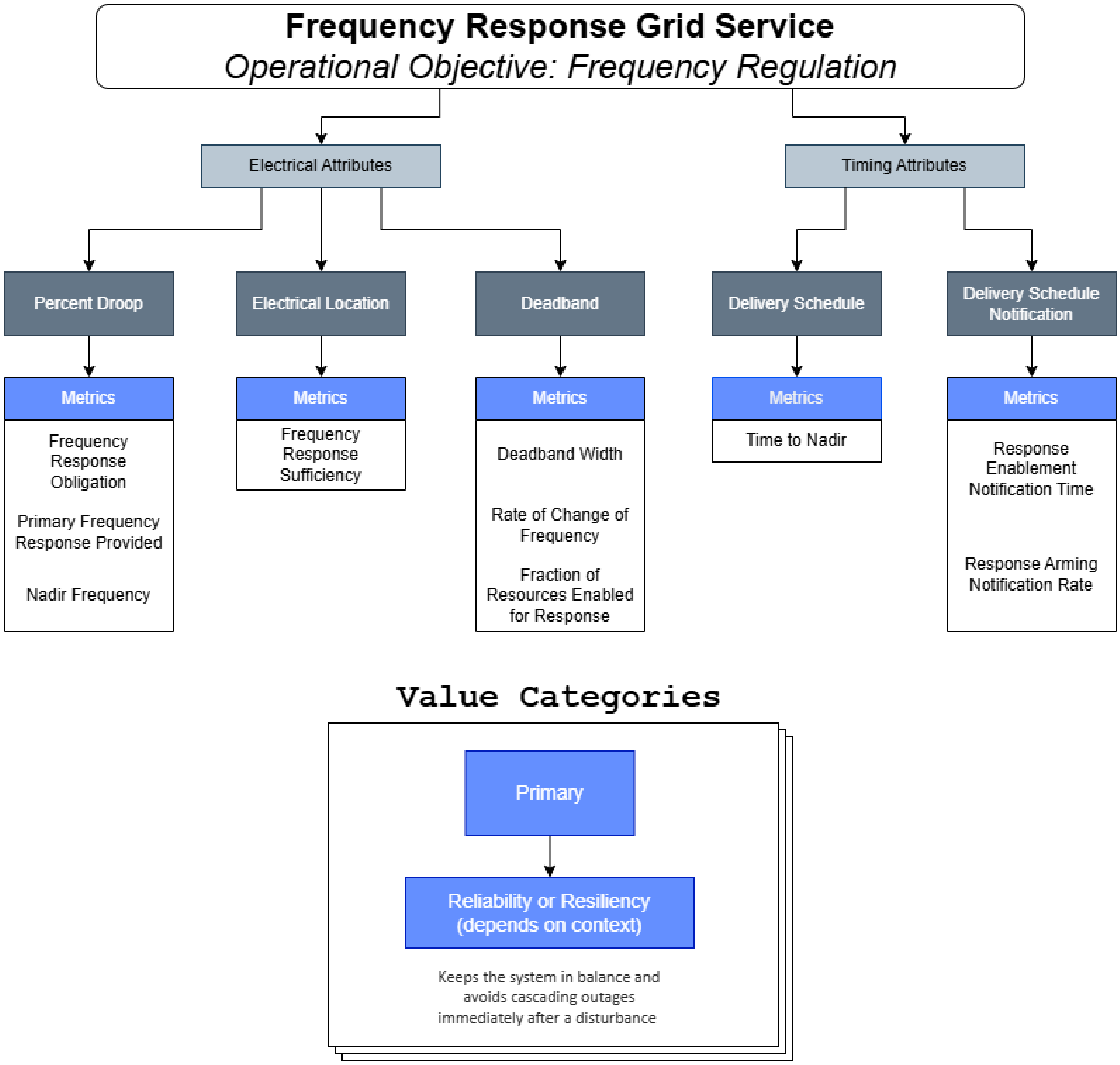

Figure 12. Frequency Response service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: reliability or resiliency) to representative metrics.

4.5 Voltage Management Service

The voltage management service raises or lowers voltage at a specified location to keep it within an acceptable operating band for equipment performance and system stability. In practice this is provided by generator exciters, power-electronic controls (e.g., an inverter's Volt/VAR and Volt/Watt curve), and network devices such as voltage regulators and switched capacitors/reactors. Value delivery hinges on the electrical attributes of target voltage and location (node/feeder/phase), and the timing attributes of delivery schedule, its notification, and the signal's periodicity.

Figure 13 shows how Voltage Management links its electrical and timing attributes to its two value categories. Reliability is the primary value category since maintaining bus and feeder voltage within bounds prevents mis-operation and protects equipment, reducing nuisance trips and voltage-collapse risk. Because both target voltage/range and electrical location attributes directly determine whether voltage is maintained in-band, the reliability category spans all attributes in the diagram. This is reflected in metrics such as percentage of time in band, severity and count of over/under-voltage violations, system-average voltage frequency index, and substation reactive demand. Each metric offers a different lens on whether the system stayed within safe operating conditions.

Cost & access, the secondary value category, only appears only under the electrical attributes. Cost & access value reflects the operational and economic efficiencies unlocked by good voltage control: lower feeder losses, reduced reactive power penalties, and avoided capital upgrades such as regulator replacements or capacitor installations. These effects stem from where and how reactive support is provided rather than from the timing of service execution. Metrics such as average reactive feeder power, max/min customer voltage, and severity indices quantify these performance and efficiency gains.

The diagram also highlights the coordinated actions required for the service across target setpoints, reactive power capability, local loading patterns, and device response periodicity. A Voltage Management service agreement formalizes these requirements by specifying the leading/lagging VAR capability, allowable voltage-regulation range, response-time bounds, tap/step limits, measurement locations, and scoring methods (e.g., % time in band, kVAR tracking accuracy) used for qualification and settlement (Hammerstrom et al. 2024).

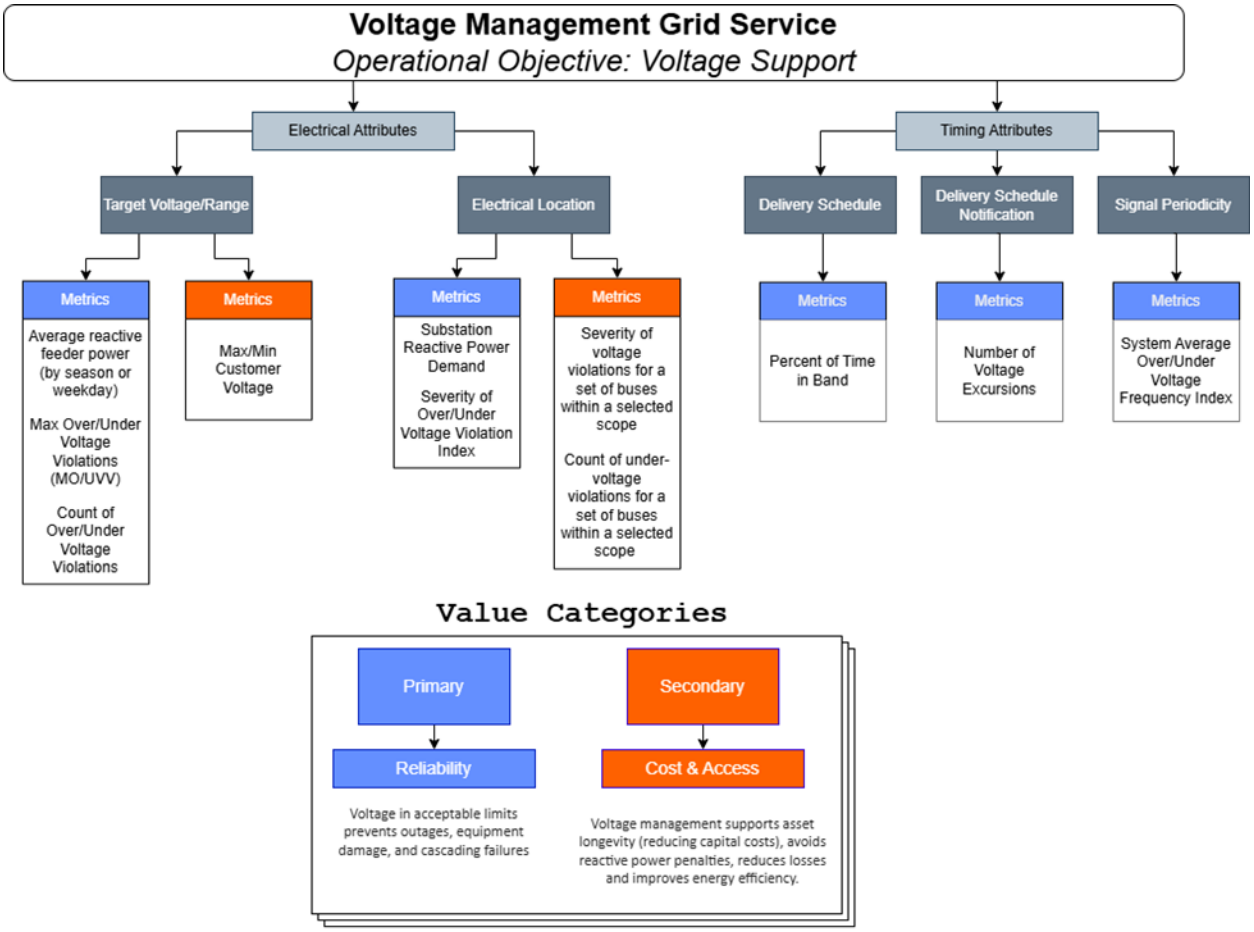

Figure 13. Voltage Management service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: reliability; secondary: cost & access) to representative metrics.

4.6 Blackstart Service

The Blackstart service is the capability to self-start without external power and energize part of the system to form an electrical "seed" from which the grid (or a microgrid) can be restored. In practice, a blackstart unit (or grid-forming asset) energizes a cranking path, establishes stable voltage and frequency, picks up initial load, and then synchronizes additional resources and islands as restoration proceeds. Delivery is defined by electrical attributes: power (MW or kW), power regulation range (power bounds), and electrical location (zone/region). These define how much of the system a Blackstart resource can energize and which restoration zones it can reach. The timing attributes of delivery schedule (start and end times of service), delivery schedule notification, and speed of response capture how quickly and predictably the resource can initiate restoration and how its availability must be communicated during outages.

