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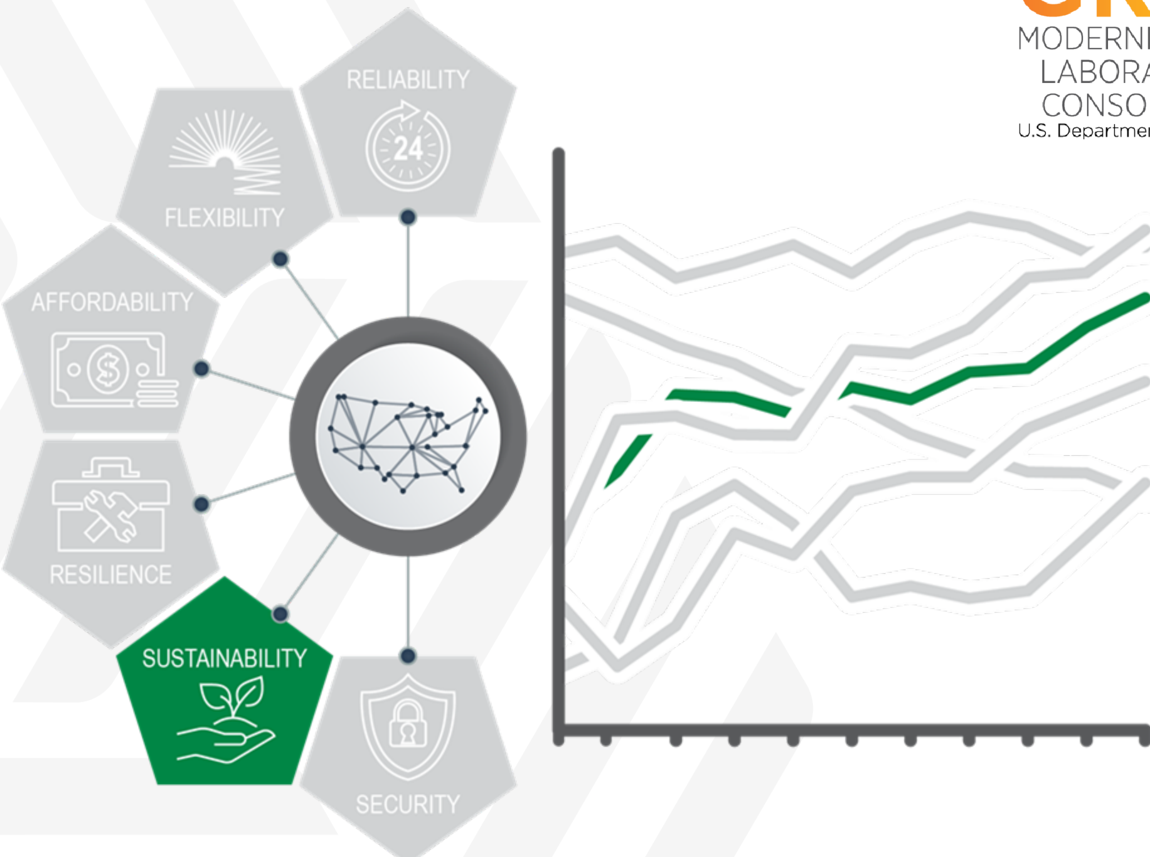

Grid Modernization: Metrics Analysis (GMLC1.1) – Sustainability

Reference Document
Volume 5

April 2020

Grid Modernization Laboratory Consortium

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Primary Authors:
1) Garvin Heath[1]
2) Jordan Macknick[1]
3) Annika Eberle[1]

Grid Modernization Laboratory Consortium Members:
Monisha Shah[1]
Rob Bickhart[1]
Ariel Miara[1]
Gian Porro[1]
Maninder Thind[1]

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Pacific Northwest National Laboratory
Richland, Washington 99352

[1] National Renewable Energy Laboratory

Summary

Lab Team: Garvin Heath, Annika Eberle, Jordan Macknick, Maninder Thind, Rob Bickhart, and Ariel Miara, National Renewable Energy Laboratory (NREL)

Sustainability
The ability to provide electric services to customers while minimizing negative impacts on humans and the natural environment.
Note that Sustainability is sometimes defined as including three pillars: 1) environmental, 2) social, and 3) economic. The GMLC metrics teamed focused only on the environmental pillar.

The Grid Modernization Laboratory Consortium (GMLC) Metric Team: 1) Reviewed and compared the major sources of information on greenhouse gas emissions (GHG) from US electricity production, identified a common data gap that is anticipated to grow through grid modernization activities (specifically, a lack of consistent and complete information on emissions from smaller generation sources), and then worked with the U.S. Energy Information Administration (EIA) to close this gap; and 2) Assessed current metrics on US power plant driven water stressors and began developing a new metric to address a gap in current metrics, which involves relating water demand to water availability.

S.1. Motivation

S.1.1 Metrics on Greenhouse Gas Emissions Associated with Electricity Generation

Some sources of electricity produce GHG emissions and some do not. Grid modernization, among other things, is expected to influence the types of sources used to generate electricity. Understanding how grid modernization could, or has, affected GHG emissions depends on having good data about the types and quantities of electricity generation sources and how those sources may change over time.

The U.S. Environmental Protection Agency (EPA) and the EIA are the two primary federal agencies that report GHG emissions from the electric power sector. Between them, they produce at least eight data products, which report estimates on aspects of GHG emissions from this sector. Since these products were initially created for distinct purposes, it was not known (prior to this GMLC project) whether they fully captured GHG emissions from the sources of electricity that might be affected by grid modernization activities. In short, prior to this project, there was no information on whether a data gap existed, how big it might be, or, most importantly, if there was a gap, what would be the best way to address it.

S.1.2 Metrics on Water Stress Associated with Electricity Generation

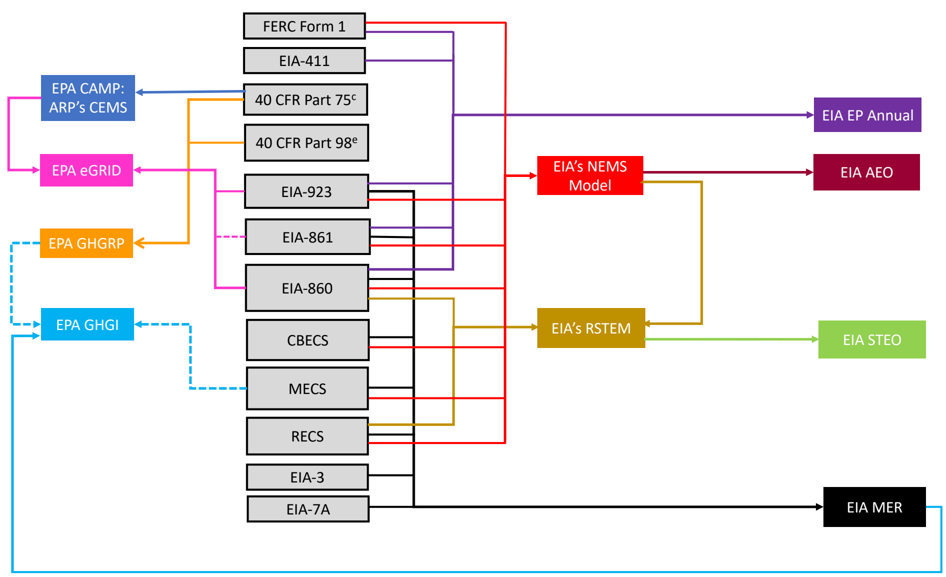
Existing metrics used in evaluating water usage in the energy sector do not provide a comprehensive or regionally-specific assessment of impacts and risks posed by grid modernization activities. In particular, existing water intensity metrics do not consider the total magnitude of the water use or the timing of energy activities. Furthermore, water scarcity definitions are inconsistent and do not factor in the actual impact of energy activities. And finally, total water use estimates fail to consider water regional availability. A recent Electric Power Research Institute (EPRI) report states specifically that “additional metrics are needed" to fully understand "location-based water scarcity," "water risk position," and "regional ecological impacts" of the energy sector (EPRI 2016a).

S.2. Outcomes/Impact

S.2.1 Metrics on Greenhouse Gas Emissions Associated with Electricity Generation

The GMLC team performed a detailed review of the eight data products that are produced by EIA and EPA on aspects of GHG emissions from the electric power sector. They found that none of these data products are able to fully capture the electric-sector portion of GHG emissions from several energy sources that are projected to grow in the future: biopower, energy storage, combined heat and power, and small-scale (< 1 MW), fossil-fueled distributed generation. Although these data gaps do not impact the data products' ability to accurately track electric-sector GHG emissions today, depending on how much these generation sources grow, the data products' ability to accurately track future GHG emissions could decrease.

The team next identified the EIA survey forms that underlie the eight federal GHG data products (Figure S.1) and completed a detailed review of six survey forms with the greatest number of connections to data on these small, but growing generation sources: EIA-860, EIA-861, EIA-923, Commercial Buildings Energy & Consumption Survey (CBECS), Manufacturing Energy Consumption Survey (MECS), and Residential Energy Consumption Survey (RECS). The team focused on MECS, CBECS, and EIA-861 because internal combustion engines (ICEs) form the largest proportion of non-net-metered distributed generations (DGs), and the majority of the ICEs are found in the industrial and commercial sectors.



Abbreviations: Environmental Protection Agency (EPA); Energy Information Administration (EIA); Federal Energy Regulatory Commission (FERC); Code of Federal Regulations (CFR); Commercial Buildings Energy & Consumption Survey (CBECS), Manufacturing Energy Consumption Survey (MECS) and Residential Energy Consumption Survey (RECS); Clean Air Markets Program (CAMP); Emissions & Generation Resource Integrated Database (eGRID); Greenhouse Gas Reporting Program (GHGRP); Greenhouse Gas Inventory (GHGI); Regional Short-Term Energy Model (RSTEM); National Energy Modeling System (NEMS); Electric Power Annual (EP Annual); Annual Energy Outlook (AEO); Short-Term Energy Outlook (STEO); and Monthly Energy Review (MER).

Figure S.1. Mapping Underlying Data Sources (grey boxes) to the Eight Federal GHG Emission Data Products (boxes on the far left and right).

The team found that because the MECS, CBECS, RECS, and EIA-861 already track generation for generators of all sizes, only the survey questions for these surveys, not the survey scope, needed modification to determine the portion of fuel consumption or generation that occurs at facilities below 1 MW. For example, although MECS already collects data about onsite electricity generation for combined heat and power (CHP), solar, wind, hydro, and geothermal power, it does not differentiate these data by nameplate capacity, which would be necessary to monitor the growth of small-scale DG sources (those < 1 MW vs. those > 1 MW). The survey also does not track detailed generation data for other types of onsite electricity generation sources, such as fuel cells, microturbines, or generator sets, and instead aggregates these data in an "Other" category.

The team reviewed its findings with EIA survey managers and provided information about the types of changes the surveys could make if they wanted to address the identified limitations. After reviewing the team's findings, the EIA survey teams for CBECS, MECS, and EIA-861 expressed interest in making changes to their surveys, and the team worked with the survey managers to develop changes to their survey questions. As part of each survey's 3-year information collection extension request, these changes were submitted for review by the Office of Management and Budget. If approved, these changes will allow the surveys to monitor how many establishments use non-renewable DG and, thus, anticipate and assess when more detailed data collection might be warranted.

S.2.2 Metrics on Water Stress Associated with Electricity Generation

The GMLC team conducted a literature review and identified 154 water evaluation metrics. The team used the review to describe the multitude of approaches used to evaluate water availability, water stress, and water scarcity[1] and evaluate the strengths, weaknesses, and gaps of each approach.

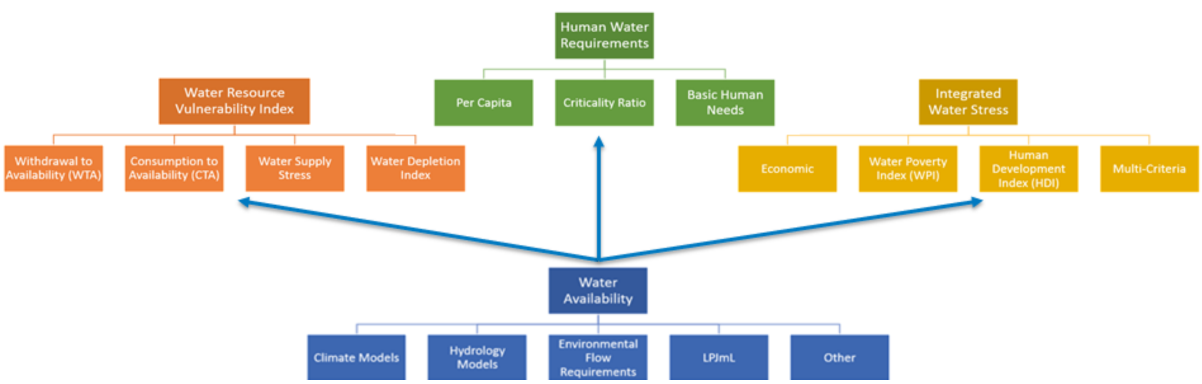


Figure S.2. Landscape of existing water stress and scarcity metrics

Through this process, the team identified a need for new metrics that would improve upon three separate existing metrics (for which data are often available), namely: water intensity (in terms of water use per

[1] Water Availability is defined as specific relation to water accessibility, obtainability, and overall source abundance available for use or consumption. Such sources include surface runoff, baseflow, and aquifer storage. Water Stress is defined as specific relation to water strain caused by over withdrawal or unsustainable use practices caused by anthropogenic sources, such as over population, agriculture, industrial intensities, or energy generation. Water Scarcity pertains to specific relation to water shortages caused by general lack of water supply from natural causes, such as low precipitation, climate, or seasonal fluctuations.

unit of energy activity), water scarcity and availability (which can have many different definitions), and total water use.

The team posited that a new metric is needed to quantify the use (both withdrawal and consumption) of water in the context of local and regional water availability across time. Such a metric is needed because the existing three metrics do not adequately capture the impacts of existing or proposed energy activities in the full context of available water resources, leading to potentially misleading and inconsistent comparisons across regions and technology types.

The team's effort built upon recent, ongoing Department of Energy (DOE) and EPRI research to develop this new metric, tentatively titled relative water risk (RWR).[2] The RWR is intended for use in assessing existing and proposed infrastructure and technological investments in the energy sector.

