Decarbonized Electric Grid

Defining, Measuring, and Integrating Decarbonization into Electricity Sector Policy and Planning

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Kamila Kazimierczuk[1]
Mercy Berman DeMenno[2]
Rebecca S. O'Neil[1]
Brian J. Pierre[3]

Pacific Northwest National Laboratories[1], Bosque Advisors[2], and Sandia National Laboratories[3]

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Summary

Traditionally, electric grid planning seeks to maintain safe, reliable, efficient, and affordable service for current and future customers. As policies, expectations of the energy system, and the threat landscape evolve, additional objectives for power system planners are emerging, including decarbonization, resilience, and equity. Renewable and clean energy goals, especially in the context of deep decarbonization strategies, are changing the mix of resources on the electric grid and prompting new considerations for grid architecture. The increased frequency and severity of extreme weather events over the last two decades, coupled with cybersecurity concerns, have elevated resilience as a key system need. More recently, there has been greater focus on equity and energy justice in grid planning to ensure that disadvantaged communities are not adversely affected by grid modernization and have equal access to its benefits. In response, new thinking around multi-objective decision planning is exploring improvements in grid planning processes to better integrate approaches to meet decarbonization, resilience, and equity objectives. To provide a foundation for this work, a series of white papers was produced to summarize these emerging objectives.

This white paper presents an overview of decarbonization in the context of electric grid policy and planning. It provides a working definition of decarbonization and a synthesis of metrics to benchmark system performance, evaluate investments, and explore tradeoffs, highlighting heterogeneity in metrics implementation across jurisdictions (Section 1.0). This paper also provides a discussion of the a) policy prioritization of decarbonization, with examples of relevant state legislation and executive orders, b) delegation of regulatory authority and development of grid planning guidance for decarbonization, and c) status of utility integration of decarbonization into grid planning processes (Section 2.0) and associated challenges and opportunities (Section 3.0). The key findings of this paper are summarized in Table S-1.

Table S-1. Summary Takeaways

	Findings
Section 1.0 Defining and Measuring Electric Grid Decarbonization	• Metrics for decarbonization are well established across state clean energy and renewable portfolio standards as well as federal reporting programs. • Decarbonization scenarios, requirements, and associated metrics tend to have longer time horizons (i.e., decades) than other emerging objectives (e.g., resilience often focuses on performance over days or weeks), which may complicate the assessment of performance and prioritization of investments across multiple objectives.
Section 2.0 Integrating Decarbonization into Policy and Planning	• Clean energy, renewable portfolio, and distributed energy resource policies have led to the relatively robust institutionalization of grid decarbonization across many states, but resulting grid planning practices vary in rigor and scope across jurisdictions.

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Acronyms and Abbreviations

Co-op	Cooperative Utility
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
IOU	Investor Owned Utilities
ISO	Independent System Operator
RTO	Regional Transmission Organization

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1.0 Defining and Measuring Electric Grid Decarbonization

1.1 Decarbonization Definition

Electric grid decarbonization is defined as reducing carbon dioxide (CO_2)—or broader greenhouse gas (GHG)—emissions produced by the electric power sector. In the context of grid planning, decarbonization encompasses both transitioning electricity generation to non-GHG-emitting resources and increasing energy efficiency of end uses and the system itself. These twin dynamics apply to both current and future grid system states as the electricity grid will be utilized to reduce GHG emissions in other sectors, such the transportation sector and for building heating and cooling. Decarbonization is a key component of grid sustainability, which is defined broadly as the "provision of electric services to customers minimizing negative impacts on the natural environment and human health" [1].

1.2 Decarbonization Metrics

Decarbonization objectives for grid planning are relatively straightforward to quantify through reductions in emissions or increases in the penetration of non-emitting energy resources. Depicted in Table 1 and Figure 1, there are well established emissions and resource metrics that have been codified in federal and state climate and energy policy, as well as voluntary commitments. These metrics enable utilities, regulators, and other stakeholders to monitor and improve system performance as it relates to decarbonization goals.

Emissions metrics usually include GHGs beyond CO_2—such as methane, nitrous oxide, sulfur hexafluoride—and such metrics are often expressed as CO_2 equivalent (CO_2e), which coverts GHGs into a common unit based on equivalent global warming impact. Emissions metrics can be mass- or rate-based. Mass-based metrics measure the amount of CO_2 emissions regardless of electricity generated, enabling measurement of the total reduction of emissions from a given baseline. Rate-based metrics measure the amount of CO_2 emissions per unit of electricity generated, enabling measurement of emissions intensity.