Figure 14 illustrates how Blackstart's electrical and timing attributes map directly to resilience as the primary value category. Metrics such as system average restoration index, time to energize, startup time, ramp rate, cranking path coverage, and the count of unserved customers restored quantify how effectively and quickly a Blackstart resource contributes to system recovery. These metrics collectively show whether the resource can stabilize conditions, energize critical pathways, and bring load back online after a blackout—each an essential measure of resilience performance.

Cost & access, by contrast, maps only to the electrical attributes. The diagram makes this distinction clear: economic and access-related value arises from how large, how flexible, and how geographically well-positioned a Blackstart resource is not from its timing behaviors. Metrics such as restoration cost of recovery, levelized cost of electricity, net revenue requirements, and restoration zone coverage quantify the economic and accessibility impacts of using certain resources for restoration. These metrics highlight how well-placed Blackstart capability can reduce emergency procurement costs, shorten restoration time, and support broader coverage of customers during recovery.

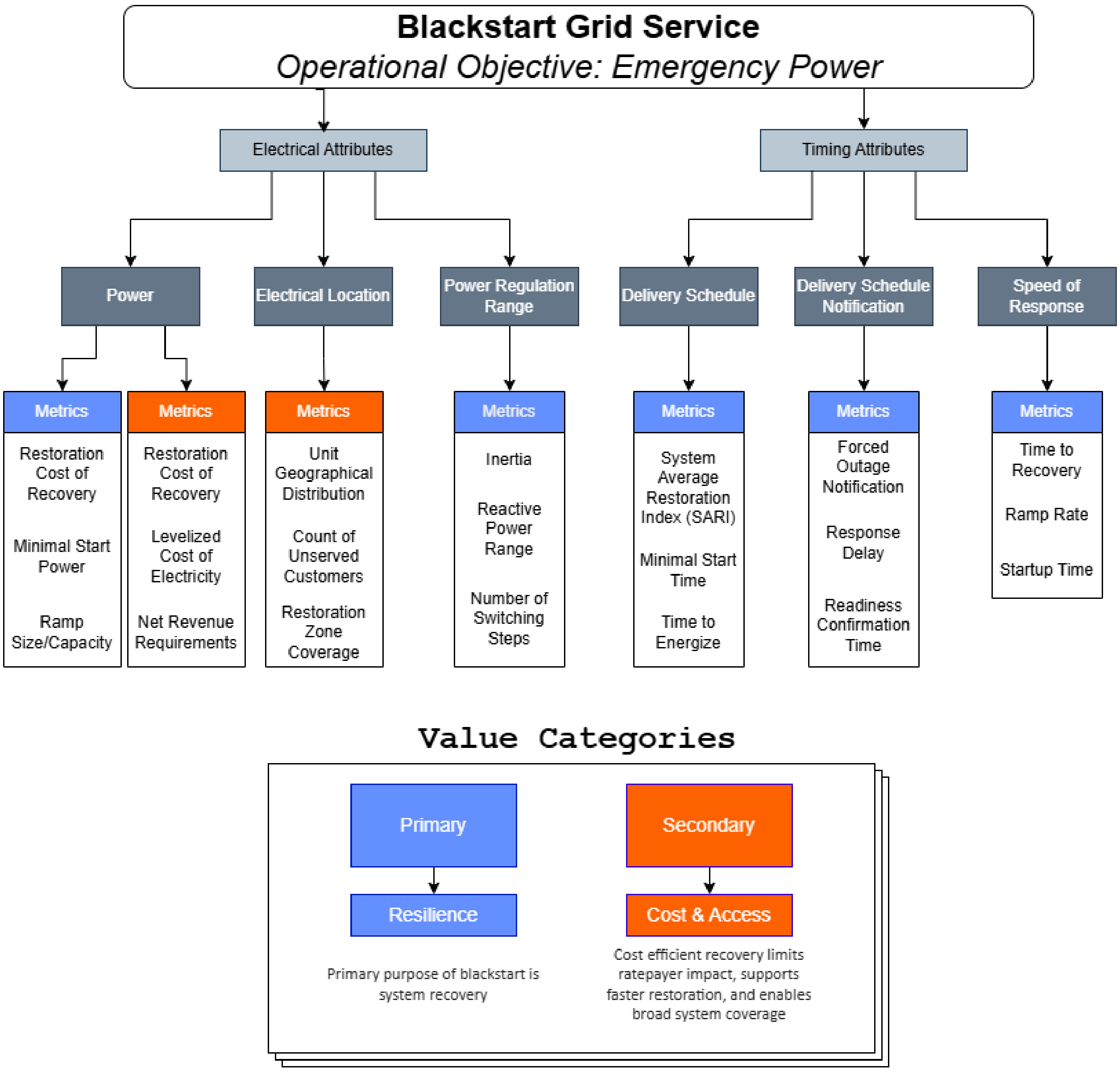

Figure 14. Blackstart service layered component diagram summarizing the operational objective electrical and timing attributes, and the mapping from attributes to value categories (primary: resilience; secondary: cost & access) to representative metrics.

4.7 Framework Reflections

Our work builds on and extends concepts introduced in (Bender et al. 2021), taking a service-centric rather than actor-centric valuation approach. Unlike Bender's framework, which identifies value exchanges through requestor–provider mappings and actor-focused questions, our framework is intentionally agnostic to requester and provider roles. It focuses instead on the grid services themselves, allowing users to adapt the structure to their own operational or market context. Even so, our work aligns closely with several steps in the valuation process outlined by (Bender et al. 2021), as shown in Figure 15. Step 1: studying the system is represented by our service definitions, which bound the portion of the grid system under analysis. Step 2: identifying value exchanges is addressed through the development of value categories and value streams, which together make those exchanges explicit and measurable. The use cases in Section 5.0 correspond to Step 3 by demonstrating actor definition within real operational contexts. Step 4: defining metrics for analysis is advanced through our mapping of metrics to specific value exchanges, creating a repeatable basis for comparison. Future modeling work will further Step 5 by translating this structure into a systematic, data-driven valuation process to be expanded in future reports. Lastly, the study objectives are captured in the value category definition which defines the scope of value to consider.

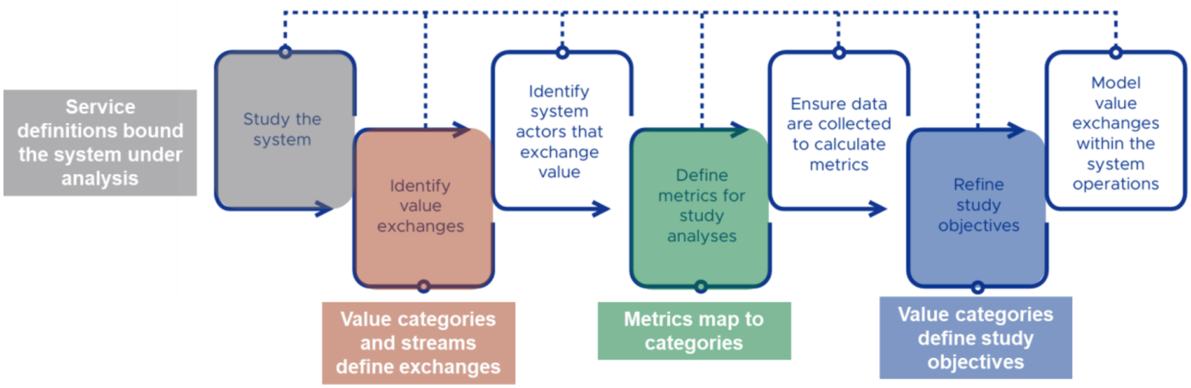

Figure 15. The service-parameter-value framework addresses the highlighted steps of the valuation methodology process in (Bender et al. 2021).

Building on that earlier valuation approach, this framework allows us to look at how six key grid services operate over different timeframes and interact through a common value lens. Taken together, these services span distinct operational response horizons while offering separate service engagement modes (e.g., via time-based schedules or direct signaling mechanisms): Frequency Response acts in the sub-second–seconds window (autonomous MW/Hz action), Regulation in seconds–minutes (continuous AGC tracking), Reserves in minutes–hours (callable capacity for deviations and adequacy), Energy is scheduled in minutes-to-hours markets but delivered over hours–days (with an emergency call-up variant), Voltage Management runs continuously at local nodes (Volt/VAR, setpoints), and Blackstart is event-driven (grid-forming restart capability). Together, these service horizons show why a layered framework is needed: it lets fundamentally different timescales and engagement modes be compared on consistent terms of attributes, value categories, and metrics.

Though the layered component diagrams present the framework in a service-by-service view, services rarely operate in isolation. In practice, cross-service interactions create both tradeoffs and synergies that shape value deliverability. This is a limitation of the visual display through component diagrams but can be captured in future work using alternate illustrations. A few high-level observations help illustrate these dynamics before we turn to the detailed use cases in Section 5.0. Frequency Response, Regulation, and Reserves compete for the same MW headroom[1]. Similarly, Voltage Management (which prioritizes reactive output) can constrain real power availability for Frequency Response and Regulation, which calls for coordinated setpoints and inverter limits. Because of this, value stacking needs explicit priority rules and opportunity-cost accounting. Blackstart readiness can reduce normal operating efficiency, so its value must be supported by explicit procurement mechanisms rather than assumed as a free byproduct. We also observe that services can amplify value in multiple value categories. For instance, better voltage profiles cut losses and increase hosting capacity; high-quality regulation lowers production costs and congestion; Reserves improve adequacy metrics and stabilize scarcity pricing; and emergency Energy call-up reduces expected unserved energy for critical loads. Recognizing these synergies within a consistent valuation framework allows planners and regulators to justify investments, design stacking rules, and compare cross-service trade-offs on common terms.