[2] See for example: Quadrennial Energy Review 1.2: Environment Baseline Vol. 4: Energy-Water Nexus. DOE-EPSA, 2017; Metrics to Benchmark Sustainability Performance for the Electric Power Industry. EPRI Technical Report: 3002007228. EPRI, 2016; Macknick, J.; Zhou, E.; O'Connell, M.; Brinkman, G.; Miara, A.; Ibanez, E.; Hummon, M. (2016). Water and Climate Impacts on Power System Operations: The Importance of Cooling Systems and Demand Response Measures. NREL/TP-6A20-66714; McCall, J.; Macknick, J.; Hillman, D. (2016). Water-Related Power Plant Curtailments: An Overview of Incidents and Contributing Factors. NREL/TP-6A20-67084; VC Tidwell, M Bailey, KM Zemlick, BD Moreland. 2016. Water supply as a constraint on transmission expansion planning in the Western interconnection. Environmental Research Letters 11 (12), 124001.

Acknowledgments

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Acronyms and Abbreviations

CAMP	Clean Air Markets Program
CBECS	Commercial Buildings Energy Consumption Survey
CDP	formerly known as "Carbon Disclosure Project" (now simply CDP)
CEMS	continuous emission monitoring system
CFR	Code of Federal Regulations
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CTA	consumption to availability
DG	distributed generation
DOE	U.S. Department of Energy
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EP	Electric Power
EPRI	Electric Power Research Institute
EPSA	DOE Office of Energy Policy and Systems Analysis
ERCOT	Electric Reliability Council of Texas
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory
GHGRP	Greenhouse Gas Reporting Program
GMLC	Grid Modernization Laboratory Consortium
GMLC1.1	Grid Modernization Laboratory Consortium Project Metrics Analysis
IPCC	Intergovernmental Panel on Climate Change
MECS	Manufacturing Energy Consumption Survey
MER	Monthly Energy Review
N_2O	nitrous oxide
NERC	North American Electric Reliability Corporation
NO_x	nitrogen oxide
PG&E	Pacific Gas and Electric Company
PUC	Public Utilities Commissions
RECS	Residential Energy Consumption Survey
RPS	renewable portfolio standard
RWR	relative water risk
SASB	Sustainability Accounting and Standards Board

SO_2	sulfur dioxide
USGS	U.S. Geological Survey
WECC	Western Electricity Coordinating Council
WSI	water stress index
WTA	withdrawal to availability

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1.0 Introduction

1.1 Project Background and Motivation

The U.S. Department of Energy's (DOE's) 2015 Grid Modernization Initiative Multi-Year Program Plan states that as the U.S. electric grid transitions to a modernized electric infrastructure, policy makers, regulators, grid planners, and operators must seek balance among six overarching attributes (DOE 2015a): (1) reliability, (2) resilience, (3) flexibility, (4) sustainability, (5) affordability, and (6) security. Some attributes have matured and are already clearly defined with a set of metrics (e.g., reliability), while others are emerging and less sharply defined (e.g., resilience). To provide more clarity to the definition and use of the attributes, DOE is funding an effort that will evaluate the current set of metrics, develop new metrics where appropriate, or enhance existing metrics to provide a richer set of descriptors of how the US electric infrastructure evolves over time.

DOE engaged nine national laboratories to develop and test a set of enhanced and new metrics and associated methodologies through the Grid Modernization Laboratory Consortium's (GMLC's) Metrics Analysis project, generally referred to by its acronym GMLC1.1.

The project supports the mission of three DOE Offices—Office of Electricity Delivery and Energy Reliability—Office of Energy Efficiency and Renewable Energy, and Office of Energy Policy and Systems Analysis (EPSA) by revealing and quantifying the current state and the evolution over time of the nation's electric infrastructure.

This project started in April 2016 and ended in March 2019.

1.2 Metric Categories Definitions

The Multi-Year Program Plan uses the term attribute to describe the characteristics of the power grid. In this report, we use the term metric areas or metric categories. Metrics are physical or economic considerations that can be measured or counted. Several metrics can be grouped into a metric category.

The six metric categories explored in this project are described in Table 1.1. The purpose of this table is to list commonly used definitions and indicate which aspects of the large breadth within a metric category this project addresses.

Table 1.1. Metrics Descriptions and Focus Areas

Metric Categories	Definitions	Focus Areas under GMLC 1.1
Reliability	Maintain delivery of electric services to customers in the face of routine uncertainty in operating conditions. For utility distribution systems, measuring reliability focuses on interruption of the delivery of electricity in sufficient quantities and of sufficient quality to meet electricity users' needs for (or applications of) electricity. For the bulk power system, measuring reliability focuses separately on both the	We are developing new metrics of distribution reliability, which account for the economic cost of power interruptions to customers, with American Public Power Association. We are developing new metrics of the bulk power system reliability for use in North American Electric Reliability Corporation's Annual State of Reliability Report

Metric Categories	Definitions	Focus Areas under GMLC 1.1
	operational (current or near-term conditions) and planning (longer term) time horizons.	We are demonstrating the use of probabilistic transmission planning metrics with Electric Reliability Council of Texas (ERCOT) and Idaho Power.
Resiliency	Can prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions, including the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents (Obama 2013).	We apply a consequence-based approach that defines a process using resilience goals to a set of defined hazards. This approach provides the information needed to prioritize investments for resilience improvements.
Flexibility	Respond to future uncertainties that may stress the system in the short term and require the system to adapt over the long term. Short-term flexibility to address operational and economic uncertainties that are likely to stress the system or affect costs. Long-term flexibility to adapt to economic variabilities and technological uncertainties that may alter the system.	We focus on flexibility of the bulk power system needed to accommodate variability of net load, which is the load minus variable generation including high penetrations of variable resource renewables.
Sustainability	Provide electric services to customers, minimizing negative impacts on humans and the natural environment.	We focus on environmental sustainability and in Years 1 and 2 specifically assess metrics for greenhouse gas emissions from electricity generation. In Years 2 and 3, we also explore water metrics.
Affordability	Provide electric services at a cost that does not exceed customer willingness and ability to pay for those services. (Taft and Becker-Dippman 2014).	We document established investment cost-effectiveness metrics and focus our research on emerging customer cost-burden metrics.
Security	Prevent external threats and malicious attacks from occurring and affecting system operation. Maintain and operate the system with limited reliance on supplies (primarily raw materials) from potentially unstable or hostile countries. Reduce the risk to critical infrastructure by physical means or defense cyber measures to intrusions, attacks, or the effects of natural or man-made disasters (Obama 2013).	We develop metrics to help utilities evaluate their physical security posture and inform decision-making and investment.

This volume provides details about the activities and outcomes in the sustainability category.

2.0 Objective

Sustainability is often defined as including three pillars: environmental, social, and economic. Given the other categories of metrics defined for the GMLC1.1 project (e.g., affordability), we focus on environmental sustainability.

For the purposes of this work, environmental sustainability is defined as the "provision of electric services to customers minimizing negative impacts on the natural environment and human health." Within environmental sustainability, there is a continuum of metrics from environmental stressors (e.g., greenhouse gas [GHG] emissions) to effects on the environment (e.g., global surface temperature increase) to impacts on humans and the environment (e.g., increased incidence of mosquito-borne diseases). The challenge increases for determining the causality of impacts as one moves from stressors to impacts because multiple causes could be responsible for any given impact (e.g., the health of US citizens). In the GMLC1.1 project, we will consider environmental stressors.

Metrics are categorized by their ability to characterize: the electricity system's properties historically (lagging metrics) or the system's ability to respond to challenges in the future (leading metrics). Lagging metrics are backwards looking or retrospective, where the impact of a collection of activities on a specific system can be assessed after their actual implementation. As such, they can be helpful aggregate indicators of progress being made in grid modernization. Leading metrics are forward looking or prospective, where the future impact of an activity can be estimated prior to its actual completion or implementation on a system. They can also be used to inform decisions on infrastructure investments or policy interventions.

Although numerous mature metrics could be used to assess the environmental sustainability of the electrical grid, they are not necessarily tailored to the electric power sector and they almost all evaluate past performance (*lagging* metrics) rather than predicting future performance (*leading* metrics). The objective of the GMLC 1.1 sustainability metric category is to critically examine a subset of these metrics, evaluate their potential for assessing changes in environmental sustainability as the grid evolves, identify the need for new metrics, and develop recommendations for improving current metrics.

3.0 Approach

As an example of the breadth of environmental sustainability metrics (described further below), the Electric Power Research Institute (EPRI) identified 249 individual metrics of environmental sustainability that electric utilities have been asked to report through voluntary (corporate) reporting programs (EPRI 2014b). Many of these metrics were established decades ago to comply with federal laws like the Clean Air Act (42 U.S.C. § 7401 et seq. [1970]), Clean Water Act (33 U.S.C. § 1251 et seq. [1972]), and Resource Conservation and Recovery Act (42 U.S.C. § 6901 et seq. [1976]), and their implementing regulations. These metrics generally measure environmental stressors like air pollutant emissions (GHG and non-GHG pollutants like nitrogen and sulfur oxides, particulate matter, etc.), pollutant discharges to water, land-use changes, and depletion of natural resources, which can then be used (generally via modeling) to assess the impact on the environment and human health (e.g., potential changes in the global surface temperature).

Because the established environmental sustainability metrics are so numerous and diverse, the first year of the GMLC1.1 project focused on an environmental sustainability issue chosen for its maturity of definition, multiple available data products, and availability of baseline data: GHG emissions. In Year 1, we assessed the current landscape of established GHG emission metrics and evaluated the potential for current methods to track GHG emissions from electricity generation as the grid evolves. In Year 2, we developed recommendations for improving GHG accounting methods and worked with stakeholders to identify opportunities for implementing changes. We also began assessing a new environmental sustainability issue: water usage by the electric power industry. In Year 3, we continued to consult with stakeholders to implement changes to current methods for GHG accounting and developed a novel metric for assessing water use in relation to its spatiotemporal availability.

Overall, the sustainability category followed the overarching timeline for the GMLC1.1 project as outlined in Figure 3.1. Year 1 of the project focused on evaluating the current landscape of environmental sustainability metrics and Years 2 and 3 focused on validating metric methodologies by applying them to real-world situations with electric sector partners and establishing partnerships with key data providers, including federal and state agencies, and regional entities that could potentially help institutionalize the final products and results of GMLC1.1.

Specific approaches to formalizing metrics varied across the six metrics category teams, depending on the maturity of metrics development and use in the area, the existence of publicly collected and disseminated sets of supporting data, and the presence of other organizations working in the space. The specific approaches for the sustainability category included:

- Reviewing the current state of environmental sustainability metrics for GHG emissions and water use and availability
- Collaborating with and leveraging established national data providers or industry associations to explore and develop new ways of looking at their data and to develop recommendations that could help improve data collection methods (GHG emissions)
- Working with a collection of system operators and utilities to carefully identify the existing measurement landscape and create new methodologies that could be effectively applied across jurisdictions (water).

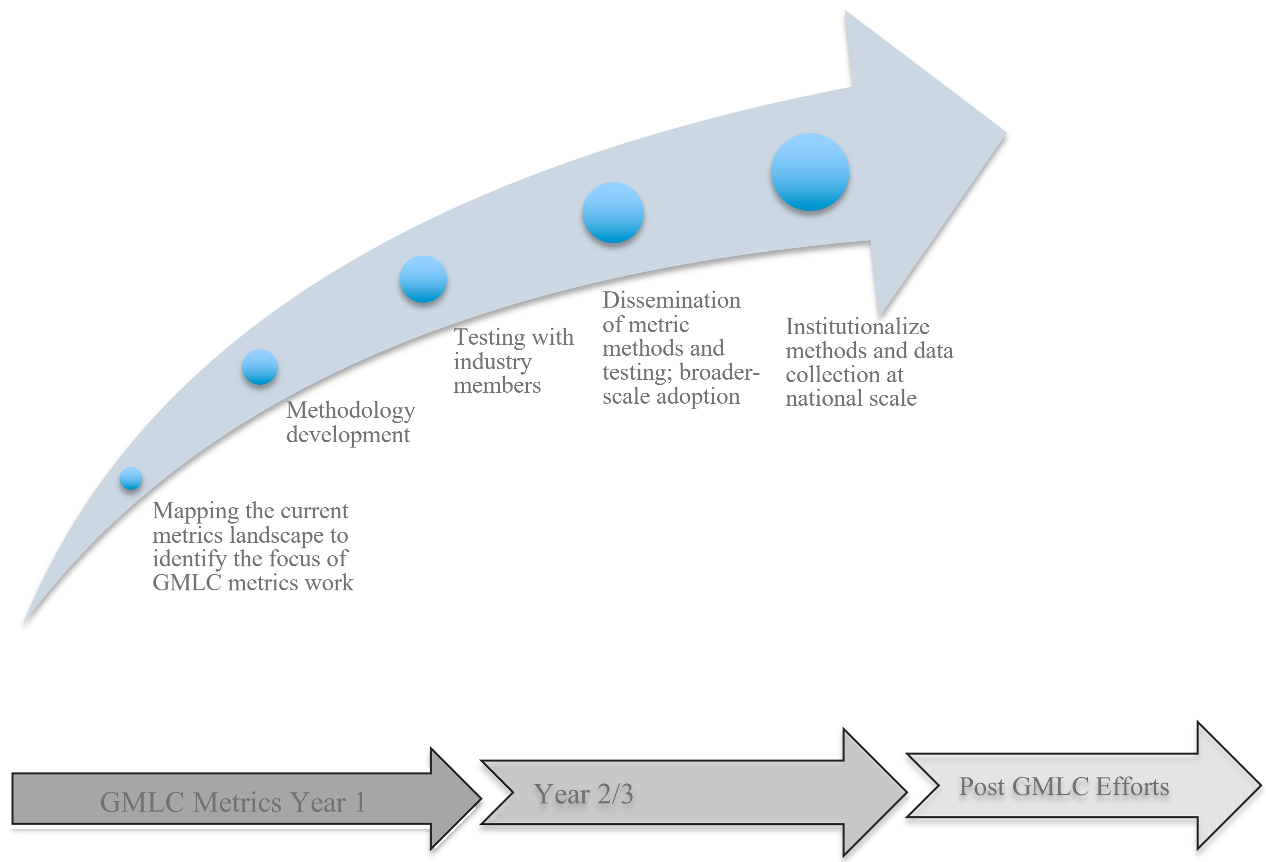

Figure 3.1. Timeline for GMLC 1.1 Activities

3.1 Stakeholders and Partners

A critical aspect of this project is to ensure the metrics being developed directly benefit the electricity sector. Throughout the process of developing and testing the metrics from this project, input and feedback are sought from stakeholders.