Resource metrics focus on the penetration of renewable or clean energy resources. Renewable portfolio standards include metrics focused on the percentage of generation from renewable resources or the percentage of renewable energy delivered to customers. Similarly, clean energy standards include metrics focused on the percentage of generation from clean energy resources (low- or zero-emitting resources) or the percentage of clean energy delivered to customers. Discussed in more detail below, the design of decarbonization policies affects how these metrics are operationalized in grid planning processes.

Table 1. Decarbonization Metrics

Emissions		**Resources**	
Mass-Based	Rate-Based	Renewable Energy Resources	Clean Energy Resources
• Absolute Carbon (Equivalent) Portfolio Emissions (e.g., tons CO2[e]) • Net-Zero Carbon (Equivalent) Portfolio Emissions (e.g., tons CO2[e]–offsets)	• Portfolio Carbon (Equivalent) Intensity (e.g., lbs. CO2[e]/net MWh)	• Portfolio Renewable Energy Resources Generated or Supplied (e.g., % of annual generation/supply from solar, wind, geothermal, hydropower, and biomass)	• Portfolio Clean (Zero-Carbon Emissions) Resources Generated or Supplied (% of annual generation/supply from solar, wind, geothermal, and nuclear)

In practice, decarbonization mandates and other emissions reporting requirements often combine emissions and resource requirements and associated metrics. For example, the U.S. Environmental Protection Agency (EPA) requires electricity generators to report mass-based GHG emissions metrics at the facility and unit level pursuant to the GHG Reporting Program (GHGRP) [2]. State decarbonization policies use a combination of mass- and rate-based metrics, often coupled with resource requirements via a renewable portfolio or clean energy standard. For example, New Mexico's 2019 Energy Transition Act established three mechanisms to enable grid decarbonization: a zero-carbon resource standard (100% by 2045 for investor owned utilities [IOUs] and 2050 for cooperative utilities [co-ops]); an amended renewable portfolio standard (80% by 2040 for IOUs and 2050 for co-ops), and a carbon intensity standard (200 pounds per megawatt hour [MWh] by 2032 for utilities that use a transition financing mechanism established in the legislation) [3].

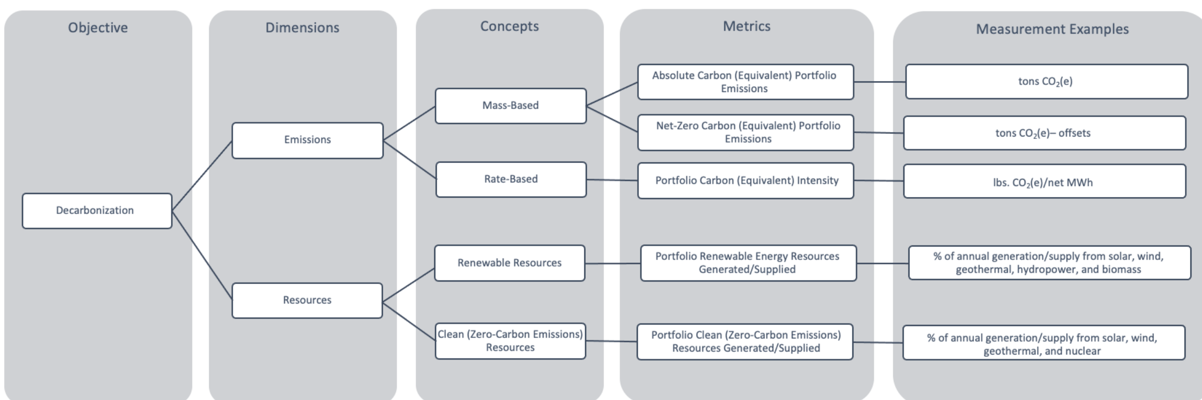

Figure 1. Decarbonization Objective Dimensions, Concepts, Metrics, and Measurement Approaches