Because framework users interpret value categories differently, the significance of a service is not fixed but shaped by stakeholder priorities. The tiered value categories (Figure 8) matter most for stakeholder interpretations. System operators (ISO/BA/DSO) may prioritize reliability through Frequency Response, Regulation, Reserves, and Voltage Management for real-time stability and treat resilience as secondary except for Blackstart, where it is primary. Utilities and planners weigh cost & access against reliability risk since the location of service need is fixed. Regulators and policymakers look for traceable, non-monetary value (e.g., through resilience or security) and distributional effects (e.g. access) to inform tariffs and cost recovery. Customers and aggregators consider all services and their value, targeting primary categories for core revenues, secondary categories to justify enablement cost, and avoid double counting via metrics. These differences underscore why the primary and secondary value category designations are useful; they make stakeholder interpretations explicit and valuation outcomes transparent across contexts.

[1] We use headroom (and footroom) to refer to how much a resource can increase (or decrease) real power from its basepoint. It indicates the MW available to go up (or down).

5.0 Use Case Examples

The framework described above is stakeholder- and application- agnostic, meaning it can be applied across different actors in the power system and extended to new contexts. Use cases help ground this framework by illustrating how grid services translate into value streams under real conditions and how technical and contextual factors shape what value is actually deliverable. With this we can evaluate the potential scale of impact between different stakeholders.

In this section, we consider three use cases which are fully defined in the following sub-sections. The first two focus on rural cooperatives (co-ops), broken down into distribution co-ops and generation & transmission co-ops (G&Ts). The third considers a customer with assets who participates in grid service programs while still purchasing retail power. These three use cases were selected because they represent distinct operational scales, roles, and constraints in the power system and thus can stress-test the framework across settings where the service–parameter–value chain behaves differently. Whereas Section 4.0 presented the framework in a standardized, service-by-service form, the use cases here stress-test the framework against these stakeholders' priorities and contextual constraints.

For each use case, grid services are paired with their corresponding value streams and representative impacts are discussed. These relationships are visualized through a sunburst diagram, a circular hierarchical chart where each inner ring branches outward into its detailed categories. The sunburst diagram is especially effective here because it captures the layered relationships between grid services, value streams and their impacts, and highlights how different services cascade into multiple forms of value to the stakeholders. It also provides a clear way to compare how these value streams manifest at different scales, from marginal to regional systems. The innermost ring contains the grid services, the next ring has the value categories, and the outermost ring describes the value streams in short phrases. Figure 16 depicts this legend. The supporting tables to these charts, which include more detailed descriptions of the value streams, are provided in the Appendix A. These examples are intended to show possible value streams under each service and do not explicitly designate primary or secondary tiering for value categories. A stakeholder would have the flexibility to select from these possibilities based on their priorities and interests and then cascade those ideas into refined value streams.

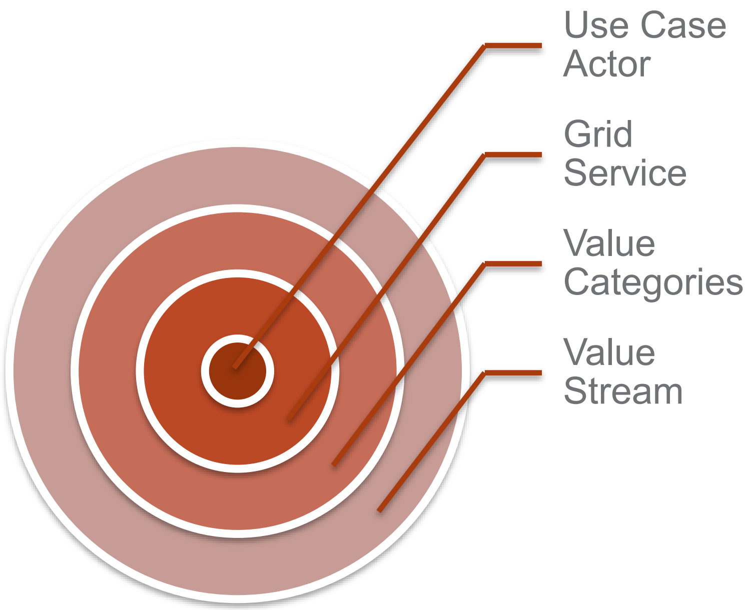

Figure 16. Legend used for interpreting the sunburst diagrams in the use-case examples (Figure 17, Figure 18, and Figure 19).

To move beyond abstractions, the use cases also include framework implementation guidelines for valuation. We discuss how deliverability, stacking, and M&V shape actual value outcomes. These considerations show how the same service may produce different realized values depending on feeder topology, telemetry quality, market rules, or aggregation strategy. Note that these use cases are not exhaustive, they highlight selected examples to demonstrate how grid services generate value at different scales.

5.1 Rural Co-op

Rural electric cooperatives are non-profit, member-owned utilities established to bring reliable and affordable power to sparsely populated rural areas that were historically left unserved due to the high cost of infrastructure (Rural Climate Partnership 2024). In total, rural electric co-ops service over 40 million Americans, roughly 12% of the U.S. electricity consumers, while owning and maintaining approximately 42% of the nation’s distribution lines (NRECA 2025).

Two types of co-ops exist, distribution co-ops, directly serve end-use customers and manage local distribution networks, while G&Ts supply bulk power and transmission services to multiple distribution co-ops. Because of this distinction, the impacts of grid services differ between them. At the distribution level, impacts are more localized to the community or area being served by the co-op. At the G&T level, impacts are more regional and coordinated across different territories.

5.1.1 Distribution Co-op

Rural distribution cooperatives typically operate long radial feeders with limited automation and sparse telemetry (Kersting and Phillips 1990). Their member bases are dispersed, loads are often agricultural or residential, and budgets are tight, limiting investment in advanced controls or redundant infrastructure (NRTC 2021; Lyle W. Williams Co 2024). These conditions make reliability and cost management central priorities and highlight why localized grid services like voltage support and regulation are so valuable. For a rural distribution co-op, Figure 17 illustrates how value streams translate into member-level impacts across the dimensions of cost & access, reliability, resilience and security.

In this context, the key services most relevant for a rural distribution co-op typically include Voltage Management (the reliability backbone), Regulation (via aggregated distribution system assets), Reserves (for adequacy and contingency coverage), and Energy (for peak reduction and load shaping). Blackstart, for example, enhances resilience by enabling faster feeder and substation restoration, thereby reducing outage durations for members. Frequency Response improves reliability by preventing feeder trips and keeping the households and farms online during disturbances. Regulation contributes to cost & access by reducing the need for additional voltage regulators or capacitor banks, thereby lowering infrastructure costs. Voltage Management strengthens reliability by minimizing flickers and brownouts, ensuring power quality for members. Reserve capacity enhances resilience by keeping local feeders online during grid interruptions and supports critical loads in the community. Finally, Energy services improve costs and access by reducing peak demand charges the distribution co-ops pay to their G&T and keeping the rates lower for their members. To calculate value, these qualitative impacts must be translated into metrics, so the next step is to show how the framework uses modeling and M&V to make the value of each service auditable.

Figure 17. Sunburst diagram showing the distribution co-op use case, mapping grid services to value streams and their associated impacts. The diagram provides examples of all potential streams with specificity defined by specific needs. More details on value streams are in Table 7.

In practice, distribution-level power flow (D-OPF/DistFlow) models can translate service attributes into node- and system-level setpoints while physical limits determine value. The resulting voltages, flows, and dispatch become tagged outputs that roll up into metrics. When these measured feeder voltages and device states are not available, they can be modeled using calibrated profiles. The deliverability of value will vary with feeder topology and constraints, and practical performance is capped by telemetry latency and measurement accuracy. Because Regulation and Reserve both draw on the same physical capability (i.e., fast ramp + available headroom/foot room) a Regulation-first priority rule can avoid double counting. Similarly, VAR injections that reduce real-power headroom for Frequency Response have their benefits bounded by inverter limits in the OPF. For a rural distribution co-op with long radial feeders, sparse telemetry, and tight budgets, this setup yields comparable, audit-ready metrics while making stacking limits and opportunity costs explicit at the feeder and node level.

5.1.2 G&T Co-op

G&T cooperatives serve as the wholesale providers for multiple rural distribution co-ops, managing generation fleets and long transmission corridors. They operate under conditions of limited system monitoring, seasonal demand peaks, and operational constraints such as congestion, intertie capacity, and ramping limits. These characteristics make adequacy, contingency planning, and cost control critical for how G&Ts deliver and value grid services. For a G&T co-op, Figure 18 highlights how services support system-level adequacy, manage tie-line and congestion constraints, and balance economic and reliability objectives across the wider footprint.

Grid services shape bulk system performance and portfolio costs, influencing how power is procured and delivered across multiple member co-ops. The services of greatest relevance generally include Reserves (for adequacy and contingency), Regulation (to lower production costs), Energy (to mitigate scarcity conditions), and Frequency Response (to support nadir protection). Blackstart enhances resiliency by allowing G&T assets to restart independently after a blackout, accelerating the system restoration. Frequency response supports reliability by maintaining interconnection stability and reliability standards by NERC thereby preventing large-scale trips. Regulation improves cost and access by reducing the need to purchase balancing services from wholesale markets at higher prices and deferring investments in new assets. Voltage Management contributes to reliability by reducing transmission line losses across rural corridors. Reserve capacity lowers cost and enhances resilience by minimizing the need for high-priced emergency power purchases for contingencies. Finally, Energy services enable the co-op to avoid transmission congestion and its associated costs and provide arbitrage for participating in the wholesale or regional markets. To quantify these impacts, the framework is implemented through production-cost and unit-commitment (UC) models, which translate service attributes into dispatch decisions under system constraints.

Figure 18. Sunburst diagram showing the G&T co-op use case, mapping grid services to value streams and their associated impacts. The diagram provides examples of all potential streams with specificity defined by specific needs. More details on value streams are in Table 8.

In practice, a G&T co-op would rely on UC models coupled to zonal transmission constraints and tie limits over a defined study horizon to realize service value. Reserve and Regulation requirements are fixed (exogenous) model inputs and model outputs show how those targets are met (i.e., who provides, where, when). Metrics are computed at 5-min, 15-min, or hourly cadence and in daily system-level summaries. Data sources include historical load/renewables (with stochastic variability draws), fleet assumptions for governor/AGC parameters, SCADA/AMI, device MW telemetry, dispatch/AGC signals, and event logs.