Key national organizations in the electric industry were identified as working partners at the inception of the project and were engaged to provide both strategic and technical input to the project as a whole. Three types of organizations were also identified for each of the six individual metric areas: (1) primary metric users, (2) subject matter experts, and (3) data or survey organizations. These stakeholders were engaged at various stages of the project, especially at the beginning and scoping stages of the effort and then to more formally review the content of a prior version of this document at the end of Year 1.

The project team engaged with, received feedback from, and in some cases, formed a partnership with the following entities:

- U.S. Environmental Protection Agency (EPA)
- Energy Information Administration (EIA)
- Arizona State University
- Minnesota Public Utilities Commission (PUC)

- National Resources Research Institute
- Sustainability Accounting Standards Board (SASB)
- ERCOT
- Western Electricity Coordinating Council (WECC)
- Xcel Energy
- Pacific Gas and Electric Company (PG&E)
- EPRI.

In Years 2 and 3, metric category teams worked with some of the stakeholders listed above, as well as additional ones, to test out the metric methodologies and demonstrate that they are technically feasible and provide value in a real-world setting. Working partners and data organizations were also engaged at various stages in the project.

3.2 Users of this Research

A key challenge in reporting grid-related metrics is that DOE is neither responsible for providing primary supporting data nor owns much of the data from which grid metrics are expected to be derived. An ideal outcome would be for the organizations that bear this responsibility to adopt metric methodologies developed and successfully tested and accepted by a broad range of electric system stakeholders via GMLC1.1.

The primary users of the sustainability portion of GMLC1.1 will likely include some of the project's stakeholders, such as the EPA, EIA, SASB, ERCOT, WECC, Xcel Energy, PG&E, and EPRI. Other users may include policy and decision-makers, researchers, analysts, and the public.

4.0 Outcomes

In alignment with the scope of work for environmental sustainability, the outcomes from this category are broken down into two categories: GHG emissions and water use and availability.

4.1 GHG Emissions

As outlined in Section 3, for GHG emissions we assessed the current landscape of established metrics and evaluated the potential to track GHG emissions from electricity generation as the grid evolves. We also developed recommendations for improving GHG accounting methods and worked with stakeholders to identify opportunities for implementing changes. The details of these activities are described below.

4.1.1 Existing Metrics

4.1.1.1 Existing Federal GHG Emissions Metrics

The EPA and EIA are the two primary federal agencies that report GHG emissions from the electric power sector. However, between these two agencies, at least eight data products use one or more of several primary data sources to report estimates of GHG emissions (Table 4.1). The primary purpose of these data products varies from satisfying federal regulations to providing information for forecasting future emissions. Six data products report only carbon dioxide (CO_2) emissions, while two report emissions for more than one GHG (i.e., CO_2, nitrous oxide [N_2O], and methane [CH_4]) and/or carbon dioxide equivalents (CO_2e). The lowest level of spatial resolution is at the unit level (e.g., boiler) and the lowest level of temporal resolution is hourly.

These federal data products use two main types of metrics to report GHG emissions from the electric power sector (Table 4.2): absolute GHG emissions (mass emissions) and GHG emissions intensities (e.g., mass emissions per unit of generation). The data products estimate these GHG emission metrics using one of three calculation methods.

- Multiplying fuel consumption by a fuel-specific emission factor (mass of GHG emitted per unit of fuel consumed)—covered in Section 4.1.1.2
- Directly measuring emissions via continuous emission monitoring systems (CEMSs)—covered in Section 4.1.1.3
- Combination of these two methods.

The following sections provide further detail about these two main calculation methods.

Table 4.1. Summary of Federal GHG Emission Data Products

Data Product	Primary Purpose	GHGs Included	Spatial Resolution for Electric-Sector Emissions	Temporal Resolution for Electric-Sector Emissions	Time Range	Reporting Lag
EPA GHG Inventory[a]	To develop an economy-wide GHG inventory	CO_2, N_2O, CH_4, HFCs, PFCs, SF_6, NF_3	National	Annually	1990-2014	2 years
EPA GHG Reporting Program (GHGRP)[b]	To satisfy federal regulations by tracking historical GHG emissions from industrial sectors listed in the Mandatory GHG Reporting Rule[i], e.g., power plants	CO_2, N_2O, CH_4, HFCs, PFCs, SF_6, NF_3, and other GHGs	Facility	Annually	2010-2015	1 year
EPA Emissions and Generation Resource Integrated Database (eGRID)[c]	To provide a comprehensive source of historical electricity data to the public	CO_2, N_2O, and CH_4	Unit within facility, entire facility, state, balancing authority, eGRID sub-region, NERC region, and national	Typically, every 2 to 3 years	1996-2014 (with several gaps)	18 months
EPA Clean Air Markets Program (CAMP)[d]	To satisfy federal regulations by tracking historical emissions from power plants	CO_2	Unit within facility, entire facility, state, EPA region, and national (only includes the 48 contiguous states)	Hourly, daily, monthly, quarterly, annually	1980-2016	0-4 months
EIA Electric Power (EP) Annual[e]	To provide historical energy-related information to the public	CO_2	State and national, with facility-level supplements available upon request	Annually	1994-2015	9 months
EIA Monthly Energy Review (MER)[f]	To provide historical energy-related information to the public	CO_2	State and national, with facility-level supplements available upon request	Monthly	1973-2017	1 month
EIA Annual Energy Outlook (AEO)[g]	To forecast long-term energy usage	CO_2	Census region and national	Annually	1993-2050	1 year
EIA Short-Term Energy Outlook (STEO)[h]	To forecast short-term energy usage	CO_2	National	Monthly, quarterly, annually	2009-2018	1 month

References: (a) EPA 2015b; (b) EPA 2016e; (c) EPA 2015a; (d) EPA 2016b; (e) EIA 2016b (f) EIA 2016c (g) EIA 2017a; (h) EIA 2017b; (i) EPA 2013
Abbreviations: CO_2: carbon dioxide, N_2O: nitrous oxide, CH_4: methane, HFCs: hydrofluorocarbons, PFCs: fluorocarbons, SF_6:sulfur hexafloride, NF_3: nitrogen trifloride

Table 4.2. Selected Electric Sector GHG Emission Metrics

Metric Name	Definition	Calculation Method
GHG emissions from Greenhouse Gas Reporting Program (GHGRP)	Absolute GHG emissions (metric tons of CO_2, CH_4, and N_2O) as reported to the EPA under a mandatory facility GHGRP	Primarily measured via CEMS
GHG emissions from Greenhouse Gas Inventory (GHGI)	Absolute GHG emissions (metric tons of CO_2e) as estimated by the EPA's GHGI	Relies on primary data from EIA's MER and other data sources
GHG emissions from eGRID	Absolute GHG emissions (short tons of CO_2 and CO_2e; pounds of N_2O and CH_4) as compiled by the EPA's eGRID	Collection of primary data from EIA's MER and EPA's CAMP and other data sources
GHG emissions intensity from eGRID	GHG emissions intensity (pounds of CO_2, N_2O, CH_4, and CO_2e per unit of generation [MWh or GWh] or per unit of heat input [mmBtu]) as estimated in the EPA's eGRID	Collection of primary data from EIA's MER and EPA's CAMP and other data sources
CO_2 emissions from CAMP	Absolute CO_2 emissions (short tons of CO_2) as reported by the EPA's CAMP based on mandatory reporting of CO_2 emissions (only includes units in the 48 contiguous states that serve a generator >25 MW)	Primarily measured via CEMS
CO_2 emissions from MER	Absolute CO_2 emissions (metric tons of CO_2) as compiled in the EIA's MER	Estimated via fuel consumption data from EIA-923 and EIA-compiled emission factors
CO_2 emissions from EIA's EP Annual	Absolute CO_2 emissions (metric tons of CO_2) as compiled in the EIA's EP Annual (includes emissions from combined heat and power)	Estimated via fuel consumption data from EIA-923 and EIA-compiled emission factors
CO_2 emissions from EIA's STEO	Absolute CO_2 emissions (metric tons of CO_2) as projected in the EIA's STEO	Estimated via fuel consumption projections from the National Energy Modeling System and EIA-compiled emission factors
CO_2 emissions from EIA's AEO	Absolute CO_2 emissions (metric tons of CO_2) as projected in the EIA's AEO	Estimated via fuel consumption projections from National Energy Modeling System and EIA-compiled emission factors

4.1.1.2 Calculating GHG Emissions via Fuel Consumption

Definition

According to the Intergovernmental Panel on Climate Change (IPCC 2006), the equation for calculating GHG emissions from fuel consumption is given by

$$E_{GHG,fuel} = FC_{fuel} \times EF_{GHG,fuel}$$

where $E_{GHG,fuel}$ equals the amount of GHG emissions (in kilograms [kg]) generated by a particular fuel type, FC_{fuel} is the amount of fuel combusted (in terajoules [TJ]), and $EF_{GHG,fuel}$ is the emission factor for a given *GHG* (in kg/TJ) by type of fuel, which for CO_2 includes the fuel-specific fraction of carbon that is oxidized during combustion (for CO_2, the IPCC assumes that the oxidation factor is 1 for all fuel types).

The total emissions of a specific GHG are then calculated by summing over all fuel types as follows:

$$E_{GHG} = \sum_{fuels} E_{GHG,fuel}$$

The level of detail of the above equations can be further increased to compute the emissions by combustion technology, not just fuel type. The specificity of the equations can also be decreased to use country-specific (rather than fuel-specific) emission factors.

Maturity Level

This measure has been well known and applied for decades, but improvements in scientific understanding occasionally adjust emission factors, fuel carbon content, the measurement of fuel consumption, and other factors.

Applications

A variety of stakeholders, including the EIA and EPA, estimate GHG emissions using fuel consumption data. To do so they use a combination of US-specific and IPCC default emission factors, as appropriate for the specific application.

Data Source and Availability

Sources of GHG emissions from the electric sector that rely completely or partially on fuel consumption-based methods include the EIA MER (*lagging*), the EIA AEO (*leading*), the EIA EP Annual (*lagging*), the EIA STEO (*leading*), the EPA GHG Inventory (*lagging*), and the EPA eGRID (*lagging*).

4.1.1.3 Measuring GHG Emissions via Continuous Emission Monitoring Systems

Definition

The EPA's CAMP oversees several market-based, air-quality programs, including the Acid Rain Program (EPA 2016a) and the Cross-State Air Pollution Rule (EPA 2016d). If a facility is regulated by one of these programs, it must monitor and report hourly emissions of sulfur dioxide (SO_2), CO_2, and nitrogen oxide (NO_x) as well as operation data such as heat input and electrical or steam output. These data are reported under the authority of Title 40 of the *Code of Federal Regulations* Part 75 (40 CFR Part 75) *Continuous Emission Monitoring* rule (EPA 2009) and are accessible using the CAMP (EPA 2016b). These data are also used by some states to implement the Regional Greenhouse Gas Initiative (2016).

The monitoring and reporting requirements for CEMSs vary by several factors including pollutant type, source type, and technology type (EPA 2016c). For example, if CO_2 is measured using a CO_2 analyzer on a wet basis, the emissions need to be calculated using

$$E_h = K * C_h * Q_h$$

where

E_h = the hourly CO_2 mass emissions (in tons per hour),
K = a conversion factor of 5.7×10^{-7} (tons per standard cubic foot per percent CO_2),
C_h = the hourly average CO_2 concentration (percent CO_2 on a wet basis), and
Q_h = the hourly average volumetric flow rate (in standard cubic feet per hour on a wet basis).

However, if CO_2 is measured using a gas or oil fuel flow meter, then the emissions must be computed using

$$W_{CO_2} = \frac{F_c * H * U_f * MW_{CO_2}}{2000}$$

where
W_{CO_2} = the amount of CO_2 emitted (in tons per hour),
F_c = the carbon-based fuel emission factor, which represents the ratio of the volume of CO_2 generated to the calorific value of the fuel combusted (in standard cubic feet of CO_2 per mmBtu),
H = the hourly heat input rate (in mmBtu per hour),
U_f = is the number of standard cubic feet of CO_2 per lb-mol, which is equal to 1/360 at 14.7 psi and 68°F, and
MW_{CO_2} = the molecular weight of carbon dioxide (44.0 lb/lb-mol).

Maturity Level

This measure has been well known and applied for decades.

Applications

The EPA requires most facilities with a generating capacity above 25 MW to report GHG emissions via CEMSs (EPA 2009). Other provisions also require certain facilities that emit 25,000 or more metric tons of CO_2e per year (of any generating capacity) to report data via CEMSs (EPA 2013).

Data Source and Availability

Many federal sources use CEMS data in developing their estimates of GHG emissions, including the EPA GHGRP (lagging), the EPA eGRID (lagging), and the EPA CAMP (lagging).

4.1.1.4 Voluntary GHG Emission Metrics

In addition to federal GHG emission metrics, dozens of voluntary sustainability reporting programs include GHG emission metrics. Beyond voluntary corporate social responsibility and integrated reporting, the following four long-standing voluntary reporting programs are generally accepted by the electric power industry (according to EPRI 2015b):

- The Climate Registry
- CDP (formerly the Carbon Disclosure Project)
- Dow Jones Sustainability Index
- The Global Reporting Initiative.

These reporting programs only represent a small portion of all voluntary reporting programs (EPRI 2015b).

Definition

EPRI performed a thorough review of voluntary sustainability reporting programs and identified an extensive list of existing metrics that have been used and/or applied to the electric utility industry (EPRI 2014b). They performed this analysis with respect to 15 material sustainability issues that included all three pillars of sustainability (environment, social, and economic). GHG emissions were one of the six material issues they examined within the pillar of environmental sustainability.

The goals of the EPRI study were to identify a comprehensive set of existing metrics for utility benchmarking and to understand the purpose of each metric (EPRI 2014b). By interviewing 52 individuals at 29 utilities and developing a database of metrics, EPRI was able to identify 448 different metrics for all 15 material sustainability issues. Of these, 249 mapped to environmental sustainability and 78 of these reported CO_2 or CO_2e emissions. For these GHG emission metrics, only two were leading, while 76 were lagging. The complete database of metrics identified by EPRI is not publicly available. However, with feedback from stakeholders, EPRI down-selected the metrics that are most relevant, cost-effective, and scientifically defensible for the purpose of benchmarking sustainability performance in the electric power industry (EPRI 2016a, 2017). Through this process, EPRI reduced the number of relevant environmental sustainability metrics down to 55, out of the 249 originally identified. The 12 metrics identified for GHG emissions are listed in Table 4.3 (please refer to EPRI 2016a and 2017 for detailed documentation of these metrics).