There can be substantial variation in how these decarbonization metrics are operationalized based on the stringency of requirements, definitions of eligible resources, measurement approaches, and other objectives (e.g., affordability) in underlying policies. For example, some states set absolute emissions requirements, whereas others have net-zero requirements, the latter generally allows meeting decarbonization targets through both emissions reductions and emissions offsets. [4]. With respect to resource definitions, marine renewable energy technologies, landfill gas, animal wastes, and combined heat and power are qualified renewable resources in some states, but not others. Many states measure renewable energy targets by percentage of retail electric sales, but Iowa and Texas require reporting in terms of renewable energy capacity. Finally, approximately 20 states have cost caps in their renewable standards to limit ratepayer impacts, which has implications for achieving the ultimate percentage target of renewables in the system [5]. The wide range of decarbonization policy designs across states—influenced by state politics, generation and resource portfolios, and economic considerations for ratepayers—creates challenges in comparing and reconciling utility activities across a multi-state region [6].

A related consideration is how decarbonization policies interact with other criteria pollutant emissions requirements, climate change mitigation and adaptation policies, and environmental sustainability goals. For example, decarbonization policies might have complementary impacts on the goals of reducing criteria air pollutants such as nitrogen oxides and sulfur oxides, but the performance measurements and underlying regulatory requirements are different. Likewise, measurement of decarbonization of the electricity sector can be complicated by driving additional electricity load through transportation and building electrification policies, while fossil fuel electricity generating plants are still in the resource stack. Building on this example, beyond simply increasing load on the electricity system, electrification activities have the potential to shift the shape and size of electricity load profiles and influence commodity markets and consumer energy costs, which, in turn, changes decarbonization strategies.

While metrics for decarbonization are well established, emissions and resource-related decarbonization strategies will need to be considered in multi-objective planning practices alongside other environmental policies that have different objectives and timelines. Moreover, decarbonization requirements are increasingly embedded in policy frameworks that envision a just transition to a more socially and economically sustainable electric power system, necessitating more systematic consideration of the equity and accessibility implications of alternative decarbonization investment strategies.

2.0 Integrating Decarbonization into Policy and Planning

2.1 Policy Prioritization of Decarbonization in Grid Planning

Motivated by a range of environmental, social, and economic objectives, federal and state climate and energy policies have driven the prioritization of electricity decarbonization in grid planning. Decarbonizing electricity is essential to mitigating climate change because electricity produces a substantial share of economy-wide emissions—31% of U.S. carbon emissions and 24% of U.S. GHG emissions in 2020—and because electrification is a key decarbonization strategy for other emissions intensive sectors, such as transportation [7, 8].

At the federal level, the Biden administration has announced a goal of transitioning to a “carbon pollution-free” electricity sector by 2035, as well as reducing economy-wide GHG emissions by 50–52% by 2030 (relative to 2005 levels) and reaching net-zero economy-wide emissions by 2050 [9, 10]. This electricity decarbonization goal builds on the ambition of the Obama administration’s Clean Power Plan—which sought to cut electricity emissions by 32% by 2030 relative to 2005 levels, but was rescinded prior to implementation [11, 7, 7]—is supported by the passage of the Inflation Reduction Act and Infrastructure Investment and Jobs Act, which include hundreds of billions of dollars of investments in and tax incentives for renewable energy resources, carbon capture and sequestration technologies, and energy efficiency developments. The materiality of physical and transition risks has also led regulators consider frameworks for measuring, disclosing, and regulating climate-related financial risks, which may further drive focus on electricity decarbonization [12]. For example, the Securities and Exchange Commission has issued a proposal rule on climate risk disclosure, which provides a framework for issuers and investors to assess and disclose climate risks, and has the potential to substantially expand the quantity and type of emissions data currently available [13].

At the state and local levels, myriad jurisdictions have developed policies that have or will accelerate electricity decarbonization. As of 2021, some 30 states, the District of Columbia, and two U.S. territories have active renewable portfolio or clean energy standards [4, 5, 14, 15]. Renewable portfolios standards can vary considerably across states, including via targets and timeframes, covered entities, eligible technologies and resources, use of carveouts or multipliers, and existence of cost caps [14]. As depicted in Figure 2, many jurisdictions have had renewable portfolio standards in place for a decade or more. In recent years, several have increased or expanded these requirements, including several jurisdictions moving to 100% renewable portfolio standards, as discussed below [5, 14].