Value is deliverable only where location, timescale, flexibility (MW/MWh/kVAR), and controllability align with the service, and where stacking rules prevent the same capability from being sold twice. For instance, Reserve benefits depend on intertie limits, zonal congestion, and unit commitment constraints. Energy services are subject to ramp rates and minimum run times, while Frequency Response effectiveness depends on available headroom and governor settings on committed units. Like the distribution case, Reserve and Regulation awards draw the same MW capability, so value stacking needs explicit priority rules. To avoid double counting, Frequency Response headroom can be explicitly set within UC, so it is not double booked with Energy schedules. Under cost & access, production cost models should keep economic effects separate from reliability measures.

With challenges such as long transmission lines, limited system monitoring, seasonal demand peaks, and operational limits such as congestion, intertie capacity, and ramping constraints, a rural G&T co-op can use this framework to inform better procurement decisions by providing standardized, transparent metrics and making the trade-offs between stacked services and deliverability limits more explicit.

5.2 Customer with Assets

A customer with assets can be both a service provider and consumer of electricity. Customers may own assets such as rooftop solar, batteries, electric vehicles, smart thermostats, or water heaters. These devices operate with small inverters, variable telemetry, and diverse feeder conditions. Customers participate in utility or aggregator programs to provide grid services while also remaining retail customers to the utility. Grid services at the individual customer level contribute significantly to the overall grid when aggregated across thousands of households. Customer participation depends on device constraints, communications, and aggregation, which influences how and when they can provide services. Importantly, customers benefit twice: they can earn revenue for providing services, and benefit from the system stability and lower costs those services help enable.

Figure 19 summarizes how the framework applies to the customer case, illustrating how value streams emerge from household-level assets. For example, Blackstart service improves resilience by allowing a customer's assets to contribute to system restart while also ensuring their own home regains power quickly during an outage. Frequency Response supports reliability as smart inverters and batteries provide rapid stabilization of the grid, that is in turn reflected back in protecting household appliances from trips. Regulation creates benefits by reducing the customers' exposure to flickers and fluctuations. Voltage Management enhances reliability by allowing these assets to provide local reactive support, which smooths feeder operations and prevents brownouts and equipment stress in home. Reserve capacity strengthens resilience similar to Blackstart by reducing the grid interruption periods. Finally, energy services reduce costs and improve access through self-consumption of these assets and thereby lowering costs, while supporting grid operations when required. In all these services, the customer also benefits from earning compensation for providing each or any of these services. To translate these qualitative benefits into measurable value, the framework is implemented at the device and aggregation level.

A customer would need asset-level scheduling with device constraints (e.g., State of Charge targets, charge/discharge limits, inverter kVAR ceilings, comfort/contract bounds) feeder conditions over time to translate service attributes into dispatch decisions and compute value. Primary data are directly measured kW/MW from devices, and where this data lacks, extrapolate profiles are extrapolated to the fleet via statistically similar customers, and hours of critical load served with confidence intervals based on device availability. Value deliverability depends on house-level constraints like contract demand and comfort, communication latency, location of the feeder (i.e., distance from regulators, phase balance), and aggregation diversity.

To tabulate value without double counting, stacking rules are needed. A customer should apply a Voltage-first stacking rule that reserves kVAR for Volt/VAR to keep voltage in band, then apply residual kW to Regulation. This will address limited inverter apparent power. Then, opportunity costs can be tracked by reserving kVAR/kW envelopes in the model and subtracting overlaps at settlement. With device constraints, limited telemetry, inverter apparent-power limits, and feeder/location variability in mind, a customer can use this framework and setup to enroll practically across programs and realize their assets' value through metrics useful to operators and regulators.

Figure 19. Sunburst diagram showing the customer use case, mapping grid services to value streams and their associated impacts. The diagram provides examples of all potential streams with specificity defined by specific needs. More details on value streams are in Table 9.

6.0 Implications for Future Modeling and Planning

Value categories can provide lenses for comparison in modeling and planning, either as weighted objectives in optimization or as reporting dimensions once metrics are calculated. Every claimed impact should be tied to a named metric emitted by the model so planners can compare services apples-to-apples. Value streams are represented as tagged outputs—intermediate time-series or event signals labeled with service, location, time resolution, and value-category metadata that can feed multiple metrics. Finally, the metrics are the audited, reportable outcomes the model must compute so valuation can be done directly from model outputs without additional interpretation.

This bridge opens several future research avenues as well. We can explore how different stakeholders (e.g., utilities, regulators, asset owners, consumers, market operators) perceive and prioritize value, and whether those priorities should be weighed during valuation. Multi-criteria methods (e.g., scorecards with stakeholder weights) can translate preferences into explicit trade-offs among value categories. Another avenue is exploring value beyond stochastic, time-series representation. Some services benefit from other analytical domains: for instance, using the power spectral density of net-load variability to estimate regulation effort in the frequency domain, or flicker indices for voltage quality. Location also matters; feeder topology and congestion can determine whether value is actually deliverable at the point of need so the same service can have different marginal value across nodes. Finally, non-financial value often suffers from sparse data, and some value categories lack metrics in our current framework. Where measurements are missing, research can explore methods capturing value using machine-learning approaches or proxy metrics that stand in for the intended value dimension (e.g., hours of critical load served as a resilience proxy during restoration) from limited observations. Investigating these research questions can aid a path to framework standardization.

6.1 Integration with Existing Grid Modeling

This framework embeds directly in planning studies and optimization by mapping each attribute to a model constraint or variable, and each value stream to one or more outputs or metrics collected at the appropriate time and location resolution. Value streams then summarize the net direction of impact across their constituent metrics, and value categories enable cross-service, cross-technology comparisons using a consistent scoreboard.

For onsite energy optimization, hosting-capacity and avoided-cost tools can become service-aware by tagging capacity increments with the value category they most affect and reporting both average and marginal effects by node and hour. The corresponding metrics then become model outputs that feed value scorecards for each technology. A similar approach applies in transmission-distribution co-simulation. Iterating between transmission-level scarcity and distribution constraints reveals how joint conditions determine deliverability and value. The metrics within our framework keep the model outputs directly usable for planning.

6.2 Path to Standardization

The framework can serve as a common language between planners, operators, regulators, and providers across several pathways to standardization. In regulatory filings, defining each service with the framework elements enables portable qualifications across programs and jurisdictions that show devices meet service requirements. Value stacking rules built on the value category tiering can be added to the framework to standardize how value is calculated (e.g., priority, opportunity-cost accounting, and anti-double-counting).

Within cost-benefit frameworks, value streams can be a weighted layer of stakeholder priorities, and the metrics can be included as both monetized and non-monetized value. Resilience tools can pair hazard scenarios with service attributes that matter in those events (e.g., blackstart autonomy hours, Volt/VAR ride-through, fast frequency response penetration) and corresponding metrics can then be compared to “blue-sky” studies with value streams describing overall impact. Standardizing the framework with added metrics and stacking rules can make service valuation traceable, comparable, and portable.

7.0 Conclusion

This report advances a service–attribute–value framework that connects what each service does to why it matters and how its benefits are evidenced. We map technology-agnostic attributes to primary and secondary value categories and anchor them in metrics across six grid services defined in previous work: Frequency Response, Regulation, Reserves, Energy, Voltage Management, and Blackstart.

Results from three use cases—a distribution co-op, a G&T co-op, and a customer with assets stress—test the framework's portability and demonstrate how value streams are adaptable to stakeholders. The same attribute-value-metric chain can be used to produce comparable, decision-ready results despite different scales and constraints. The cases also showed stakeholder adaptability: primary value categories aligned with Figure 8's proposal, while secondary benefits shifted with local objectives and feeder or portfolio conditions.

The framework is immediately usable in planning models, DER optimization, and transmission-distribution co-simulation by treating attributes as constraints, value streams as tagged outputs, and metrics as reportable. It also points to a practical path for portable qualifications and consistent stacking rules in tariffs and filings, and it accommodates stakeholder weighting and non-monetary value via proxy metrics. Remaining gaps, such as data sparsity, locational feasibility, and empirical validation of non-monetary metrics, define research opportunities in the near-term agenda.

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Appendix A – Full Metrics List

As described in our methodology and visual framework sections, this appendix presents the full mapping of each grid service to its associated value categories and corresponding metrics. The metrics included are not exhaustive. The mapping process began by reviewing each grid service and identifying its attribute types (electrical attributes and temporal attributes). For each attribute category, we compared the service's parameters against relevant value categories classified as primary or secondary based on the typical contributions of that service to grid performance (e.g., reliability, cost and access, resilience). Metrics for these value categories were sourced from (Anderson, 2017) *X* and *Y*, then evaluated for alignment with the attribute parameters of the service. Only metrics with clear definitional and unit-level relevance were included. This process was repeated systematically for all grid services.

A.1 Energy Service

Energy service has the operational objectives of providing peak load shaving, load shaping, and emergency power. Reliability, the primary value category, address the core service function is to deliver continuous, sufficient power. Secondary value through cost & access comes from the service's ability to directly affect affordability and rate design; secondary value is provided through resilience because of energy service's contribution to energy continuity.