In addition to the metrics outlined by EPRI, SASB has developed a sustainability accounting standard for electric utilities and power generators (SASB 2018). This standard includes gross global Scope 1 emissions, which are also included in EPRI's list of metrics for benchmarking GHG emission performance, though the SASB calculation methodology for Scope 1 emissions differs from EPRI's and also describes six other metrics (Table 4.3). Four of the additional metrics defined by the SASB are percentages of emissions covered by 1) emissions-limiting[1]; 2) emissions-reporting[2] regulations; 3) percentages of customers served in markets subject to renewable portfolio standards (RPSs); and 4) percentage fulfillment of RPS targets by market. The fifth metric describes the absolute total GHG emissions associated with power deliveries, which is equivalent to the numerator of EPRI's emissions intensity metric for power deliveries. The sixth metric is qualitative and describes the long- and short-term strategies for managing emissions, meeting emission reduction targets, and evaluating performance against those targets.

Table 4.3. Voluntary Metrics Used to Assess GHG Emissions (EPRI 2016a and SASB 2018)

Metric Name	Definition	Calculation Method	Organization
Total CO_2 emission rate for net generation from coal	GHG emissions intensity for company, equity-owned coal net generation in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI

[1] Emissions-limiting regulations are intended to limit or reduce emissions (e.g., cap-and-trade programs, carbon tax systems, emissions control and permit-based systems).
[2] Emissions-reporting regulations require the disclosure of data, but do not impose limits, costs, targets, or controls on the amount of emissions generated.

Metric Name	Definition	Calculation Method	Organization
Total CO_2 emission rate for net generation from natural gas	GHG emissions intensity for company, equity-owned natural gas net generation in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total CO_2 emission rate for net generation from oil	GHG emissions intensity for company, equity-owned oil net generation in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total CO_2 emission rate for net generation from fossil fuel	GHG emissions intensity for company, equity-owned fossil-fueled net generation in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total CO_2 emission rate for net generation from biopower	GHG emissions intensity for company, equity-owned biomass-fueled net generation in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total CO_2 emissions rate for total net generation	GHG emissions intensity for all company, equity-owned net generation (i.e., full fleet) in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total CO_2 emissions rate for power deliveries	GHG emissions intensity for power deliveries to a utility's customers (i.e., equity-owned generation and power purchased power) in metric tons CO_2 per MWh	Unspecified[(a)]	EPRI
Total Scope 1 CO_2e emissions	Total mass of GHG emissions from all direct company operations in metric tons of CO_2e	EPRI: The Climate Registry's General Reporting Protocol[(b)] SASB: The World Resources Institute's GHG Protocol[(c)]	EPRI and SASB
Total Scope 1 CO_2e emissions intensity	GHG emissions intensity from all direct company operations in metric tons of CO_2e per MWh	Unspecified	EPRI
Total Scope 1 and 2 CO_2e emissions	Total mass of GHG emissions from all direct operations (Scope 1) plus indirect operations from the consumption of purchased electricity, heat, or steam (Scope 2)	General Reporting Protocol[(b)]	EPRI
Total Scope 1 and 2 CO_2e emissions intensity	GHG emissions intensity from all direct operations plus indirect operations from consumption of purchased electricity, heat, or steam in metric tons CO_2e per MWh	Unspecified	EPRI
Total Scope 3 CO_2e emissions	Total mass of GHG emissions associated with upstream and downstream emissions from a customer's supply chain	General Reporting Protocol[(b)]	EPRI

Metric Name	Definition	Calculation Method	Organization
GHG emissions covered by emissions-limiting regulations	Percentage of Scope 1 emissions covered under emissions-limiting regulations	SASB Electric Utilities Standard[(d)]	SASB
GHG emissions covered by emissions-reporting regulations	Percentage of Scope 1 emissions covered under emissions-reporting regulations	SASB Electric Utilities Standard[(d)]	SASB
Strategy for managing emissions and discussion of performance	Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emissions reduction targets, and an analysis of performance against those targets	Qualitative metric description: SASB Electric Utilities Standard[(d]	SASB
GHG emissions associated with power deliveries	Total GHG emissions associated with owned and purchased electric power that is delivered to retail customers	SASB Electric Utilities Standard[(d)]	
Customers in markets subject to RPSs	Number of customers served in markets subject to RPSs	SASB Electric Utilities Standard[(d)]	SASB
Fulfillment of RPS target	Percentage fulfillment of RPS target by market	SASB Electric Utilities Standard[(d)]	SASB

Notes: (a) Likely calculated using data reported to federal sources in Table 4.1; (b) The Climate Registry 2013; (c) WRI/WBCSD 2004; (d) SASB 2018.

Maturity Level

These voluntary metrics vary in maturity but are more recent than the federal GHG data products' metrics. However, in some cases, these voluntary metrics rely on the established methods used for federal GHG emission metrics.

Applications

Electric utilities may choose to report information about their GHG emissions to voluntary programs to benchmark against peers, increase stakeholder communication/engagement, and measure/improve their own performance (EPRI 2014b).

Data Source and Availability

Data sources include, among others, The Climate Registry, the CDP, the Dow Jones Sustainability Index, the Global Reporting Initiative, corporate social responsibility reports, and integrated (comprehensive sustainability and financial) reports.

4.1.1.5 Challenges with Existing Metrics

Federal Metrics

Each of the eight federal electric-sector GHG data products has its own specific purpose, scope, and methods (see Table 4.1 for a high-level summary). It is not the intent of this analysis to suggest the estimates provided by these data products are not accurate or do not meet their intended purpose. Rather, we find the communication of the results challenging to overlapping audiences of analysts, investors, intervenors, decision-makers, and the general public, for whom the subtleties of legitimate differences between the data products are important for proper interpretation and use of the GHG emission data. At least four of these data products are publicly communicated as representing "electric-sector CO_2 emissions" (EIA 2015, 2017b; EPA 2016f, 2017a), yet the difference between estimates in a given year is up to 9.4% (Eberle and Heath, paper in preparation).

The absolute differences among these data products are not an indication of uncertainty. Instead, variation in the data products' scopes (e.g., threshold for inclusion of facilities such as capacity, which fuel types are tracked [e.g., biomass]) and other factors lead to disparities in coverage, which result in different estimates of CO_2 emissions. For example, the EPA's CAMP data are the lowest because they only account for emissions from units that supply generators above 25 MW, and the EIA's EP Annual is the largest because it includes emissions from combined heat and power (CHP).

When this project began, no objective and comprehensive review of the landscape of federal GHG emission estimation products was available. Thus, it was a valuable function of GMLC1.1 to develop such a critical review (Eberle and Heath, paper in preparation).

Voluntary Metrics

There are two major challenges with voluntary reporting schemes: data availability and methodological transparency. With regard to availability, many voluntary reporting schemes are proprietary or, if publicly released, only report aggregated data (not total GHG emissions), which will make them challenging to use in the GMLC context. Furthermore, the calculation methods for these metrics are often not defined specifically enough to ensure consistency in responses from different utilities.

However, voluntary GHG emission metrics are generally calculated using data reported to federal sources and many companies use what they report in their own corporate sustainability reports and in reports to PUCs (Scott 2016[1]). As a result, mapping the relationship between federal (mandatory) and voluntary reporting will be useful to stakeholders in ensuring clarity, consistency, comparability, and accuracy.

4.1.2 Emerging and Future Metrics

Because of the abundance and diversity of established environmental sustainability metrics, one purpose of GMLC1.1 Year 1 was to catalog, characterize, critically compare, and synthesize the available federal GHG emission metrics for applicability and utility for electric grid actors in the context of a modernizing grid. This work involved evaluating the ability of established federal GHG metrics to capture changes in emissions that might result from grid modernization and to assess the need for developing new metrics or

[1] Scott, M. 2016. Personal correspondence with Morgan Scott, the manager of EPRI's Energy Sustainability Interest Group, regarding GMLC1.1 sustainability efforts and EPRI's report titled Metrics to Benchmark Sustainability for the Electric Power Industry. Phone conversation on December 1, 2016.

modifying existing metrics to better capture future emissions. The results of this work are summarized in Section 4.1.3, and details are provided by Eberle and Heath (paper in preparation).

4.1.3 Federal GHG Emission Metrics in the Context of Grid Modernization

As the grid evolves, certain generation sources that currently produce small amounts of electricity (e.g., distributed generation [DG], CHP systems and biopower) are expected to increase.[1–4] DG, a subset of what are often referred to as "distributed energy resources," is defined as the use of modular, moderately sized generation sources (e.g., < 1 MW to 20 MW wind plants, solar photovoltaic systems, fuel cells, and diesel generator sets) that are used to produce electricity, or CHP, near the site of end use.[5] The EIA's 2017 AEO (EIA 2017a) projects that electricity generation from DG in residential and commercial establishments could more than triple from 2015 to 2040 (Figure 4.1).

Although much of this growth is expected to be met from renewable DG, detailed projections from the 2017 AEO[7] indicate that generation from non-renewable, small-scale DG (e.g., microturbines, fuel cells, natural gas gensets, and diesel gensets below 1 MW) could increase by a factor of six from ~6 TWh in 2015 to ~38 TWh in 2040. This increase in non-renewable, small-scale DG is expected to be driven by a variety of factors, including increased demand for reliable and resilient power, deployment mandates (e.g., RPSs), improved technology and decreased cost of DG, low natural gas prices, and high retail electricity rates.[8–11]

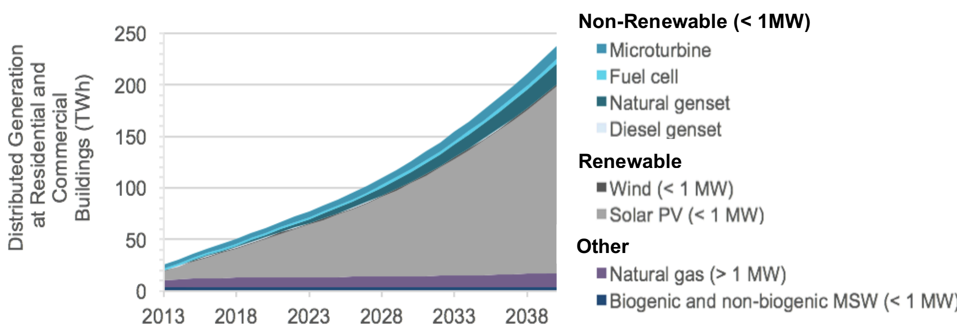

Figure 4.1. Projected Growth in DG at Residential and Commercial Buildings from 2013 to 2040 (EIA 2017a)

Although the EPA's eGRID (EPA 2015a) and GHGI (EPA 2017f), and the EIA's MER (2016c), AEO (EIA 2017a), EP Annual (EIA 2016b), and STEO (EIA 2017b) currently track DG sources above 1 MW, none of these data products provide complete data for small-scale (< 1 MW) DG. For example, the AEO includes small-scale DG at certain sites where they are deployed—commercial and residential buildings—but it omits these sources at industrial sites.

To understand how the GHG emissions from small-scale (< 1 MW) DG could be tracked, we mapped the existing federal GHG data products to their underlying data sources (Figure 4.3). We then assessed how the most prominent underlying EIA surveys collect data on small-scale renewable and non-renewable DG, as shown in Table 4.4 where green highlights availability; orange indicates data gap for all surveys. We found that none of the EIA surveys currently track detailed data for small-scale, non-renewable DG.

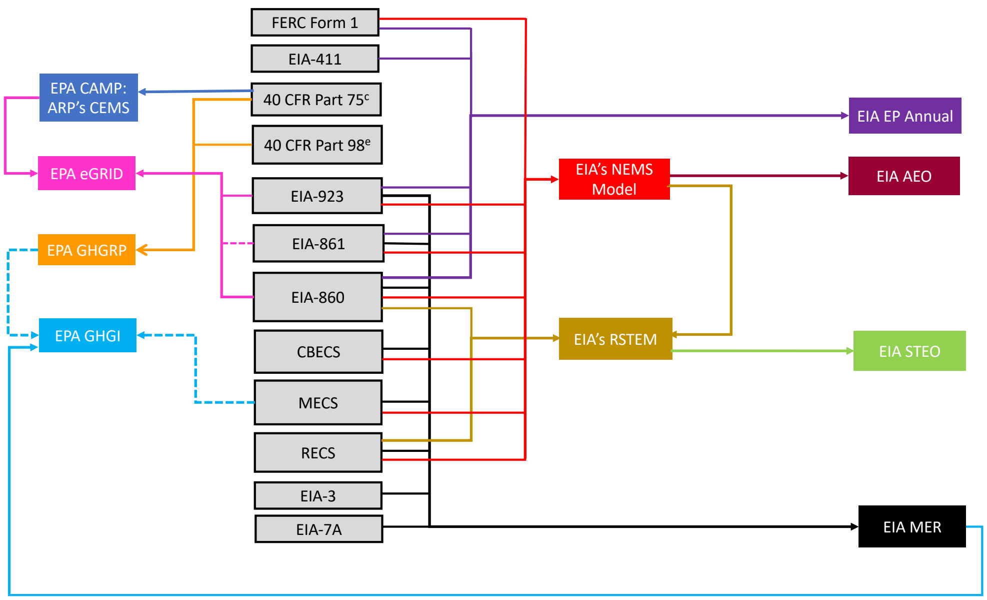

Figure 4.2. Mapping Underlying Data Sources (grey boxes) to the Eight Federal GHG Emission Data Products (boxes on the far left and right)

Table 4.4. Overview of EIA Surveys

Survey	Scope	Is fuel consumption, capacity, or generation by fuel type, capacity range and technology type available for non-renewable DGs? *For all capacity*	*By capacity range* ≥ 1 MW	*By capacity range* < 1 MW	Type of data available	Data gaps
EIA - 861	Many electric power industry entities; covers interconnected DGs	N	N	N	Capacity by capacity range and technology type for net-metered and non-net-metered DG	Capacity by technology *and* fuel type
EIA - 860	Utilities with facility ≥ 1 MW	N	Y	N	Capacity and capacity factor by capacity range, technology type, and fuel type	Data for facilities < 1 MW
EIA - 923	Utilities with facility ≥ 1 MW	N	Y	N	Generation and fuel consumption by capacity range, technology type, and fuel type	Data for facilities < 1 MW
CBECS	Sample from commercial sector	N	N	N	Fuel consumption by fuel type and technology type	Fuel consumption by capacity range
MECS	Sample from manufacturing sector	Y	N	N	Generation and fuel consumption by fuel type	Fuel consumption or generation by capacity range
RECS	Sample from residential sector	N	N	N	Capacity and technology type of the onsite electricity system	Capacity by technology *and* fuel type

In addition to examining the EIA surveys that provide data for the federal products, we searched for non-EIA sources that might provide detail on small-scale, non-renewable DG. The only data we identified in the United States that provide generation, fuel consumption, and CO_2 emissions for this sector of electricity generation is California's Self-Generation Incentive Program, which is administered to DGs that are above and below 1 MW capacity. However, these data are limited to California. We were unable to locate any publicly available data source that holistically tracks either 1) the capacity or generation by fuel and technology type or 2) the fuel consumption for all types of DG for across the entire United States. As a result, monitoring the growth of small-scale, non-renewable DG could be challenging for the EIA and other interested parties.