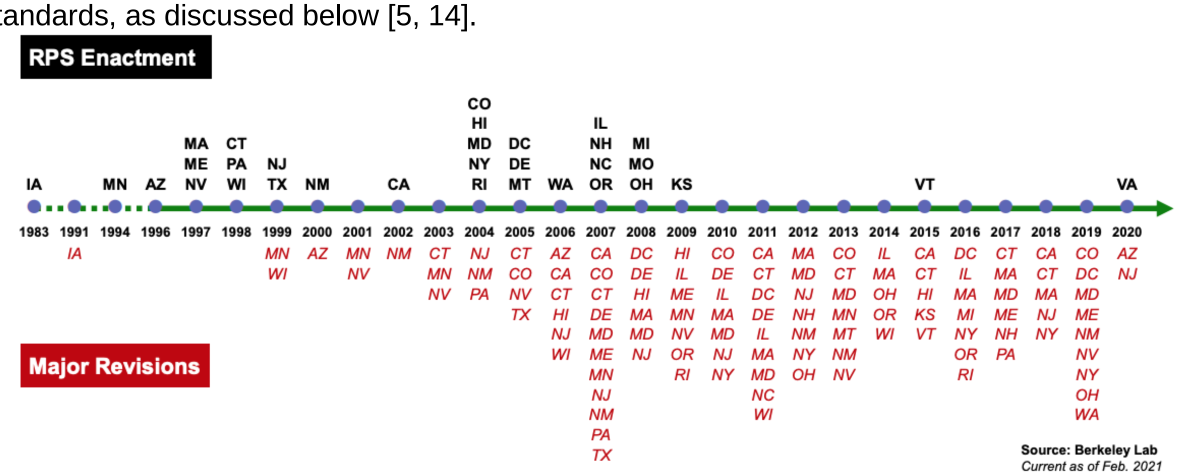

Figure 2: Major Revisions to U.S. Renewable Portfolio Standards, 1934-2020 (Source: [14])

With respect to clean energy standards, a growing number of jurisdictions have adopted economy-wide and electricity sector-specific decarbonization policies with emissions-based goals, which are often coupled with renewable portfolio standards. Depicted in Table 2, as of June 2023, 18 states and territories have adopted power sector or economy-wide zero or net-zero GHG (or carbon) emissions goals, and five have adopted 100% renewables generation goals via legislation, executive order, or board decision [16]. The scope, stringency, and enforceability of these requirements vary, creating a heterogenous landscape of grid planning requirements for decarbonization.

Table 2: U.S. States and Territories with Decarbonization Policies or 100% Renewable Energy (Source: [16], adapted and updated by authors)

Jurisdiction and Policy	Economywide Decarbonization	Electric Power Decarbonization	100% Renewable Energy
California (SB 100, EO B-55-18)	2045	2045	
Colorado (SB 19-236)		2050	
Connecticut (SB No. 10)		2040	
District of Columbia (DC Act 22-583)			2032
Hawaii (HB 623)			2045
Illinois (SB 2408)		2050	
Louisiana (EO 2020-18)	2050		
Maine (LD 1494, LD 1679)			2050
Maryland (SB 528)	2045		
Massachusetts (Bill S.9)	2050		
Michigan (EO 2020-10)	2050		
Nebraska (NPP Board Decision)		2050	
Nevada (SB 358)		2050	
New Jersey (EO 28)		2050	
New Mexico (SB 489)		2050	
New York (S 6599)	2050	2040	
North Carolina (HB 951, EO 246)	2050	2050	
Oregon (HB 2021)		2040	
Puerto Rico (SB 1121)			2050
Rhode Island (EO 20-01, H7277 SUB A)			2033
Virginia (SB 851)		2050	
Washington (SB 5116, SB 5126)	2050	2045	
Wisconsin (EO 38)		2050	

2.2 Development of Grid Planning Regulation and Guidance for Decarbonization

These clean energy and renewable portfolio standards generally establish clear utility requirements and delegation of regulatory authority, and the associated decarbonization objectives are relatively well integrated into utility planning rules and guidance. Several decarbonization statutes and executive orders also direct state agencies and regulators to produce clean energy plans to describe roadmaps for complying with decarbonization targets, and regulators will need to determine how these plans interact with other planning processes (e.g., integrated resource planning, transportation electrification planning). For example, pursuant to 2021 Oregon legislation establishing a goal of reducing electricity emissions by 100% below baseline emissions by 2040, Oregon utilities are required to submit Clean Energy Plans to the Oregon Public Utility Commission and Department of Environmental Quality that are based on (or included in) their integrated resource plans and demonstrate progress toward decarbonization goals [17]. Similarly, pursuant to 2018 California legislation establishing a goal of 100 percent carbon-free electricity by 2045, the California Energy Commission, California Public Utilities Commission, and California Air Resources Board released a grid decarbonization roadmap that leverages integrated resource planning modeling and assumptions [18]. In order to meet the decarbonization requirements that unfold over years, and in some cases decades, utilities and their stakeholders must strengthen implementation roadmaps to stay on schedule and reduce costs and risks to consumers.