Table 1. Full framework mapping for Energy service

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power	Primary	Reliability	Customer Average Interruption Frequency Index (CAIFI)	Events per unit time per customer
Electrical	Power	Primary	Reliability	Average Service Availability Index (ASAI)	Dimensionless
Electrical	Power	Primary	Reliability	Monthly Average Interruption Frequency Index (MAIFI)	Monthly events per customer
Electrical	Power	Primary	Reliability	Customers Experiencing Multiple Interruptions (CEMI)	Dimensionless
Electrical	Power	Primary	Reliability	Customers Experiencing Multiple Sustained Interruption and Momentary Interruptions (CEMSMI)	Dimensionless
Electrical	Power	Primary	Reliability	Customers Interrupted (CI)	Customers per unit time period
Electrical	Power	Primary	Reliability	Customer Minutes Interrupted (CMI)	Minutes per customer per unit time period
Electrical	Power	Primary	Reliability	Average system interruption frequency index (ASIFI)	Dimensionless
Electrical	Power	Primary	Reliability	Average System Interruption Duration Index (ASIDI)	Hours
Electrical	Power	Primary	Reliability	Customers Experiencing Long Interruption Durations (CELID)	Dimensionless
Electrical	Power	Primary	Reliability	Correct Operation Rate (COR)	%
Electrical	Power	Primary	Reliability	Devices Experiencing Long Interruptions (DELI)	Count

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power	Primary	Reliability	Devices Experiencing Multiple Interruptions (DEMI)	Count
Electrical	Power	Primary	Reliability	Average Circuit Outage Duration (ACOD)	Minutes
Electrical	Power	Primary	Reliability	Average Circuit Sustained Interruptions (ACSI)	Count/time
Electrical	Power	Primary	Reliability	Transmission Availability Composite Score (TACS)	Dimensionless
Electrical	Power	Primary	Reliability	Forced Outages Per Hundred Circuit Miles Per Year (FOHMY)	Outages per hundred miles per year
Electrical	Power	Primary	Reliability	System Regulating Capability (TVA)	Normalized
Electrical	Power	Primary	Reliability	Flexible Resource Indicator (WECC)	Normalized
Electrical	Power	Primary	Reliability	Periods of Flexibility Deficit (EPRI)	MW of flexibility deficit in the up or down direction for each hour
Electrical	Power	Primary	Reliability	Flexibility Metric (ISO-NE)	Binary (is there a shortage or not?)
Electrical	Power	Primary	Reliability	LOLE_flex (LOLE multi_hour and LOLE_intra_hour)	Days with Loss of Load in 10 Years
Electrical	Power	Primary	Reliability	Binding flexibility ratio	Normalized
Electrical	Power	Primary	Reliability	Flexible Capacity Need (CAISO)	MW of flexible capacity
Electrical	Power	Primary	Reliability	Percent of unit-hours mitigated	Normalized
Electrical	Power	Primary	Reliability	Demand response (DR)	Normalized
Electrical	Power	Primary	Reliability	Accuracy of Predictive Model	None
Electrical	Power	Primary	Reliability	Average Customer Demand	MW/kW
Electrical	Power	Primary	Reliability	Count of unserved customers during an outage event	Count
Electrical	Power	Primary	Reliability	Unserved Load	None
Electrical	Power	Primary	Reliability	Resource shutdown event count	Count
Timing	Delivery Schedule	Primary	Reliability	System Average Interruption Frequency Index (SAIFI)	None
Timing	Delivery Schedule	Primary	Reliability	System Average Interruption Duration Index (SAIDI)	None
Electrical	Power	Primary	Reliability	Peak Demand	MW
Electrical	Power	Primary	Reliability	Mean Absolute Percentage Error (MAPE)	None
Electrical	Power	Primary	Reliability	Minimum Resource Margin	MW
Electrical	Power	Primary	Reliability	Max indoor air temperature deviation (MIATD)	degrees F/C
Electrical	Power	Primary	Reliability	Highest market price (over 8,760 h)	$
Electrical	Power	Primary	Reliability	Loss of Load Expectation (LOLE)	Count
Electrical	Power	Primary	Reliability	Market Activity	MW
Electrical	Power	Primary	Reliability	Distribution of PV real power generation by hour	Count/hour

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power	Primary	Reliability	Average indoor air temperature deviation (AIATD)	degrees F/C
Electrical	Power	Primary	Reliability	Available Generation Capacity (AvGenCap)	MW
Electrical	Power	Primary	Reliability	PV Average Real Power Generation by Hour	Watt
Electrical	Energy	Primary	Reliability	Variable Energy Resource Penetration (TVA)	Normalized
Electrical	Energy	Primary	Reliability	Flexibility Turndown Factor (TVA)	Normalized
Electrical	Energy	Primary	Reliability	Renewable Curtailment	Normalized
Electrical	Energy	Primary	Reliability	Expected Energy Not Served (EENS)	MWh
Electrical	Energy	Primary	Reliability	System Energy Losses (SEL)	MWh
Electrical	Energy	Primary	Reliability	Hot Water Supply Deficit (HWSD)	BTU
Electrical	Energy	Secondary	Reliability	Feeder Energy Losses (FEL)	MWh
Electrical	Energy	Primary	Reliability	Feeder energy transport losses	kWh
Electrical	Electrical Location	Primary	Reliability	Average real feeder power	MW/kW
Electrical	Electrical Location	Primary	Reliability	Substation Peak Real Power Demand (SPRPD)	MW
Electrical	Electrical Location	Primary	Reliability	Average real feeder power by day of week	MW
Electrical	Electrical Location	Primary	Reliability	Average real feeder power by season	MW
Electrical	Electrical Location	Secondary	Cost & Access	Locational Marginal Price	$
Timing	Delivery Schedule	Primary	Reliability	CAIDI	Hours per customer
Timing	Delivery Schedule	Primary	Reliability	CTAIDI	Hours per customer
Electrical	Energy	Secondary	Cost & Access	Levelized cost of electricity (LCOE)	$/MWh, $/kWh
Electrical	Energy	Secondary	Cost & Access	Internal Rate of Return (IRR)	Percentage
Electrical	Energy	Secondary	Cost & Access	Simple Payback Period (SPP)	# of years or months
Electrical	Energy	Secondary	Cost & Access	Net Revenue Requirements	$/year
Electrical	Energy	Secondary	Cost & Access	Avoided Cost	$
Electrical	Energy	Secondary	Cost & Access	Customer cost burden	fraction
Electrical	Energy	Secondary	Cost & Access	Affordability gap factor	factor or fraction
Electrical	Energy	Secondary	Cost & Access	Affordability gap headcount	# Households or % of households
Electrical	Energy	Secondary	Cost & Access	Affordability gap index	index

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Energy	Secondary	Cost & Access	Affordability gap headcount index	index
Electrical	Energy	Secondary	Cost & Access	Monetary Value of System-Wide Energy Losses	$
Electrical	Energy	Secondary	Cost & Access	Total Resource Cost (from a supply and utility perspective)	$
Electrical	Energy	Secondary	Cost & Access	Transmission Losses	MW
Electrical	Energy	Secondary	Cost & Access	Total Demand Response Incentives	$
Electrical	Energy	Secondary	Cost & Access	System Energy Losses	MWh
Electrical	Energy	Secondary	Cost & Access	Total Cost of Energy Resources	$
Electrical	Energy	Secondary	Cost & Access	Total Distribution Substation Transformer Life Impact Expectation (TDSTLIE)	None
Electrical	Energy	Secondary	Cost & Access	Total Cost of Balancing Frequency Regulation	$
Electrical	Energy	Secondary	Cost & Access	Predicted Mean Vote (human thermal comfort	None
Electrical	Energy	Secondary	Cost & Access	Minimum market price (over 8,760 h)	$
Electrical	Energy	Secondary	Cost & Access	Peak Marginal Resource Unit Cost	$/MWh
Electrical	Energy	Secondary	Cost & Access	Market volatility	$
Electrical	Energy	Secondary	Cost & Access	Market Fairness	None
Electrical	Energy	Secondary	Cost & Access	Market Stability	$
Electrical	Energy	Secondary	Cost & Access	Market Efficiency	$
Electrical	Energy	Secondary	Cost & Access	Market average unit price (over 8,760 h)	$
Electrical	Energy	Secondary	Cost & Access	Market Net Consumer Surplus	$
Electrical	Energy	Secondary	Cost & Access	Market Net Supplier Surplus	$
Electrical	Energy	Secondary	Cost & Access	Market price distribution	$
Electrical	Energy	Secondary	Cost & Access	Deviation from conditioned space temperature setpoint	MW
Electrical	Energy	Secondary	Cost & Access	Adjusted Social Welfare (ASW)	$
Electrical	Energy	Secondary	Cost & Access	efficiency	None
Electrical	Energy	Secondary	Cost & Access	Number of iterations (NOI)	Count
Electrical	Power	Secondary	Resilience	Cumulative (critical) customer-hours of outages	Hours

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power	Secondary	Resilience	Cumulative (critical) customer energy demand not served	MWh
Electrical	Power	Secondary	Resilience	Average number (or percentage) of (critical) customers that experience an outage during a specified time period	Count or %
Electrical	Energy	Secondary	Resilience	Added costs to utility	$
Electrical	Power	Secondary	Resilience	Critical services without power (e.g., hospitals, fire stations, police stations)	Count
Electrical	Power	Secondary	Resilience	Critical services without power for more than N hours (e.g., N > hours of back up fuel requirement)	Count
Electrical	Power	Secondary	Resilience	Key production facilities without power	Count
Electrical	Power	Secondary	Resilience	Key military facilities without power	Count
Electrical	Energy	Secondary	Resilience	Loss of assets and perishables	Count
Electrical	Power	Secondary	Resilience	Emergency Scarcity Power Purchase	MW
Electrical	Power	Secondary	Resilience	Unscheduled Flows	MWh
Electrical	Power	Secondary	Resilience	Emergency Scarcity Power Sells	$
Electrical	Power	Secondary	Resilience	Expected Load Loss	MW
Timing	Delivery Schedule	Primary	Reliability	Mean-Time-to-Fix (MTTF).	Hour or Min
Timing	Delivery Schedule	Primary	Reliability	Early Notification Metric	%
Timing	Delivery Schedule	Primary	Reliability	Cancellation Metric	%
Timing	Delivery Schedule	Primary	Reliability	Load Forecast Accuracy	%
Timing	Delivery Schedule	Primary	Reliability	Multi-Hour Forecast Error	%
Timing	Delivery Schedule	Primary	Reliability	Net Load Forecast Error	%
Timing	Delivery Schedule	Primary	Reliability	Locational Uncertainty Reserve requirements	MW
Timing	Delivery Schedule	Secondary	Resilience	Deviation/Diversions from schedule (MSRE)	%
Timing	Delivery Schedule	Primary	Reliability	Energy Imbalance (Forecasted/committed vs actual output)	MW
Timing	Delivery Schedule	Primary	Reliability	Outages and Deratings	MW or MWh
Timing	Delivery Schedule	Primary	Reliability	# of de-listings, derates	Count
Electrical	Power	Primary	Reliability	Energy Imbalance (Forecasted/committed vs actual output)	MW

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Timing	Delivery Schedule Notification	Primary	Reliability	# of Energy Emergency Alerts	Count
Electrical	Energy	Secondary	Resilience	Business interruption costs	$
Electrical	Energy	Secondary	Resilience	Impact on Gross Municipal Product (GMP)	$
Electrical	Energy	Secondary	Resilience	Impact on Gross Regional Product (GRP)	$
Electrical	Energy	Secondary	Resilience	Avoided outage cost	$
Electrical	Energy	Secondary	Resilience	Cost of recovery	$
Electrical	Energy	Secondary	Resilience	Cost of grid damages	$

A.2 Reserve Service

Reserve service addresses resource adequacy, contingency planning, and sustaining capacity objectives. The primary value from reliability is provided because Reserve services are especially procured and called to respond during forecasted or real-time operational load variability. Secondary resilience value comes from the use of Reserve Service during external disturbances. There is additional value in cost & access because reserves avoid and defer outage expenses, fuel price spikes, and any financial risk in operations. Energy arbitrage can also be gained by supplying co-optimized ancillary services in the wholesale markets.