As DG and these other source categories grow in their contribution to total US electricity generation, these data products could misattribute and/or misallocate the CO_2 emissions, which could lead to an inaccurate accounting of the electric sector's contribution to national CO_2 emissions and subsequently hinder the prioritization of sources, potentially leading to inefficient allocation of mitigation resources. While these emission categories currently account for a small portion of electric-sector CO_2 emissions, we show that they could potentially expand to ~0.6–12 percent of US electric-sector emissions by 2040 (Eberle and Heath, paper in preparation). These results highlight the need for modifying the GHG emission data products (and their data collection surveys) to better capture and allocate electric-sector GHG emissions in the future.

4.1.4 Institutionalizing Changes to GHG Emission Metrics

In Years 2 and 3, we identified several recommendations for improving the underlying data sources for the federal GHG data products and consulted with the data owners about these recommendations. We started this work by performing a more detailed review of the six EIA survey forms that have the greatest number of connections to the data that underlie the federal GHG data products (see Figure 4.3): EIA-860, EIA-861, EIA-923, Commercial Buildings Energy & Consumption Survey (CBECS), Manufacturing Energy Consumption Survey (MECS), and Residential Energy Consumption Survey (RECS).

While several EIA surveys could be enhanced to increase data collection in this area, due to the decentralized nature of DG sources, the EIA's end-use surveys (i.e., the MECS, CBECS, and RECS) and electric power sales survey (EIA-861) appear to be the best to collect the type of data that are currently missing for small-scale, non-renewable DG sources (Table 4.4). For example, although the EIA-860 tracks capacity for facilities with a nameplate capacity above 1 MW, it does not track data for facilities below this threshold. Thus, to monitor small-scale DG, the scope of this survey would need to be modified to include facilities below 1 MW. Because the MECS, CBECS, RECS, and EIA-861 already track generators of all sizes, only the survey questions for these surveys, not the survey scope, would need to be modified to determine the portion of fuel consumption or generation that occurs at facilities below 1 MW.

Even if changes to the survey scope are not required, we recognize that it could be challenging for EIA to collect detailed data on small-scale (< 1 MW), non-renewable DG because they currently generate a small amount of electricity and are relatively large in number of units (EIA, 2017a). As a result, instead of collecting detailed data at this time, if the EIA deems that monitoring the deployment of small-scale, non-renewable DG would be valuable, then their survey teams could instead add a new question that would allow for monitoring how many establishments use non-renewable DG and then use these data to anticipate and assess when more detailed data collection might be needed. For example, the following type of question could be added to the MECS survey section entitled "Electricity – Generated On-Site."

Does this establishment have a total generator nameplate capacity (sum for generators at a single site) of less than 1 megawatt (MW, or 1,000 kW) and, if so, does it generate onsite electricity using fuel cells, internal combustion engines, or microturbines?

The reason for structuring an additional question in this manner is twofold. First, although other EIA surveys (e.g., EIA-923 and EIA-860) collect data for some small-scale DG sources, none of these surveys currently collect detailed data disaggregated to non-renewable generators with a total generator nameplate capacity below 1 MW. Thus, formulating the survey questions to only cover establishments with a total generator nameplate capacity below 1 MW, and to only query about generation from the three most prominent types of non-renewable DG would allow the best alignment across EIA surveys. Second, the yes/no structure of the question would impose a relatively small burden on survey respondents as compared to requesting detailed data about fuel consumption or generation from these sources. Although such an approach would not provide detailed data about non-renewable, small-scale DG such as capacity, generation, or fuel consumption, the potential benefit of this change is meaningful. It would allow EIA and other interested parties to track the deployment of sources that are expected to grow and for which no data are currently available and build justification, if and when warranted, for asking respondents more burdensome but also more quantitative questions.

Since internal combustion engines form the largest proportion of non-net-metered DGs and the majority of the engines are found in the industrial and commercial sectors (Figure 4.3), we focused our work on MECS, CBECS, and EIA-861. We reviewed the limitations of these surveys with the survey managers and discussed the types of changes they could make if they deemed monitoring the deployment of small-scale, non-renewable DG would be valuable. For example, although MECS already collects data about onsite electricity generation for CHP, solar, wind, hydro, and geothermal power, it does not differentiate these data by nameplate capacity, which would be necessary to monitor the growth of small-scale DG sources (those < 1 MW vs. those > 1 MW). The survey also does not track detailed generation data for other types of onsite electricity generation sources, such as fuel cells, microturbines, or generator sets, and instead aggregates these data in an "Other" category.

Recognizing that this type of information could be valuable to multiple stakeholders, the survey teams for CBECS, MECS, and EIA-861 have each indicated they are planning to make changes to their surveys (similar to the one proposed for MECS above) that will allow them to monitor how many establishments use non-renewable DG and then use these data to anticipate and assess when collection of more detailed data collection might be warranted.

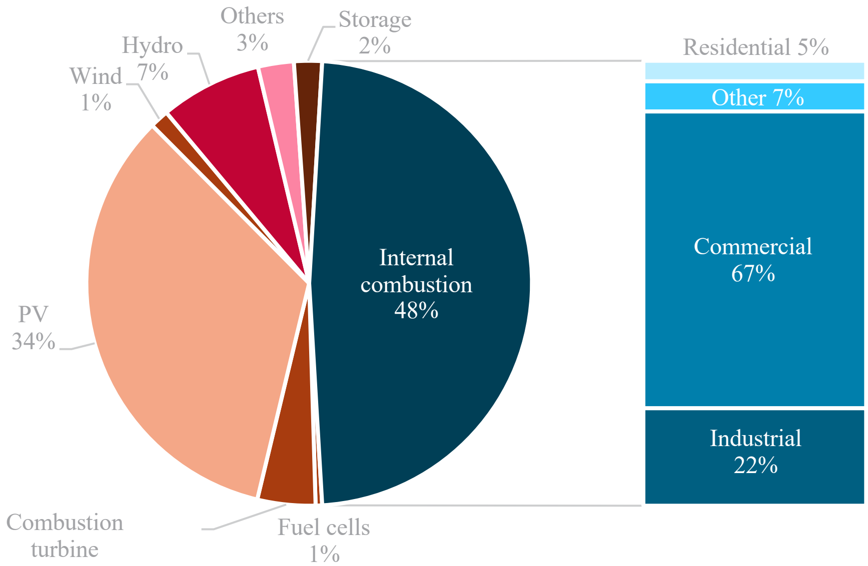

Figure 4.3. Share of Capacity by Technology Type for Non-Net-Metered Distributed Generators (left) with Breakdown of Capacity by End Use Sector for Installed Non-Net-Metered Internal Combustion Engines (right). Data source: 2016 EIA-861.

4.2 Water Use and Availability

The 2016 Quadrennial Energy Review highlighted tradeoffs in the energy-water nexus as an area worthy of future research (DOE 2015c). The report also noted that "significant regional variability in energy and water systems, their interactions, and resulting vulnerabilities" make addressing the energy-water nexus issues challenging (EPSA 2017). Existing metrics used in evaluating water usage in the energy sector are inadequate and do not provide a comprehensive assessment of impacts and risks. In particular, water intensity metrics do not consider the total magnitude of water use or the timing of energy activities, water scarcity definitions are inconsistent from application to application and do not factor in the actual impact of energy activities, and total water use estimates fail to consider water availability. Indeed, a recent EPRI report states specifically that "additional metrics are needed" to fully understand "location-based water scarcity," "water risk position," and "regional ecological impacts" of the energy sector (EPRI 2016a).

4.2.1 Existing Water Usage and Risk Metrics

Existing water usage and scarcity metrics generally derive from consideration of two separate metrics: withdrawal and consumption. According to the U.S. Geological Survey (USGS), "withdrawal" is defined as the amount of water removed from the ground or diverted from a water source for use, while "consumption" refers to the amount of water that is evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment (Kenny et al. 2009). While both water withdrawal and consumption metrics are relevant and necessary for evaluating water impacts and risks, they are not sufficient alone and often only one metric (either withdrawal or consumption) is reported. The USGS has not reported water consumption from power plants since 1995 (Kenny et al. 2009). To better understand relative water risks, more metrics beyond total water usage must be included: local estimates of water availability and water usage rates. When these multiple metrics are combined, they provide estimates of risk and scarcity in terms of units of water usage per units of water available, and often utilize different methods and boundaries of water availability metrics, while also considering different quantitative thresholds of water risk or water scarcity. The result is a number of disjointed water risk and water scarcity metrics that often cannot be easily compared or applied to different regions.

Recognizing a lack of consistency, we employ a systematic, nearly exhaustive, literature screening process that identifies 154 water evaluation metrics. Our comprehensive and critical review can help the community to better recognize complementarities and incompatibilities in existing metrics and highlight remaining gaps. We define the following definitions of water availability, water stress, and water scarcity as follows:

- Water availability is defined as water accessibility, obtainability, and overall source abundance available for use or consumption. Such sources include surface runoff, baseflow, and aquifer storage
- Water stress is defined as water strain caused by over withdrawal or unsustainable use practices caused by anthropogenic sources, such as over population, agriculture, industrial intensities, or energy generation
- Water scarcity is defined as water shortages caused by general lack of water supply from natural causes, such as low precipitation, climate, or seasonal fluctuations.

The goal of this effort is to review available metrics regarding water availability, water stress, and water scarcity to identify the multitude of approaches as well as the strengths, weaknesses, and gaps of each approach. Thereby, through a series of literature review screening processes and corresponding harmonization approaches, we can derive a new metric that provides additional insight and encompasses all the positive approaches of existing metrics.

4.2.1.1 Literature Review and Screening Approach

A comprehensive literature search was performed to compile a database containing 154 of the published water metric evaluation studies. Screens were applied in two phases, followed by three characterizations, using methodology consistent with the National Renewable Energy Laboratory's Lifecycle Assessment Harmonization Project[1]. The two screens sought to limit references by adhering to precise questions. The three characterizations did not seek to eliminate references, but rather obtain specific information required for the harmonization phase. Note that none of the screens require a particular publication type (e.g., journal article), instead relying on expert assessment of quality and relevance, consistent with the practice of systematic review in the biosciences. The first screen employed guiding principles as a metric to judge quality and usability based on the following yes or no questions:

1. Is the reference relevant to the topic definition of water availability, stress, or scarcity?
2. Are the reference goals, calculations, assumptions, and methods clear? Does the author clearly define the criteria and can the methods be reproduced?
3. Is the reference from a credible and reliable source such as a journal article, peer-reviewed paper, or online tool?

The initial screen also employed criteria to eliminate the following:

1. References not written in English.
2. Articles published in trade magazines fewer than three published pages in length.
3. Abstracts, conference posters, and PowerPoint presentations.

[1] https://www.nrel.gov/harmonization.html

A secondary screen stage evaluated the characterization and methodology of each reference strictly pertaining to water classification and quantitative measurements. The second screen required each reference to attempt an objective, novel approach to quantitatively measure physical water, based on the following factors:

1. Does the reference pertain to a novel approach, method, or model?
2. Is the type of water considered and specified (e.g., fresh water or brackish water)?
3. Are the referenced data based on a physical source? (Virtual water trade networks are not included).
4. Is the reference unbiased and neutral in opinion?
5. Does the reference include the liquid phase of water? (Snow-only [solid phase] studies are not included).
6. Does the reference contain an explicit numerical valuation, numerical data, or numerical metric to define possible solutions?

Following the two screens, three characterizations were undertaken that did not seek to eliminate references from the final pool, but rather identify details for use in categorization and harmonization stages. The first characterization assessed fundamental methodological approaches of the studies, covering 15 topics grouped into three bins. The first bin grouped five spatial relationships, followed by natural distributions, and finally data distinctions. The first spatial bin exhibited the following questions and corresponding answers:

1. What is the date of the published data or model? References were not restricted to any publishing date, mapping history, or future projections. These reference dates were then categorized in the following bins: <1990, 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2015, and >2015.
2. What is the geographic scope and location of the study region? This search is not restricted to US only references, but may contain global or regional information and studies generated from anywhere in the world.
3. What is the spatial resolution and how is the area extent categorized? Potential answers include, but are not limited to: political boundaries, watershed, or grid dimensions.
4. How detailed is the spatial resolution? Answers are specifically tailored to question 3, such as the grid size spacing (0.5’ x 0.5’) or watershed basin (HUC 8).
5. What is the temporal resolution? Reference timeframes were divided into hourly, daily, monthly, annual, or seasonal distributions.

The second bin grouped natural elements such as hydrogeology, ecosystem, and human intervention by asking the following questions:

1. To what extent were the hydrology or climate models represented? Was the water availability data measured, modeled, used, represented, or borrowed from another source?
2. How was the supply of available water accurately measured? Water availability must be feasible to access and within geological limits. Possible geological variable answers include runoff, groundwater, precipitation, baseflow, surface water, reservoirs, rivers, soil, evaporation, transpiration, evapotranspiration, recharge, discharge, radiation, wind, pressure, streamflow, and temperature.
3. How is the water demand calculated? Differentiation between hydrology models that include anthropogenic impacts and purely natural hydrology models.
4. Are the water rights clearly defined, such that legal and physical waters are distinguishable to account for actual water supply?

5. Are the minimum and maximum water flows considered and represented? Are the inter and intra annual minimum and maximum flows considered?
6. Are the natural system boundaries defined?

The third and final bin of the first characterization phase was grouped by data or empirical distributions and included the following questions:

1. Is the model analyzing hysteretic, current, or projecting future interpolations? Possible answers include past, present, and future.
2. How were the data collected and presented? Were they modeled, measured, referenced, or simply used?
3. What specific sources were used to calculate water supply and demand? Answers include specific available databases, models, or measurements.
4. Does the reference create or provide a publicly available tool or data source?