2.3 Utility Integration of Decarbonization into Grid Planning

To understand the level to which decarbonization is already embedded in grid planning processes, a robustness assessment was conducted. The assessment uses a rubric scoring methodology, and considers a number of factors: a) the existing literature on the objective, associated metrics, and its role in grid planning; b) federal, state, and local policies and regulations that require or incentivize utilities to consider the objective in their planning processes; c) other market and technology drivers that have pushed planners to incorporate the objective to varying degrees; d) the (relative) assessment of traditional objectives; and e) insights from subject matter experts with experience in grid planning processes. The latter is particularly important to capture situational knowledge about the current practices and the extent to which policy prioritization of emerging objectives has led to institutionalized practices, whereby regulatory guidance or other standards provide for systematic consideration of emerging objectives in planning processes and integration into investment decisions.

Table 3 shows the level to which decarbonization has been integrated into traditional grid planning paradigms, with “none” indicating no translation of the objective and “robust” indicating well-institutionalized implementation.[1] Decarbonization is robustly integrated into the integrated resource planning process, but has only been considered in a limited capacity across transmission planning and distribution system planning processes. While practices vary, decarbonization is well integrated in grid planning processes within states that have adopted decarbonization goals or implemented comprehensive clean energy or renewable portfolio standards as well as policies focused on distributed energy resources adoption.

[1] The four scores used in the rubric—“robust,” “connected,” “limited,” and “none”—are defined as follows:

- Robust: the planning paradigm systematically integrates the objective, with institutionalized implementation guidance/practices that guide quantitative evaluation (e.g., via performance-based metrics) and directly inform investment decisions
- Connected: the planning paradigm partially integrates the objective, but in the absence of institutionalized implementation guidance/practices, evaluation is largely qualitative and only indirectly informs investment decisions
- Limited: the planning paradigm integrates ad hoc references the objective, but the objective is neither discussed in detail nor quantitatively/qualitatively evaluated and thus does not inform investment decisions
- None: the planning paradigm does not integrate the objective (and thus does not inform investment decisions), suggesting that any policy prioritization of the objective has not translated into practice.

It should be noted that the rubric evaluates how well the emerging objectives are currently integrated into grid planning paradigms, not the extent to which these planning paradigms are aligned to eventually capture these emerging objectives.

Table 3. Decarbonization Integration Robustness Assessment

Planning Paradigms	Traditional Objectives				Emerging Objectives		
	Safety	Reliability	Efficiency	Affordability	**Decarbonization**	Resilience	Equity
Integrated Resource	Connected	Robust	Robust	Robust	**Robust**	Limited	Limited
Transmission	Robust	Robust	Connected	Connected	**Limited**	Connected	None
Distribution System	Robust	Robust	Robust	Connected	**Limited**	Connected	Limited

Integrated resource plans consider a portfolio of alternative resources to meet customer demand into the future to identify the least-cost resource portfolios that comply with applicable environmental regulations and reliability requirements. As such, decarbonization is embedded in resource planning processes in jurisdictions with clean energy or renewable portfolio standards. In these jurisdictions, integrated resource plans generally explore how alternative generation and storage resources, demand-side management strategies, load forecasts, and associated sensitivities (e.g., policy developments, technology and commodity market dynamics, transmission constraints, and pace electrification, economic development, and population growth) affect total emissions, emissions intensity, or alignment with resource standards [19].