Table 2. Full framework mapping for Reserve Service

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power	Primary	Reliability	Insufficient Ramping Resource Expectation	Number of observations with insufficient ramping
Electrical	Power	Primary	Reliability	Net Demand Ramping Variability (NERC ERSTF)	MW of net demand variability
Electrical	Power	Primary	Reliability	Binding flexibility ratio	Normalized
Electrical	Power	Primary	Reliability	Flexible Capacity Need	MW
Electrical	Power	Primary	Reliability	Planned Reserve Margin	MW
Electrical	Power	Primary	Reliability	System Flexibility	MW
Electrical	Power	Primary	Reliability	Energy Reserve Margin	MW
Electrical	Electrical Location	Primary	Reliability	Local Reserve Sufficiency	MW
Electrical	Power	Primary	Reliability	Flexibility Metric (ISO-NE)	Binary
Electrical	Power	Primary	Reliability	Unserved Load	None
Electrical	Power	Primary	Reliability	Resource shutdown event count	Count
Electrical	Power	Primary	Reliability	Minimum Resource Margin	MW

Electrical	Power	Primary	Reliability	Loss of Load Expectation (LOLE)	Count
Electrical	Power	Secondary	Resilience	Emergency Scarcity Power Purchase	MW
Electrical	Power	Secondary	Resilience	Emergency Scarcity Power Sells	$
Electrical	Power	Secondary	Resilience	Expected Load Loss	MW
Electrical	Power	Secondary	Resilience	Customers Benefitted	Count
Electrical	Power	Secondary	Resilience	System Survival Margin	MW
Electrical	Power	Secondary	Resilience	Load Shed Avoided	MW
Timing	Delivery Schedule	Secondary	Resilience	Planned Reserve Margin	MW
Electrical	Power	Secondary	Cost & Access	Total cost of balancing variability	$
Electrical	Power	Secondary	Cost & Access	Avoided cost of emergency generation procurement	$
Electrical	Energy	Secondary	Cost & Access	Operational cost savings from reserve services	$
Electrical	Energy	Secondary	Cost & Access	Market value for ancillary service	$
Electrical	Energy	Secondary	Cost & Access	Deferred costs from loss of load	$
Electrical	Electrical Location	Secondary	Cost & Access	LMPs value from Congestion Management	$
Timing	Delivery Schedule	Secondary	Cost & Access	Day ahead scheduling value	$
Electrical	Power	Secondary	Cost & Access	Net Revenue Requirements	$/year
Timing	Delivery Schedule	Primary	Reliability	Net Load Forecast Error	%
Electrical	Power	Primary	Reliability	Locational Uncertainty Reserve Requirements	MW
Electrical	Energy	Primary	Reliability	Generating Capacity by Fuel Type	MW
Timing	Delivery Schedule	Secondary	Resilience	Deviation/Diversions from Schedule (MSRE)	%
Electrical	Energy	Primary	Reliability	Forecasted/Committed Energy Imbalance	MWh
Timing	Delivery Schedule	Primary	Reliability	Actual Energy Imbalance	MWh
Timing	Speed of Response	Primary	Reliability	Headroom	MW
Timing	Speed of Response	Primary	Reliability	Response rate	MW/min
Timing	Speed of Response	Primary	Reliability	Reserve Duration	Hours or Minutes

Timing	Delivery Schedule Notification	Primary	Reliability	Number of Energy Emergency Alerts	Count
Electrical	Power	Primary	Reliability	Number of Unplanned/Forced Deratings	Count
Electrical	Energy	Primary	Reliability	Energy Not Served	MWh

A.3 Regulation Service

Regulation service provides AGC to correct second-to-minute imbalances. The primary and secondary value categories can be reliability or resilience depending on the characteristics of the regulation signal.

Table 3. Full framework mapping for Regulation service

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Power regulation range	Primary	Reliability	Control Performance Standards (CPS1, CPS2, BAAL)	Normalized
Electrical	Power	Primary	Reliability	System Regulating Capability (TVA)	Normalized
Electrical	Power	Primary	Reliability	Insufficient Ramping Resource Expectation	Number of observations with insufficient ramping
Electrical	Power regulation range	Primary	Reliability	Correct Operation Rate	%
Electrical	Power	Primary	Reliability	Net Demand Ramping Variability (NERC ERSTF)	MW of net demand variability
Electrical	Power regulation range	Primary	Reliability	Mean Absolute Percentage Error (Signal tracking of regulation)	%
Electrical	Electrical location	Primary	Reliability	Area Control Error	%
Timing	Signal periodicity	Primary	Reliability	Imbalance Volume	Count
Electrical	Power regulation range	Primary	Resilience or Reliability (depends on context)	Frequency Nadir	Hz
Electrical	Power regulation range	Primary	Resilience or Reliability (depends on context)	Rate of Change of Frequency	Hz/sec
Timing	Delivery schedule notification	Primary	Resilience or Reliability (depends on context)	Time to Nadir	Sec
Timing	Speed of Response	Primary	Reliability	Tracking Performance	Sec or Min
Electrical	Power regulation range	Primary	Reliability	Tracking Performance	MW
Electrical	Power mileage	Primary	Reiliability	Absolute amount of energy injected and withdrawn	MWh
Timing	Delivery schedule notification	Primary	Reliability	Dispatch Window	Seconds

Timing	Speed of Response	Primary	Reliability	Regulation Interval	Seconds
Timing	Speed of Response	Primary	Reliability	Sampling Rate	Seconds
Timing	Speed of Response	Primary	Reliability	Disturbance Recovery Period	Seconds
Electrical	Power	Primary	Reliability	Frequency Related Compliance Factor	None
Timing	Delivery Schedule	Primary	Reliability	Number of Disturbances Per Year	Count
Timing	Delivery Schedule	Primary	Reliability	Regulation Ramping Rate	MW/sec
Timing	Speed of response	Primary	Reliability	Imbalance Volume	Count

A.4 Frequency Response Service

Frequency Response service handles frequency regulation needs to keep the system in balance and avoid cascading outages after a disturbance. Hence, reliability and resilience can be primary or secondary value categories depending on the use of the service.

Table 4. Full framework mapping of Frequency Response service.

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Percent Droop	Primary	Reliability or Resilience (depends on context)	Frequency Nadir	Hz
Timing	Delivery schedule	Primary	Reliability or Resilience (depends on context)	Time to Nadir	Sec
Electrical	Deadband	Primary	Reliability or Resilience (depends on context)	Rate of Change of Frequency	Hz/sec
Electrical	Percent Droop	Primary	Reliability or Resilience (depends on context)	Frequency Response Obligation	MW
Electrical	Percent Droop	Primary	Reliability or Resilience (depends on context)	Primary Frequency Response Provided	MW
Electrical	Electrical location	Primary	Reliability or Resilience (depends on context)	Frequency Response Sufficiency	MW
Electrical	Deadband	Primary	Reliability or Resilience (depends on context)	Deadband width	Hz or %
Electrical	Deadband	Primary	Reliability or Resilience (depends on context)	Response initiation delay	Sec

Electrical	Deadband	Primary	Reliability or Resilience (depends on context)	Fraction of resources enabled for response	None
Timing	Delivery Schedule Notification	Primary	Reliability or Resilience (depends on context)	Response Enablement Notification Time	Sec
Timing	Delivery Schedule Notification	Primary	Reliability or Resilience (depends on context)	Response Arming Notification Rate	Sec

A.5 Voltage Management Service

Voltage Management service provides voltage support. Reliability is the primary value category because voltage within acceptable limits prevents outages, equipment damage, and cascading failures. Cost & access is a secondary value category because Voltage Management supports asset longevity (reducing capital costs), avoids reactive power penalties, and helps reduce losses.

Table 5. Full framework mapping of Voltage Management service.