The second characterization gathered additional data from each reference categorized into a statistical, metric, and personal annotation bins. The first statistical bin grouped economics and viability by asking the following questions:

1. Does the reference include any economic or monetary policy such as water infrastructure, water cost, or social implications?
2. Are the data or results presented as a single or numerical range?
3. Does the study compare its results to other existing and comparable metrics?
4. Has the study performed any statistical analysis on the results and is there any error or variance within the results?

In the final characterization phase, six previous water metric review studies were carefully examined. References that passed the screening process were placed into existing categories defined by the review author. If the reference was not examined by the review author, a corresponding category was assigned based on the estimated potential location of the metric, had the author reviewed the reference. The following six water metric review articles were used for evaluation.

1. Rijsberman (2002) presented the first review and discussion of water metric evaluations and organized metrics into four categories: Falkenmark water stress indicator, water resources vulnerability index, physical and economic scarcity indicators, and the water poverty index.
2. Brown (2011) expanded the initial review to include new metrics and divided these metrics into four broad categories: indices based on human water requirements, water resources vulnerability index, indices incorporating environmental water requirements, and lifecycle assessment and water foot printing.
3. Kounia (2012) did not review or critique water metrics but did provide additional expansion into the organization of metrics through seven categories: water resource per capita, human development index, basic water needs, withdrawal-to-availability (WTA) ratio, consumption-to-availability (CTA) ratio, water poverty index, and a sensitivity index.
4. Jemmali (2012) evaluated several water metrics into three groups: indices based on human and environment water requirements, water resource vulnerability index, and a multidimensional approach.

5. Brauman (2016) uses a similar approach to Jemmali with expanding the thresholds of each indicator. These indicator thresholds were further expanded in our paper to incorporate all metrics in the harmonization phase. Brauman groups water metrics into five categories: per capita water availability, use-to-availability ratio, environmental flow withholding, inter and intra annual compound use-to-availability ratio, and integrated water stress indicators.
6. Damkjaer (2017) is the most recent review and water metric critique that redefines water scarcity in terms of freshwater storage. Damkjaer uses eight categories to group all the water metrics: water stress index (WSI), WTA ratio, social water stress index, physical and economic water scarcity, water poverty index, environment as a water use, water resources sustainability indicators, and planetary boundaries.

Each of the six reviews separated water metrics into different categories, yet all were incomplete in regard to some metrics. To address this, we created a new categorization scheme that incorporates the strengths of each review while including all of the water metrics. There are four broad categories, each of which has multiple subsets and variations. Figure 4.4 shows the new categorization scheme.

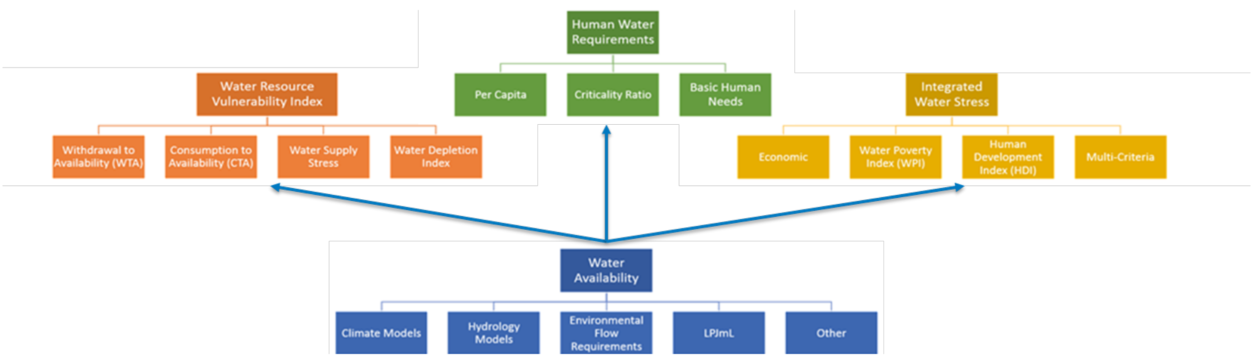

Figure 4.4. Water Metric Categorization Scheme

The human water requirements category contains estimates of water stress and scarcity that are based on regional population estimates along with water availability and assumes there are basic minimum water requirements to satisfy varying levels of human and societal development. The water resource vulnerability index category contains estimates of water stress and scarcity that are based on actual or estimated regional water demands as a percentage of available water, with varying definitions and boundaries of water usage and water availability. The integrated water stress category contains estimates of water stress that combine physical water usage and availability data with other factors such as policies, legal structures, socioeconomic conditions, and infrastructure quality to provide a more nuanced assessment. The water availability category assesses available water for human and ecosystem usage, utilizing a variety of different approaches.

4.2.1.2 Harmonization of Key Water Metrics

Water stress and scarcity metrics are all built on the simplified ratio of water use to water availability for a given area. While every metric presents a different numerator, all contain a similar denominator: water availability (even if the definitions and boundaries of water availability can be quite distinct). Even consistent across all metrics, water availability calculations are diverse. This diversity stems from regionally dependent and available data, calculation boundary conditions, and focus region. For example, the same metric can lead to differing assessments of water scarcity or stress results based on the variables and boundary conditions used to calculate total water availability, highlighting the need for standardization.

In an attempt to illustrate the initial fundamental problem, we use the categorization scheme and highlight three categories: human water requirements per capita, water resource vulnerability index WTA, and water resource vulnerability index CTA. Each category is ranked into similar stress distributions: adequate water, water problems, water stress, water scarcity, and absolute scarcity, following Falkenmark (1989).

Water Availability per Capita

Fifteen water metrics were classified as a "per capita" distribution, meaning water availability functional unit was determined by water volume, capita, and year. In each original study, each of the 15 metrics concluded slightly different distributions of stress. For example, Falkenmark (1989) created the "criticality ratio" and used the functional unit of volume per year divided by capita, whereas Engelman and Leroy (1993) reversed the numerator and denominator to create a functional unit of volume by capita per year. Four papers determined water stress by using the criticality ratio approach and 11 papers used the per capita Engelman and Leroy approach.

In the third technical harmonization step of data guidance, each of the 15 metrics was rearranged into five concrete thresholds of increasing water stress: adequate water, water problems, water stress, water scarcity, and absolute scarcity. These thresholds were determined because, out of all 15 metrics, the maximum amount of divisions of thresholds is five. Falkenmark (1989), Chaves and Alipaz (2007), and Gerten (2011) all use five thresholds to separate the levels of water stress based on a per capita water metric. The other 12 metrics use less than five thresholds to separate levels of water stress. This technique would be equivalent to determining a 100% utilization rate across similar statistical and numerical values. It is important to note that none of the original 15 metric values was changed; the metrics that used fewer than five thresholds were simply expanded into the five categories. Figure 4.5 highlights the differences across per capita estimates of water stress.

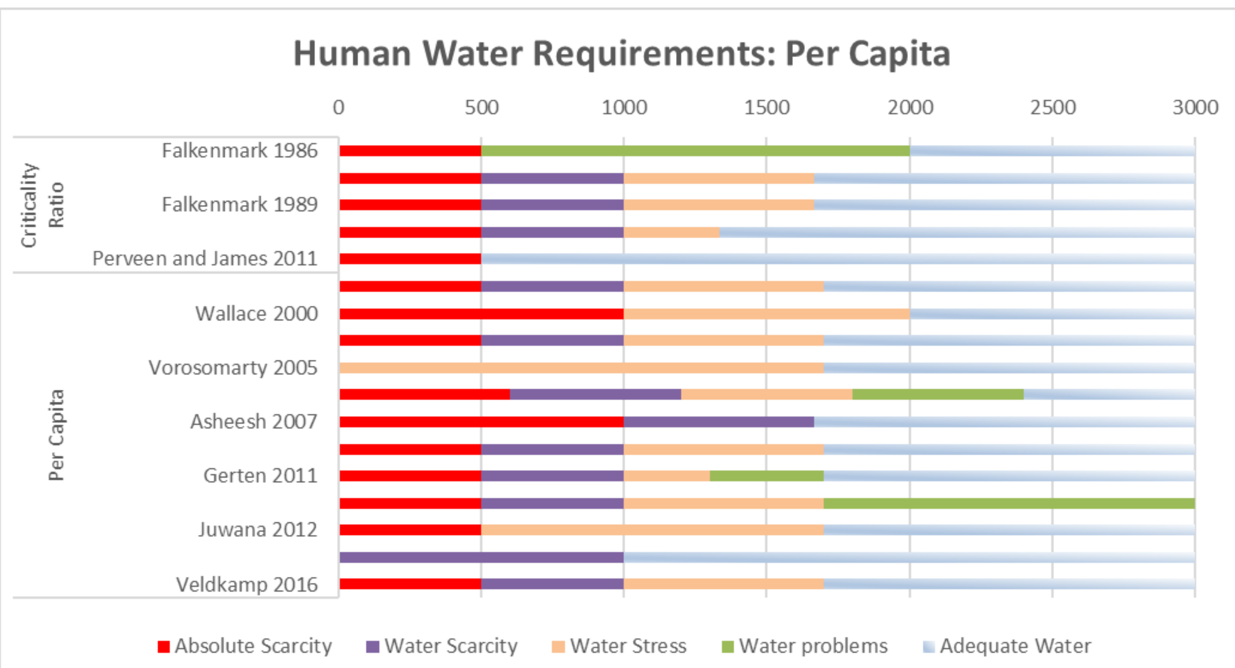

Figure 4.5. Per Capita Water Stress Estimates

Each author used different indicator thresholds. For example, within the per capita approach, Engelman and Leroy (1993) concluded everything greater than 1700 m^3 per capita per year as adequate water, 1700-1000 m^3 per capita per year as low stressed, 1000-500 m^3 per capita per year as stressed, and less than 500 m^3 per capita per year as a high-stress environment. Asheesh (2007) concluded everything greater than 1667 m^3 per capita per year as a low-stress environment, 1667-1000 m^3 per year as stressed, and everything below 1000 m^3 per year as stressed. And, Perveen and James (2011) concluded everything in between 1700-1000 m^3 per capita per year as low-stress, 1000-500 m^3 per capita per year as stressed, and anything below 500 m^3 per capita as a high-stress environment.

Withdrawal-to-Availability Ratio

Harmonization was also applied to the WTA and CTA ratios. WTA differs from CTA because WTA is based on water withdrawals to include both domestic and environmental use. Several adaptations are categorized as WTA, including the WSI originally developed by Vorosmarty (2005), an adaptation by Smakhtin (2005) to include environmental water requirements, and a third expansion of WSI by Pfister (2009) to include climatic variability. The water supply stress index, originally developed by Sun (2008), is a subset of the WTA and further explained below.

Eighteen water metrics were classified as a WTA ratio. Seven water metrics used the WSI approach or a variation, including Pfister (2009), Boulay (2011), Wada (2011), Strzepeck (2013), Blanc (2014), DOE (2014), Freyman (2014), and Hejazi (2014). The other 11 metrics used a similar approach of water withdrawal to water availability, such as Alcamo (2003). Smakhtin (2004) calculated WTA using a denominator of mean annual runoff and environmental water requirement. Similar to the water availability per capita metrics, each metric uses a variety of thresholds to distinguish varying levels of stress. In the third technical harmonization step of data guidance, each of the 18 metrics were rearranged into five concrete thresholds of increasing water stress: adequate water, water problems, water stress, water scarcity, and absolute scarcity. As such, none of the thresholds was changed numerically; they were simply rearranged into these five concrete thresholds. Strzepeck (2013) is the only exception to this rule, which uses thresholds that extend to a value of 2; all others max at 1. For this WTA metric, the metric thresholds were normalized by dividing by 2, to create thresholds that equate to 1. Figure 4.6 highlights the different WTA metrics.

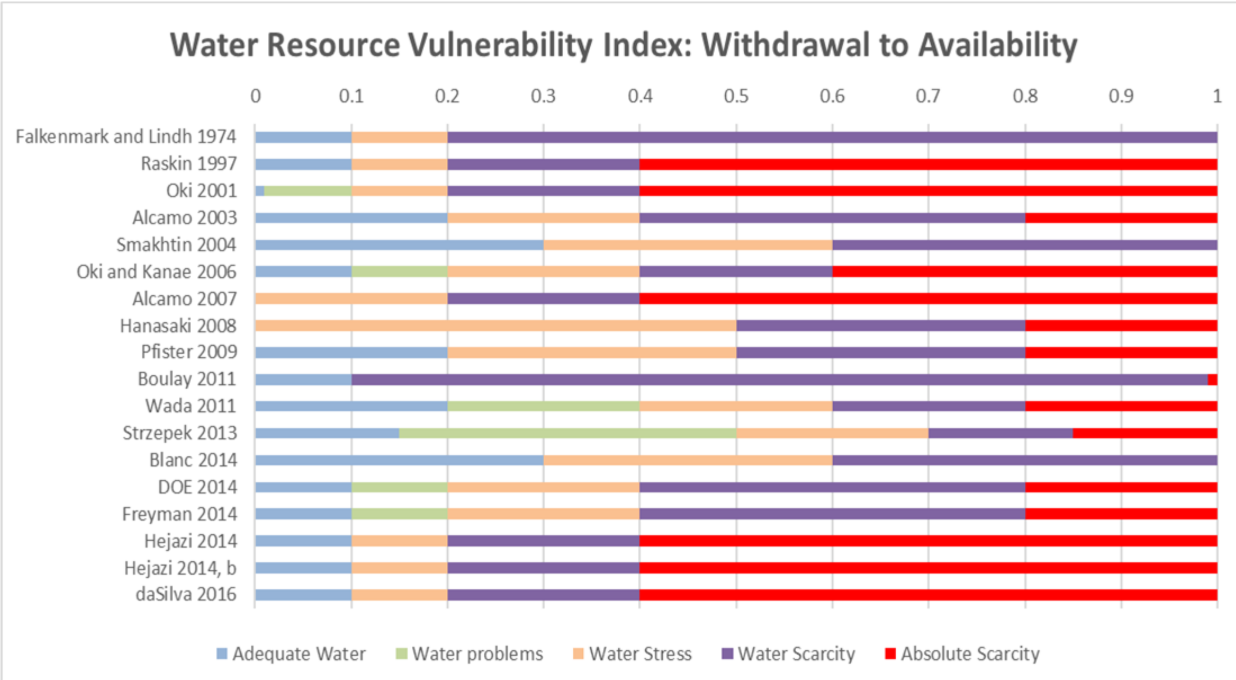

Figure 4.6. Withdrawal to Availability Water Stress Estimates

Estimates of adequate water range from withdrawals of 0% to 30% of available water supplies. Water stress ranges from withdrawals under 10% to 70% of available water supplies. Water scarcity ranges from withdrawals of 10% to 100% of available water supplies, and absolute water scarcity begins in some papers at withdrawals of 40% of available water supplies.