Within transmission planning efforts, utilities and system planners consider how decarbonization and electrification shape resource mixes and demand, which in turn affect transmission needs. For example, the Federal Energy Regulatory Commission (FERC) has issued a proposed rule requiring long-term scenario-based regional transmission planning that accounts for changes in resource mix and demand resulting from local, state, and federal policies, technology and commodity costs, extreme weather events, and interconnection requests/withdrawals [20]. Regional transmission organizations (RTO) and independent system operators (ISO) have explored various wholesale market mechanisms to align with state decarbonation goals (e.g., carbon pricing, forward clean energy, and integrated clean capacity markets) [21, 22], but market reforms may be needed to align RTO/ISO incentives with state-level decarbonization requirements. For example, the Illinois Commerce Commission has noted as a key challenge in assessing statewide electricity system emissions and achievement of decarbonization goals is the lack of granular and consistent carbon accounting practices among RTOs and ISOs, which inhibits assessment of upstream (i.e., Scope 2) emissions. [22].

At the distribution level, states such as Colorado, California, New York, and Michigan are working toward implementing distribution system planning rules to govern the continued proliferation of distributed energy resources, including to achieve decarbonization mandates. For example, Colorado has taken a comprehensive approach to increasing transparency around utility distribution system investments and facilitating new opportunities for deployment of distributed energy resources [23]. Similarly, Portland General Electric's 2021 distribution system plan notes that while it will primally address Oregon's electricity decarbonization goals via its integrated resource planning process, it envisages that the improved management of distributed energy resources will have an increasingly prevalent role in reaching the emissions reduction targets [24].

3.0 Challenges and Opportunities

In view of this baseline condition, there are several technical challenges to incorporating decarbonization as a goal for future grid investments. These challenges are outlined below.

3.1 Integrating Multi-State Decarbonization Requirements for Regional Planning

Studying decarbonization is a maturing practice in traditional planning processes, primarily because of state-level clean energy and renewable portfolio standards. However, the scope, stringency, and enforceability of these requirements vary, creating a heterogenous landscape of grid planning requirements for decarbonization. The variety of pathways for decarbonization can pose barriers to inclusive planning for decarbonization beyond a single state’s border much less at a national level. As evolving planning paradigms necessitate more regionally integrated planning, challenges may emerge with adjudicating among disparate state-level decarbonization requirements and measurement approaches. Institutionalizing processes for setting regionally coherent decarbonization objectives and metrics is thus a key challenge.

3.2 Decarbonization Interactions with Other Sustainability Goals and Grid Panning Objectives

Measuring progress on decarbonization objectives can be complicated by interactions with other sustainability policies with shared underlying objectives but different mechanisms, such as air pollutant standards or transportation tax incentives. Moreover, decarbonization strategies—which are generally long term and thus sensitive to a range of technology, infrastructure, market, and policy uncertainties—will need to be evaluated with traditional and emerging grid planning objectives across both short-term and long-term planning horizons. Electricity decarbonization creates resilience, flexibility, equity, and affordability complexities for planning paradigms to consider. These policy goals are not mutually exclusive and should not be in conflict; however, the interactions between policies should be understood and accounted for, and priorities should be explicit.

3.3 Rigorous and Holistic Measurement of Decarbonization Progress

Decarbonization policies for the electric grid are widely motivated by the social and economic effects of climate change. However, metrics of progress on decarbonization focus on the causes of climate change (i.e., GHG emissions), rather than the consequences for the environment or people. Moreover, with multiple utility planning processes, decarbonization requirements, and measurement approaches emerging, rigorously and holistically assessing decarbonization throughout a utility’s value chain (from generation to end-use) and progress toward underlying policy goals, will become increasingly important and complex.

4.0 Conclusion

A decarbonized grid generates electricity from renewable and non-emitting resources and supports economywide decarbonization by increasing energy efficiency across current and future end-use applications, thereby reducing GHG emissions and adverse environmental, economic, and social consequences of unmitigated climate change. While policy and regulatory requirements for decarbonization are more mature than other emerging objectives, they have largely been implemented at the state and local level, resulting in heterogeneity in grid planning practices across jurisdictions. A key challenge going forward will be the assessment of how decarbonization strategies affect other traditional and emerging objectives across various planning paradigms and timelines, especially as grid policymakers, planners, and operators seek more regional solutions. While metrics and measurement strategies for decarbonization are better established than those for other emerging objectives, there may be substantial variation in the scope and connection between these metrics and underling policy goals.

Decarbonization is somewhat integrated into grid planning paradigms, but there are opportunities for incremental and idealized expansion of grid planning to better incorporate decarbonization. The integration of emerging objectives—i.e., decarbonization, resilience, and equity— into grid planning necessitates the development of frameworks and methodologies to evaluate grid performance and prioritize and balance investments across traditional and emerging objectives.

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