Attributes	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Electrical	Target voltage/range	Primary	Reliability	Maximum Transmission Under-Voltage Violation (MTUVV)	Voltage
Electrical	Target voltage/range	Primary	Reliability	Transmission Voltage Magnitude (TVM)	Voltage
Electrical	Target voltage/range	Primary	Reliability	Maximum Transmission Over-Voltage Violation (MTOVV)	Voltage
Electrical	Electrical Location	Primary	Reliability	Severity of Over-Voltage Violation Index (SOVVI)	Second*Voltage
Electrical	Electrical Location	Primary	Reliability	Severity of Under-Voltage Violation Index (SUVVI)	Second*Voltage
Electrical	Electrical Location	Primary	Reliability	Substation Reactive Power Demand (SRPD)	MVar
Electrical	Target voltage/range	Primary	Reliability	Phase Imbalance	None
Electrical	Target voltage/range	Primary	Reliability	Max Over-Voltage Violations (MUVV)	None
Electrical	Target voltage/range	Primary	Reliability	Max Under-Voltage Violations (MUVV)	None
Electrical	Target voltage/range	Primary	Reliability	Max Duration of Over-Voltage Violations (MUVV)	None
Electrical	Target voltage/range	Primary	Reliability	Max Duration of Under-Voltage Violations (MUVV)	None

Electrical	Delivery Schedule	Primary	Reliability	Duration of Under-Voltage Violation (DUVV)	Seconds
Electrical	Target voltage/range	Primary	Reliability	Duration of Over-Voltage Violation (DOVV)	Seconds
Electrical	Target voltage/range	Primary	Reliability	Count of Transmission Under-Voltage Violation Events (CTUVVE)	Count
Electrical	Target voltage/range	Primary	Reliability	Average reactive feeder power by season	MW
Electrical	Target voltage/range	Primary	Reliability	Average reactive feeder power	MVAr
Electrical	Target voltage/range	Primary	Reliability	Count of Over-Voltage Violations	Count
Electrical	Target voltage/range	Primary	Reliability	Average customer voltage	Voltage per unit
Electrical	Target voltage/range	Primary	Reliability	Average reactive feeder power by day of week	MW
Electrical	Target voltage/range	Primary	Reliability	Average reactive feeder power by day of week	MW
Electrical	Target voltage/range	Primary	Reliability	System Average RMS (Variation) Frequency Index (SARFI)	Avg events per customer
Electrical	Target voltage/range	Primary	Reliability	System Instantaneous Average RMS (Variation) Frequency Index (SIARFI)	Events per customer
Electrical	Target voltage/range	Primary	Reliability	System Temporary Average RMS (Variation) Frequency Index (STARFI)	Avg events per customer
Electrical	Target voltage/range	Primary	Reliability	System Momentary Average RMS (Variation) Frequency Index (SMARFI)	Avg events per customer
Electrical	Electrical Location	Secondary	Cost & Access	Severity of voltage violations for a set of buses within a selected scope	None
Electrical	Electrical Location	Secondary	Cost & Access	Count of under-voltage violations for a set of buses within a selected scope	Count
Electrical	Target voltage/range	Secondary	Cost & Access	Minimum customer voltage	Voltage

Electrical	Target voltage/range	Secondary	Cost & Access	Maximum customer voltage	Voltage
Timing	Delivery Schedule	Primary	Reliability	Percent of Time in Band	%
Timing	Delivery Schedule Notification	Primary	Reliability	Number of voltage excursions	Count
Timing	Signal Periodicity	Primary	Reliability	System Average Overvoltage Frequency Index	None

A.6 Blackstart Service

Blackstart services are called upon for emergency power after disturbances cause outages. Since the primary purpose of this service is system recovery, resilience is the primary value category, and cost & access value is a byproduct; Cost efficient recovery limits ratepayer impact, supports faster restoration, and enables broad system coverage.

Table 6. Full framework mapping for Blackstart service.

Attribute	Attribute Parameter	Value Category Type	Value Category	Metric	Units
Timing	Delivery Schedule	Primary	Resilience	System Average Restoration Index (SARI)	Minutes per outage
Timing	Speed of Response	Primary	Resilience	Time to Recovery	Minutes
Electrical	Power	Primary	Resilience	Restoration cost of recovery	$
Electrical	Power	Secondary	Cost & Access	Restoration cost of recovery	$
Electrical	Power	Secondary	Cost & Access	Levelized cost of electricity (LCOE)	$/MWh, $/kWh
Electrical	Power	Secondary	Cost & Access	Net Revenue Requirements	$/year
Electrical	Power	Secondary	Cost & Access	Avoided Cost	$
Electrical	Electrical Location	Primary	Resilience	Count of unserved customers during an outage event	Count
Electrical	Electrical Location	Primary	Resilience	Critical Services without Power	Count
Electrical	Electrical Location	Primary	Resilience	Critical Services without Power for more than N hours	Count

Electrical	Electrical Location	Primary	Resilience	Local Key Facilities without Power	Count
Electrical	Electrical Location	Primary	Resilience	Restoration Zone Coverage	%
Timing	Delivery Schedule Notification	Primary	Resilience	Forced Outage Notification	None
Electrical	Power	Primary	Resilience	Minimal Start Power	MW
Timing	Delivery Schedule	Primary	Resilience	Minimal Start time	Sec or Min
Electrical	Power	Primary	Resilience	Nameplate Capacity	MW
Timing	Speed of Response	Primary	Resilience	Ramp Rate	MW/min
Electrical	Power	Primary	Resilience	Ramp Size/Capacity	MW
Timing	Speed of Response	Primary	Resilience	Startup Time	Timestamp
Electrical	Power Regulation Range	Primary	Resilience	Inertia	MW-s
Electrical	Power Regulation Range	Primary	Resilience	Frequency Control Characteristics: Droop Coefficient	Hz/MW
Electrical	Power Regulation Range	Primary	Resilience	Frequency Control Characteristics: Response Gain	MW/Hz
Electrical	Delivery Schedule Notification	Primary	Resilience	Frequency Control Characteristics: Response Delay	Sec
Electrical	Power Regulation Range	Primary	Resilience	Frequency Excursion Capabilities	Hz
Electrical	Power Regulation Range	Primary	Resilience	Voltage Control Characteristics: Voltage Control Sensitivity	%V/MVAR
Electrical	Power Regulation Range	Primary	Resilience	Voltage Control Characteristics: Reactive Power Range	Reactive Power Range (MVAR)
Electrical	Power Regulation Range	Primary	Resilience	Voltage Control Characteristic	Binary: Automatic Voltage Regulation

				s: Regulation Mode	(AVR), Power Factor Control (PF)
Electrical	Power Regulation Range	Primary	Resilience	Voltage Excursion Capabilities	% of nominal voltage
Electrical	Power Regulation Range	Primary	Resilience	Cranking Path Characteristic s: Number of Switching Steps	Count
Electrical	Power Regulation Range	Primary	Resilience	Cranking Path Characteristic s: Redundancy Level	N, N-1, N-2, …
Electrical	Power Regulation Range	Primary	Resilience	Cranking Path Characteristic s: Voltage Class	kV
Electrical	Delivery Schedule	Primary	Resilience	Cranking Path Characteristic s: Time to Energize	minutes
Electrical	Electrical Location	Primary	Resilience	Unit Geographical Distribution	Coordinates, distance
Timing	Delivery Schedule Notification	Primary	Resilience	Restoration Start Notification	Timestamp
Timing	Delivery Schedule Notification	Primary	Resilience	Status Reporting Latency	Sec or Min
Timing	Delivery Schedule Notification	Primary	Resilience	Readiness Confirmation Time	Timestamp

Appendix B – Use Case Examples

This appendix provides the full table breakdown of value streams for each use case. For every service, we list the value category, the stream definition (how value is realized), the value stream phrase, the detailed impact, and the corresponding impact scale. Read across rows to see service to stream traceability.

For the use-case examples, we evaluate each stakeholder or actor by mapping the grid services they might receive to the types of value those services can deliver. For every value category, we then describe how that value translates into tangible outcomes for the stakeholder (e.g., cost deferral, reduced outage impacts). These outcomes are further expanded into specific impact statements with illustrative examples. The impacts are hypothesized based on established literature regarding common grid challenges or operational concerns faced by that stakeholder; therefore, they represent generalized patterns and may not apply to every individual stakeholder. Each identified impact is subsequently assessed on a spatial scale and assigned at an impact level. This process is repeated for every value category associated with each grid service, and across all stakeholders and use-case scenarios.

B.1 Rural Distribution Co-op

Table 7 contains full text of the value streams depicted in Figure 17. We are assuming that the co-op is receiving these services. If co-op provides these services through self-owned assets, then they also can participate in markets that may add additional value streams.

Table 7. Full breakdown of value streams for a rural distribution co-op.

Grid Service	Value Category	Value Stream Phrase	Value Stream Impact	Impact Scale
Blackstart	Resilience	Restoration support	Enabling local feeders/substations to come back online faster	Feeder/Substation-level
Blackstart	Resilience	Restoration support	Critical services like hospitals, water pumps etc. can get restored sooner	Community-level
Blackstart	Resilience	Restoration support	Keep local power flowing even if bulk recovery lags	Community-level
Blackstart	Resilience	Outage impact reduction	Reduces member outage duration	Community-level
Blackstart	Cost & Access	Efficient Asset Use	Reduces system restoration costs and crews cost	Distribution grid level
Blackstart	Cost & Access	Peak Price Avoidance	Avoid G&T peak demand charges	Distribution grid level
Blackstart	Cost & Access	Upgrade deferral	Defer distribution infrastructure upgrades - backup generation/reserve capacities	Distribution grid level
Blackstart	Security	Situational awareness	Reduces vulnerability to bulk system security threats	Distribution grid level
Frequency Response	Reliability	Control system support	Prevents local frequency trips that can disconnect feeders from the bulk grid	Feeder/Substation-level
Frequency Response	Resilience	Control system support	Enables feeders to remain online and stable through disruptions	Feeder/Substation-level
Frequency Response	Cost & Access	Outage impact reduction	Reduces outage restoration + equipment resets	Distribution grid level

Grid Service	Value Category	Value Stream Phrase	Value Stream Impact	Impact Scale
		Upgrade deferral	Defer distribution infrastructure upgrades like upsizing substations	Distribution grid level
	Security	Reduce Operational Vulnerability	Feeders are less vulnerable to instability through physical/cyber attacks	Feeder/Substation-level
			Reduces vulnerability to bulk system security threats	Distribution grid level
Regulation	Reliability	Frequency control support	Reduces flickers and improves power quality	Community-level
			Balance variable loads from agricultural/industrial customers	Community-level
	Resilience	Frequency control support	Prevents frequency decline that could cause outages	Distribution grid level
	Cost & Access	Upgrade deferral	Defer distribution infrastructure upgrades like regulators or capacitor banks	Distribution grid level
	Security	Reduce Operational Vulnerability	Reduces vulnerability to bulk system security threats	Distribution grid level
Voltage Management	Reliability	Asset Protection	Reduces flicker, brownouts and equipment trips	Community-level
		Voltage compliance	Reduces losses, avoids reactive power penalties, and improves energy efficiency	Distribution grid level
	Resilience	Islanding	Support local feeder islanding during hazards	Feeder/Substation-level
	Cost & Access	Upgrade deferral	Defer distribution infrastructure like substations or capacitor bank upgrades	Feeder/Substation-level
	Security	Reduce Operational Vulnerability	Feeders are less vulnerable to instability through physical/cyber-attacks.	Feeder/Substation-level
			Reduces vulnerability to bulk system security threats	Distribution grid level
Reserve	Reliability	Grid Independence	Reduces dependence on upstream power stability	Distribution grid level