CTA Ratio

The CTA refers to indices based on water consumption and includes 15 analyzed studies. CTA harmonization was almost identical to WTA. The major difference, besides the category, was the end result. The CTA was initially grouped into three final categories based on individual author thresholds. These categories included demand CTA with a ratio of 0:1, demand CTA with a ratio of 0:2, and a reversed water abstraction to demand consumption with a ratio of 1:0. The following works fall into the first category of demand CTA with ratio of 0:1: Bouley (2016) AWARE Index for relative regional water stress, Wada and Bierkens (2014) Blue Water Scarcity Index, Gassert (2014) AQUEDUCT Overall Water Risk Assessment, Wada (2013) Blue Water Supply Stress Index, and Hoekstra and Hung (2005) Water Dependency Index. The following works fall into the second reversed category: Gerten (2011) LPJml hydrological water requirements per capita and Hanasaki (2013) CAD H08. Finally, the last works fall into the third CTA category with a ratio of 0:2: Hoekstra (2011) Consumption to Availability, Hoekstra (2012) Blue Water Scarcity Index WSblue, Asheesh (2007) Water Scarcity Index, and Alcamo (2007) Consumption to Q90 ratio. Figure 4.7 shows the different CTA metrics.

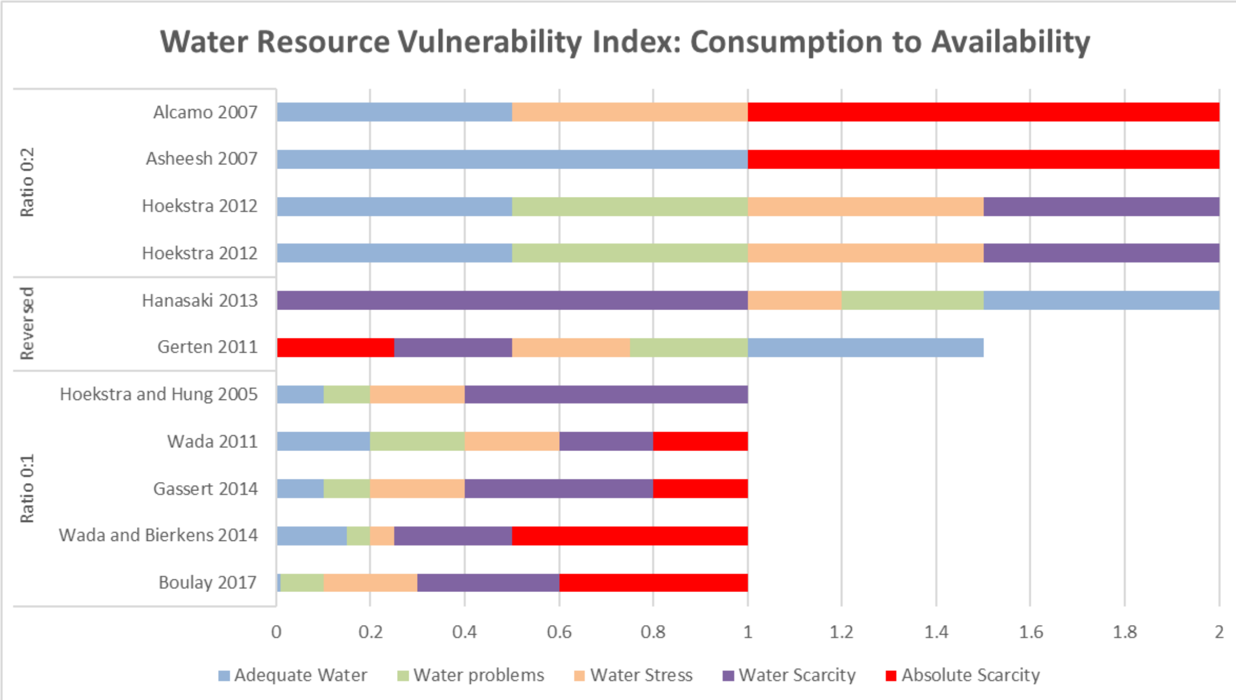

Figure 4.7. Consumption to Availability Water Stress Estimates

CTA water stress estimates range widely, partly due to differences in ratios but also to differences in definitions of water scarcity thresholds. Estimates of absolute water scarcity range from consumption of 50% to 80% of available water, for example.

The variations in existing water stress metrics, their thresholds, and the underlying methodological differences pose challenges for their use in assessing power plant risks. A more consistent approach and water risk metric is needed to provide greater certainty to decision-makers in evaluating water-related risks of power generation. Specific guidelines and thresholds could be developed to inform grid and generator investment decisions that utilize standard approaches allowing for a specific level of risk. Such standards would help ensure water-related risks are consistently addressed in planning and investment decisions.

4.2.2 Future Water Usage and Risk Metrics

This effort is designed to build upon recent DOE and EPRI research to develop a new metric, tentatively titled relative water risk (RWR), that addresses water sustainability and impacts for a modernized power grid. The RWR could be used to assess existing and proposed infrastructure and technological investments in the energy sector. Specifically, this metric would quantify the use (both withdrawal and consumption) of water in the context of local and regional water availability across time. This new metric would improve upon three separate existing metrics (for which data are often available), namely: water intensity (in terms of water use per unit of energy activity), water scarcity and availability (which can have many different definitions), and total water use. This metric is needed because the existing metrics do not adequately capture the impacts of existing or proposed energy activities in the full context of available water resources, leading to potentially misleading and inconsistent comparisons across regions and technology types.

An RWR metric would build upon recent advancements in estimating water availability and impacts of energy technology activities to provide a more comprehensive assessment of the sustainability of energy activities in the context of regional water availability. The development of this metric aligns with the stated research goals in the Quadrennial Energy Review, which advocate additional research in alternative cooling systems and carbon capture and storage systems, both of which can have significant impacts on power plant water requirements. This new metric would allow for a consistent, transferrable comparison among different technology advancements in different regions to better assess the sustainability of future investments and is complementary to (and non-duplicative of) DOE Water Energy Technology Team initiatives.

Recent studies (van Vliet et al. 2016; Miara et al. 2017) have highlighted water-related vulnerabilities that can affect thermoelectric and hydropower generators. These vulnerabilities could affect the ability of thermoelectric and hydropower generators to provide energy and capacity services to the grid. Incorporating improvements assessing potential water-related risks via the RWR could help reduce potential vulnerabilities of new generators, providing benefits to grid reliability.

The effort to develop this metric would involve extensive stakeholder engagement with a diverse set of participants (e.g., Western States Water Council, state-level water managers and engineers, energy industry, environmental non-governmental organizations, and federal agencies) through at least one regional workshop or stakeholder meeting. This stakeholder engagement activity would build on existing contacts the sustainability team has developed related to characterizing water availability and differences in water rights regimes across the country. In addition, this effort would consider two relevant case studies with interested stakeholders to demonstrate the feasibility and usefulness of an RWR metric. Case studies would consider diversity in location, energy activity, and/or water rights structures, and would build upon existing contacts and ongoing projects.

4.3 Scope of Applicability

4.3.1 GHG Emission Metrics

The GHG emission metrics assessed in Year 1 of the GMLC1.1 project are applicable across a wide range of spatial scales.

4.3.1.1 Asset, Distribution, and Bulk Power Level

Two of the federal GHG data products—the EPA’s eGRID and CAMP—report emissions at the asset (generator/boiler) level. eGRID also reports GHG emissions at the balancing authority level.

4.3.1.2 Utility Level

The data from the voluntary reporting programs are often at the utility level. In addition, all but three of the federal GHG data products provide emissions at the facility level, which could be aggregated to the utility level. These data products include the EPA’s eGRID, GHGRP, and CAMP, and the EIA’s EP Annual and MER. However, utility-level aggregation of these data may be difficult because small and medium facilities have units that are owned by multiple utilities and the ownership of these units changes frequently through purchases, mergers, and closures.

4.3.1.3 State Level

Voluntary GHG emission metrics are generally not reported at the state level. While data from these voluntary metrics could be aggregated to the state level, it could be challenging to capture all electric-sector GHG emissions at this level because voluntary metrics are compiled at the utility level and not all utilities report these voluntary metrics. However, all but two of the federal data products (the EPA's GHGI and the EIA's STEO) report data at the state level.

4.3.1.4 Regional Level

Similar to state-level metrics, voluntary GHG emission metrics are not generally reported at a regional level. It might be possible to aggregate the voluntary data to the regional level, but the accounting would likely be incomplete. However, three federal data products explicitly report GHG emissions at a regional level: 1) EPA's CAMP reports at the EPA regional level, 2) EIA's AEO reports data by Census region, and 3) EPA's eGRID reports at the NERC regional and eGRID sub-regional levels.[1] In addition, all but two of the federal data products (the EPA's GHGI and the EIA's STEO) report data in a manner that could be summarized at a regional level.

4.3.1.5 National Level

All of the federal GHG emission metrics are reported in a manner that allows for aggregation at the national level, albeit with different boundaries and scopes of emission sources, GHGs, and other factors that result in differences in the estimate of total US electric-sector CO_2 emissions. Because of their utility-specific boundaries, the voluntary GHG emission metrics are not well suited to this level of aggregation.

4.3.1.6 Other Level

The data reported by several of the federal GHG emission data products could be aggregated to a variety of other levels, such as by city or zip code, based on power supplied to that area. For example, the EPA's Power Profiler web tool (EPA 2017b) uses eGRID data to provide users with estimates of emission intensities based on their distribution company's service area.

4.3.2 Water Metrics

The water metrics and new RWR metric assessed in Year 3 of the GMLC1.1 project are applicable across a wide range of spatial scales.

4.3.2.1 Asset, Distribution, and Bulk Power Level

The EIA reports water usage (withdrawal, consumption) at the asset level. Improved metrics on water usage in the context of local water availability could be integrated to complement water usage values.

[1] An eGRID sub-region represents a portion of the U.S. power grid that is contained within a single NERC region and generally consists of one or more power control areas that have similar emissions and resource mix characteristics.

4.3.2.2 Utility Level

Water metrics could be aggregated and summarized at the utility level to provide an indication of the relative water impact and risks of a given utility's fleet. Certain metrics could be summarized simply, such as total water withdrawal or consumption. However, for other metrics such as relative water risk, individual units would have unique impacts and risks, so aggregating this to the utility level would require generation or capacity weighting to capture fleet-level characteristics.

4.3.2.3 County, State, and National Level

Water withdrawal metrics are currently collected every five years by the USGS at the county level, which are aggregated up to the state and national level. Additional water metrics, including relative water risk, could also be aggregated up to these levels in similar ways as utility-level data would be aggregated. One key challenge for county and state-level data would be that water availability for power plants might come from across county and state boundaries, making data at too fine of resolution problematic. Moreover, conditions could vary greatly within a particular state and across the nation, which poses challenges for describing general trends.

4.3.2.4 Watershed Level

The data collected along with new metrics could be applied at a watershed level, which would provide water managers with data at a more relevant spatial boundary. Multiple power plants could share the same watershed, watersheds can cross political boundaries; and this spatial boundary would be able to capture the multiple stresses and impacts from various sources in a more accurate manner than using political boundaries.

4.4 Use Cases for Metrics

4.4.1 GHG Emission Metrics

GHG emission metrics have a variety of different use cases, including corporate (voluntary) and federal reporting (see Section 3 for more detail). For example, federal laws and regulations in the United States require that most large electric generating units report their CO_2 or GHG emissions (CO_2, CH_4, and NO_x) to the EPA and their fuel consumption to the EIA [31–33]. These agencies use the data collected to produce six US federal data products that track historical electric-sector CO_2 emissions (EIA 2016b, EIA 2016c, EPA 2015a, EPA 2016b, EPA 2016c, and EPA 2016e) and two that forecast future emissions (EIA 2017a and EIA 2017b) (Table 4.1). The primary purpose of these data products varies from satisfying federal regulations to providing information for forecasting future emissions. In addition, corporations and other organizations use GHG emission metrics to track and assess their performance on long- and short-term emissions reduction targets. In some cases, GHG emission metrics are also used to track compliance within emission trading programs, such as the Regional Greenhouse Gas Initiative.

4.4.2 Water Metrics

Water usage and risk metrics have a variety of different use cases, including regional reliability councils (e.g., WECC, ERCOT) evaluating the reliability of alternative capacity developments, utilities managing existing assets and planning for future development, and state water managers assessing water availability for multiple users within a state. State agencies have differing requirements on water usage and thermal impacts of power plants. On a federal reporting level, the EPA monitors thermal effluent discharges from generator cooling systems and the USGS works with state agencies to collect water withdrawal data. Thus, water metrics serve an important role for satisfying state and federal regulations but are also relevant for planning and reliability purposes.

4.5 Value of Metrics

Stakeholders have provided feedback to the Sustainability Metrics Team about the work they have completed to date, emphasizing its value to their needs.

4.5.1 GHG Emission Metrics

According to the stakeholders, the development of an accurate and unbiased comparison between the various federal data sources will:

- Provide greater clarity to their users and decision-makers about the federal GHG data products, their methods, and proper use
- Help utilities better understand and communicate the differences in federal and voluntary GHG data reporting to their stakeholders, such as PUCs and intervenors
- Potentially enable wider use of these metrics and thereby improve performance tracking.

By evaluating the federal GHG data products with regard to their ability to discern changes in GHG emissions in the context of a modernizing grid, this work will:

- Assist federal data product owners in identifying potential improvement opportunities for the existing data products
- Allow utilities, municipalities, and policy makers to understand the potential future coverage gaps associated with these established metrics, which may be deemed important in certain contexts.

4.5.2 Water Metrics

Stakeholders have indicated there is a lack of “location-based water scarcity” metrics and for utilities that want to “fully understand their water risk position as well as regional ecological impacts, additional metrics are needed.” Having improved data and water risk metrics would:

- Provide greater clarity to water risk and water usage decision-makers about the relative risk profile and ecological impacts of power generation
- Help utilities, regional reliability councils, and state agencies evaluate the potential impacts and relative risk of new and proposed generating units in multiple locations
- Establish more useful and regionally relevant metrics that can be used by multiple government, industry, and non-governmental stakeholders.