Grid Service	Value Category	Value Stream Phrase	Value Stream Impact	Impact Scale
Energy	Resilience	Restoration support	Keep local power flowing even if bulk recovery lags	Community-level
		Outage impact reduction	Critical services like hospitals, water pumps etc. can get restored sooner	Community-level
			Reduces member outage duration	Community-level
	Cost & Access	Efficient Asset Use	Reduces emergency procurement costs from wholesale markets/G&Ts	Distribution grid level
		Peak Price Avoidance	Avoid G&T peak demand charges	Distribution grid level
		Upgrade deferral	Defer distribution infrastructure upgrades - backup generation/reserve capacities	Distribution grid level
	Security	Reduce Operational Vulnerability	Reduces vulnerability to bulk system security threats	Distribution grid level
	Reliability	Grid Independence	Reduces dependence on upstream power supply	Distribution grid level
		Service Continuity	Enables feeders to remain online and stable through disruptions	Feeder/Substation-level
			Balance variable loads from agricultural/industrial customers	Community-level
	Cost & Access	Peak Price Avoidance	Avoided G&T and market wholesale rates and peak demand charges	Distribution grid level
		Rate Stability	Enables to keep rates affordable for members	Community-level
		Upgrade deferral	Defer distribution infrastructure upgrades like feeder upgrades or capacity expansions	Distribution grid level
	Resilience	Restoration support	Keep local power flowing even if bulk recovery lags	Distribution grid level
	Security	Reduce Operational Vulnerability	Reduces vulnerability to bulk system security threats	Distribution grid level

B.2 Rural G&T Co-ops

Table 8 contains full text of the value streams depicted in Figure 18.

Table 8. Full breakdown of value streams for a rural generation & transmission co-op.

Grid Service	Value Streams	Value Stream Phrase	Value Stream Impact	Impact Scale
Blackstart	Resilience	Backbone Recovery	Faster recovery of transmission backbone	Transmission Grid-level
		Stepwise Restoration	Stepwise restoration for member co-ops	Regional
		Independent Restart	Reduced dependency on external utilities or markets	Regional
	Cost & Access	Restoration Savings	Avoided high-cost wholesale purchases for restoration	Regional
		Secure Islanding	Reduced costs of idle and stranded generation assets	Transmission Grid-level
		Restoration Savings	Market re-entry and generation sales	Regional
	Security	Cyber-resilience	Reduced vulnerability to cascading failures from cyber/physical attacks	Transmission Grid-level
Frequency Response	Reliability	Trip Prevention	Prevents tripping of large generators, transmission lines or area-wide loads to shed	Transmission Grid-level
		Stability Support	Maintains interconnection stability with regional grid and supports NERC standards	Regional
	Resilience	Stability Support	Keeps bulk transmission corridors stable enough for blackstart or reserves to engage	Transmission Grid-level
		Cascade Risk Cut	Avoid cascading outages across the service territory	Regional
	Cost & Access	Energy Arbitrage	Lowers procurement costs from wholesale markets or utilities	Transmission Grid-level
		Restoration Savings	Reduces outage restoration costs through less equipment damage	Regional

		Upgrade Deferral	Defer infrastructure investments like oversized substations etc.	Transmission Grid-level
	Security	Cyber-resilience	Prevents destabilization from cyber/physical attacks	Transmission Grid-level
Regulation	Reliability	Renewable Smoothing	Smooths fluctuations from renewable generators	Transmission Grid-level
		Power Quality	Reduces flicker, voltage swings to member co-ops	Regional
		Standards Compliance	Maintains NERC standards for the grid	Regional
	Cost & Access	Energy Arbitrage	Avoid purchase of service from external markets	Regional
		CapEx Deferral	Defer investment for capacitors, fast-ramping generators	Transmission Grid-level
		Flex integration	Integrate renewables flexibility without additional balancing costs	Transmission Grid-level
	Security	Cyber-resilience	Reduces vulnerability to cyber/physical threats	Transmission Grid-level
Voltage Management	Reliability	Voltage stability	Reduces brownouts or voltage swings to member co-ops	Regional
		Equipment Protection	Minimize equipment trips or stress on large loads connected	Transmission Grid-level
		Loss Reduction	Reduces transmission line losses	Transmission Grid-level
	Resilience	Reactive Power Collapse	Prevents cascading collapse from reactive power shortages	Regional
	Cost & Access	CapEx Deferral	Defer investment for capacitors, voltage regulators	Transmission Grid-level
		Hosting Boost	Improves hosting capacity for renewables without major grid upgrades	Transmission Grid-level
		Energy Arbitrage	Lowers procurement costs from wholesale markets or utilities	Regional

	Security	Reduce Ops Vulnerability	Reduces vulnerability to cyber/physical threats	Transmission Grid-level
Reserve	Reliability	Outage Impact Reduction	Covers unexpected generator/transmission line outages without service disruption	Transmission Grid-level
		Local Reserves	Reduces dependence on upstream balancing authorities for reserves	Regional
		Capacity Margin	Provides capacity margin for NERC standards	Regional
	Resilience	System Continuity	Keeps transmission systems online through blackouts	Transmission Grid-level
		Staged Restoration	Enables staged restoration for member co-ops	Regional
	Cost & Access	Capacity Purchase Avoid	Avoid purchasing capacity from wholesale markets	Regional
		Congestion Avoidance	Reduces transmission congestion costs	Transmission Grid-level
		Backup Deferral	Defers investment in backup generators or flexible reserves	Transmission Grid-level
	Security	Hardening	Deters cascading failures by ensuring immediate backup	Regional
Energy	Reliability	Upstream Independence	Reduce dependency on upstream markets for meeting demand	Regional
		Load Balancing	Balances variable loads across member co-ops	Regional
		Steady Supply	Steady supply for member co-ops and reduces fluctuations	Regional
	Cost & Access	Congestion Avoidance	Avoid transmission congestion charges	Transmission Grid-level
		Peak Price Avoidance	Avoids peak wholesale prices and keep rates affordable for member co-ops	Regional
		Upgrade Deferral	Defer investment in new generation plants	Transmission Grid-level

	Resilience	Outage Curtailment	Reduces outage duration and reliance on external imports	Regional
		Restoration Savings	Reduces outage restoration costs through less equipment damage	Regional
	Security	Cascade Risk Cut	Reduced vulnerability to cascading failures from cyber/physical attacks	Transmission Grid-level

B.3 Customer with Assets

Table 9 contains full text of the value streams depicted in Figure 19.

Table 9. Full breakdown of value streams for a customer with assets.

Grid Service	Value Streams	Value Stream Phrase	Value Stream Impact	Impact Scale
Blackstart	Resilience	Faster Restoration	Supports faster restoration of the system	Grid-level
		Critical Load Uptime	Critical loads and appliances come online quickly	Marginal (home)
		Shorter Outages	Avoid long outage durations	Marginal (home)
	Cost & Access	Participation Revenue	Compensation for service participation	Marginal (home)
		Reduce Outage Cost	Avoids loss of load costs due to outages	Marginal (home)
	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level
Frequency Response	Reliability	Frequency Stabilization	Stabilize local frequency and supports bulk system	Grid-level
		Appliance Protection	Lower likelihood for home appliance tripping or resets	Marginal (home)
	Resilience	Recovery Headstart	Immediate response buys system recovery time	Grid-level

		Blackout Risk Cut	Reducing blackout chances and stable power at home	Marginal (home)
	Cost & Access	Participation Revenue	Compensation for service participation	Marginal (home)
		Appliance Protection	Avoided cost of appliance damages	Marginal (home)
	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level
Regulation	Reliability	Variability Balancing	Helps balance variability from renewables and demand	Grid-level
		Better Power Quality	Experience fewer power quality issues and steady power flow	Marginal (home)
	Cost & Access	Participation Revenue	Compensation for service participation	Marginal (home)
		Bill Savings	Lowering retail rates from high demand charges	Marginal (home)
	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level
Voltage Management	Reliability	Intertie Voltage Support	Supports stabilizing voltage at interconnection	Grid-level
		Voltage Smoothing	Supports lowering voltage swings at the feeders	Grid-level
		Fewer Brownouts	Experience lower number of brownouts and trips.	Marginal (home)
	Resilience	Islanding	Supports local islanding or keeping neighborhoods online	Community-level
		Reduce Outage Impact	Lower outages and disruptions to home	Marginal (home)
	Cost & Access	Participation Revenue	Compensation for service participation	Marginal (home)
		Appliance Protection	Avoided cost of appliance damages	Marginal (home)

	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level
Reserve	Reliability	Stability Support	Help maintain stability and system adequacy	Grid-level
		Critical Load Support	Not-on-service assetscan support keeping critical loads running	Marginal (home)
	Resilience	Grid Stability	Contributes to grid stability through major blackouts	Grid-level
		Critical Service Continuity	Ensures continuity of critical services	Grid-level
	Cost & Access	Participation Revenue	Compensation for service participation	Marginal (home)
		Reduce Outage Cost	Avoided cost of loss of loads and competitive high utility prices	Marginal (home)
	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level
Energy	Reliability	Demand Strain Relief	Reduces strain or demand on the grid and complement supply	Grid-level
		Self-Demand Reduction	Reduce their own demand on the grid	Marginal (home)
	Cost & Access	Bill Savings	Compensation for service participation	Marginal (home)
			Reduced retail bills or demand charges	Marginal (home)
	Resilience	Grid Stability	Contributes to keeping grid online and stable during disruptions	Grid-level
		Islanding	Can island their own home and loads to reduce outages	Marginal (home)
	Security	Reduce Vulnerability	Contributes to lowering system vulnerability	Grid-level

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