By evaluating, comparing, and harmonizing existing water metrics and developing a new water risk metric in conjunction with regional reliability councils, this work will:

- Produce results, analysis, and metrics that are most useful to decision-makers
- Offer a new metric paradigm for evaluating power plant risk as it relates to water resources.

4.6 Links to Other Metrics

Within the context of sustainability metrics, there are a variety of connections to other metric areas. For instance, as more flexible resources (such as renewables) are placed on the grid, they will have impacts on existing combustion generators that not only affect their capacity factor but also emission rates during operating hours (e.g., part load, startup, and shutdown emissions). Such relationships have been explored to some degree in, for instance, renewable integration studies (e.g., Western Wind and Solar Integration Study by Lew et al. 2013), but not at decision-relevant spatial scales. Additional relationships should be explored for reliability, affordability, and resilience.

5.0 Next Steps

Analysis of GHG emissions and metrics should be completed once institutionalized with the respective agencies who own the data—EIA and EPA. Further work on GHG metrics is not planned at this time.

With regard to water metrics, especially the newly proposed relative water risk metric, more work is needed to further clarify and gain stakeholder acceptance of the metric. The effort to develop this metric would involve extensive stakeholder engagement with a diverse set of participants (e.g., Western States Water Council, state-level water managers and engineers, energy industry, environmental non-governmental organizations, and federal agencies) through at least one regional workshop or stakeholder meeting. This stakeholder engagement activity would build on existing contacts the sustainability team has developed related to characterizing water availability and differences in water rights regimes across the country. In addition, this effort would consider two relevant case studies with interested stakeholders to demonstrate the feasibility and usefulness of an RWR metric. Case studies would consider diversity in location, energy activity, and/or water rights structures, and would build upon existing contacts and ongoing projects. Following evaluation of the case studies, institutionalization should follow with state, regional, and federal agencies and other stakeholders.

There are many other potential sustainability metrics, both additional environmental sustainability related ones as well as social and economic, which could be addressed going forward. In addition, connections with other GMLC metrics including reliability, affordability, and resilience can be further explored with linkages identified, developed, and matured.

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Appendix A

Metrics Inventory

Appendix A

Metrics Inventory

A.1 GHG

A.1.1 Data

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	Sector	Category *(from list)*	Electric System Infrastructure Component *(from list)*	Metrics Name	Description	Motivation	Units	Metric Type *(from List)*	Metric Classification *(from List)*	Metric Use *(from List)*	Primary User *(from List)*	Secondary User *(from List - if applicable)*	Metrics Tense *(Lagging/ Leading)*	Applicable to Valuation Project *(Yes/No)*	Data Available? (Yes/No)	Geospatial Resolution *(from list)*	Temporal Frequency of Data Reporting *(from list)*	Citation/Data Source Reference #	Potential Issues/ Comments
1	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from GHGRP	Absolute CO_2 emissions as reported to the GHGRP under mandatory facility reporting to EPA	Mandatory reporting under EPA's GHGRP (CFR 40 Part 98); facilities that emit 25,000 metric tons or more per year of GHGs are required to submit annual reports to EPA under the GHGRP	Metric tons of CO_2 equivalents	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	EPA	Utility	Lagging	Yes	Yes	Generation plant	Annually	SUS1	
2	Electricity	Sustainability	Generation central	Electric sector GHG emissions from GHGI	Absolute GHG emissions as estimated by the EPA's GHGI, an annual top-down assessment of total US GHG emissions and removals by source and economic sector	For submission to the United Nations in accordance with the Framework Convention on Climate Change	Metric tons of CO_2 equivalents	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	United Nations	Policy makers	Lagging	No	Yes	National	Annually	SUS2	
3	Electricity	Sustainability	Generation central	Electric sector GHG emissions from eGRID	Absolute GHG emissions as compiled by the EPA into its eGRID data product; data sources include the Clean Air Market Division (CAMD) and the EIA's MER	For consumers, researchers, and other stakeholders to develop GHG inventories, carbon footprints, consumer information disclosure, avoided emission estimates, etc.	Pounds of CO_2; Pounds of N_2O; Pounds of CH_4; Pounds of CO_2 equivalents	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Utility	Lagging	Yes	Yes	Boiler	Biennially	SUS3	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	Sector	Category *(from list)*	Electric System Infrastructure Component *(from list)*	Metrics Name	Description	Motivation	Units	Metric Type *(from List)*	Metric Classification *(from List)*	Metric Use *(from List)*	Primary User *(from List)*	Secondary User *(from List - if applicable)*	Metrics Tense *(Lagging/ Leading)*	Applicable to Valuation Project *(Yes/No)*	Data Available? (Yes/No)	Geospatial Resolution *(from list)*	Temporal Frequency of Data Reporting *(from list)*	Citation/Data Source Reference #	Potential Issues/ Comments
4	Electricity	Sustainability	Generation central	Electric sector GHG intensity from eGRID	GHG intensity as estimated in the EPA's eGRID data product; data sources include CAMD and the EIA's MER	For consumers, researchers, and other stakeholders to develop GHG inventories, carbon footprints, consumer information disclosure, avoided emission estimates, etc.	Pounds of CO_2 per MWh; Pounds of N_20 per MWh; Pounds of CH_4 per MWh; Pounds of CO_2 equivalents per MWh	Intensity	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Utility	Lagging	Yes	Yes	Generation plant	Biennially	SUS3	
5	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from CAMD	Absolute CO_2 emissions as reported to the EPA CAMD for mandatory reporting of CO_2 emissions data from continuous emission monitoring systems	Mandatory reporting under EPA's Acid Rain Program (40 CFR 75)	Metric tons of CO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	EPA	Utility	Lagging	Yes	Yes	Boiler	Hourly	SUS4	
6	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from MER	Absolute CO_2 emissions as compiled by the EIA MER	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Metric tons of CO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Lagging	Yes	Yes	State	Monthly	SUS5	
7	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from EI''s EP Annual	Absolute CO_2 emissions as compiled by the EIA in its EP Annual	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Metric tons of CO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Lagging	Yes	Yes	Facility	Annually	SUS6	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	**Sector**	**Category** ***(from list)***	**Electric System Infrastructure Component** ***(from list)***	**Metrics Name**	**Description**	**Motivation**	**Units**	**Metric Type** ***(from List)***	**Metric Classification** ***(from List)***	**Metric Use** ***(from List)***	**Primary User** ***(from List)***	**Secondary User** ***(from List - if applicable)***	**Metrics Tense** ***(Lagging/ Leading)***	**Applicable to Valuation Project** ***(Yes/No)***	**Data Available? (Yes/No)**	**Geospatial Resolution** ***(from list)***	**Temporal Frequency of Data Reporting** ***(from list)***	**Citation/Data Source Reference #**	**Potential Issues/ Comments**
8	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from EI's STEO	Absolute CO_2 emissions as projected by the EIA STEO	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Metric tons of CO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Leading	No	Yes	National	Monthly	SUS7	
9	Electricity	Sustainability	Generation central	Electric sector CO_2 emissions from EIA's AEO	Absolute CO_2 emissions as compiled by the EIA AEO	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Metric tons of CO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Leading	Yes	Yes	National	Annually	SUS8	
11	Electricity	Sustainability	Generation, transmission, and distribution	Corporate CO_2 emissions from SASB	Absolute GHG emissions (gross global scope 1) as reported SASB	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Metric tons of CO_2 equivalents	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Lagging	No	Varies	Corporation	Varies	SUS9	
12	Electricity	Sustainability	Generation, transmission, and distribution	GHG emissions associated with power deliveries	Total GHG emissions associated with owned and purchased electric power that is delivered to retail customers	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Metric tons of CO_2 equivalents	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Utility	Electric Generator	Lagging	No	Varies	Utility	Varies	SUS9	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	**Sector**	**Category *(from list)***	**Electric System Infrastructure Component *(from list)***	**Metrics Name**	**Description**	**Motivation**	**Units**	**Metric Type *(from List)***	**Metric Classification *(from List)***	**Metric Use *(from List)***	**Primary User *(from List)***	**Secondary User *(from List - if applicable)***	**Metrics Tense *(Lagging/ Leading)***	**Applicable to Valuation Project *(Yes/No)***	**Data Available? (Yes/No)**	**Geospatial Resolution *(from list)***	**Temporal Frequency of Data Reporting *(from list)***	**Citation/Data Source Reference #**	**Potential Issues/ Comments**
13	Electricity	Sustainability	Generation, transmission, and distribution	GHG emissions covered under emissions-limiting regulations	Percentage of emissions covered under emissions-limiting regulations	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Percentage	Quantitative	Process	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Lagging	No	Varies	Corporation	Varies	SUS9	
14	Electricity	Sustainability	Generation, transmission, and distribution	GHG emissions covered under emissions-reporting regulations	Percentage of emissions covered under emissions-reporting regulations	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Percentage	Quantitative	Process	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Lagging	No	Varies	Corporation	Varies	SUS9	
15	Electricity	Sustainability	Generation, transmission, and distribution	Corporate emission reduction strategy	Description of long-term and short-term strategy or plan to manage Scope 1 emissions, emission-reduction targets, and an analysis of performance against those targets	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	NA	Qualitative	Process	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Leading	No	Varies	Corporation	Varies	SUS9	
16	Electricity	Sustainability	Generation, transmission, and distribution	Corporate fulfillment of RPS target by market	Percentage fulfillment of RPS target by market	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Percentage	Quantitative	Process	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Lagging	No	Varies	Corporation	Varies	SUS9	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	Sector	Category *(from list)*	Electric System Infrastructure Component *(from list)*	Metrics Name	Description	Motivation	Units	Metric Type *(from List)*	Metric Classification *(from List)*	Metric Use *(from List)*	Primary User *(from List)*	Secondary User *(from List - if applicable)*	Metrics Tense *(Lagging/ Leading)*	Applicable to Valuation Project *(Yes/No)*	Data Available? (Yes/No)	Geospatial Resolution *(from list)*	Temporal Frequency of Data Reporting *(from list)*	Citation/Data Source Reference #	Potential Issues/ Comments
17	Electricity	Sustainability	Generation, transmission, and distribution	Customers served in RPS markets	Number of customers served in markets subject to renewable portfolio standards	To develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors	Number of customers	Absolute	Process	Learning, Decision-making, Accountability, Demonstration	Utility	Consumer	Lagging	No	Varies	Corporation	Varies	SUS9	
18	Electricity	Sustainability	Generation central	Electric sector CO_2 intensity from EIA	GHG intensity used to compute CO_2 emissions from fuel consumption in the EIA's MER and EP Annual	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Million metric tons of CO_2 per quadrillion Btu	Intensity	Outcome	Learning, Decision-making, Accountability, Demonstration	EIA		Lagging	No	Yes	National	Not recently updated	SUS10	
19	Electricity	Sustainability	Generation central	Electric sector CO_2 intensity from the EPA's GHGRP	GHG intensity reported in the CFRs for use in the GHGRP	Mandatory reporting under EPA's GHGRP (40 CFR 40 98); facilities that emit 25,000 metric tons or more per year of GHGs are required to submit annual reports to EPA under the GHGRP	Kilograms CO_2 per million Btu	Intensity	Outcome	Learning, Decision-making, Accountability, Demonstration	EPA		Lagging	No	Yes	National	One-time release	SUS11	
20	Electricity	Sustainability	Generation central	Electric sector SO_2 and NOx emissions from eGRID	Absolute NOx and SO_2 emissions as compiled by the EPA into its eGRID data product; data sources include CAMD and the EIA's MER	For consumers, researchers and other stakeholders to develop criteria pollutant emission inventories, air quality analysis, consumer information disclosure, avoided emission estimates, etc.	Tons of NOx and SO_2	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Utility	Lagging	Yes	Yes	Boiler	Biennially	SUS3	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	**Sector**	**Category** ***(from list)***	**Electric System Infrastructure Component** ***(from list)***	**Metrics Name**	**Description**	**Motivation**	**Units**	**Metric Type** ***(from List)***	**Metric Classification** ***(from List)***	**Metric Use** ***(from List)***	**Primary User** ***(from List)***	**Secondary User** ***(from List - if applicable)***	**Metrics Tense** ***(Lagging/ Leading)***	**Applicable to Valuation Project** ***(Yes/No)***	**Data Available? (Yes/No)**	**Geospatial Resolution** ***(from list)***	**Temporal Frequency of Data Reporting** ***(from list)***	**Citation/Data Source Reference #**	**Potential Issues/ Comments**
21	Electricity	Sustainability	Generation central	Electric sector SO_2 and NOx emissions from eGRID	Absolute NOx and SO_2 emissions as compiled by the EPA into its eGRID data product; data sources include CAMD and the EIA's MER	For consumers, researchers and other stakeholders to develop criteria pollutant emission inventories, air quality analysis, consumer information disclosure, avoided emission estimates, etc.	lb NOx and SO_2 per MWh	intensity	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Utility	Lagging	Yes	Yes	Generation plant	Biennially	SUS3	
22	Electricity	Sustainability	Generation central	Electric sector SO_2 and NOx emissions from CAMD	Absolute SO2 and NOx emissions as reported to the EPA CAMD for mandatory reporting from continuous emission monitoring systems	Mandatory reporting under EPA's Acid Rain Program (40 CFR)	lb of SO_2 and NOx	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	EPA	Utility	Lagging	Yes	Yes	Boiler	Hourly	SUS4	
23	Electricity	Sustainability	Generation central	Electric sector SO_2 and NOx emissions from CAMD	Absolute SO2 and NOx emissions as reported to the EPA CAMD for mandatory reporting from continuous emission monitoring systems	Mandatory reporting under EPA's Acid Rain Program (40 CFR)	lb of SO_2 and NOx per mmBTU (and NOx per MWh)	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	EPA	Utility	Lagging	Yes	Yes	Boiler	Hourly	SUS4	
24	Electricity	Sustainability	Generation central	Electric sector SO_2 and NOx emissions from EIA's EP Annual	Absolute NOx and SO_2 emissions as compiled by the EIA in its EP Annual	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	lbs SO_2 and NOx	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Lagging	Yes	Yes	State	Annually	SUS6	

	Categorization			Summary											Historical Supporting Data - Lagging Metrics				
Metric #	**Sector**	**Category *(from list)***	**Electric System Infrastructure Component *(from list)***	**Metrics Name**	**Description**	**Motivation**	**Units**	**Metric Type *(from List)***	**Metric Classification *(from List)***	**Metric Use *(from List)***	**Primary User *(from List)***	**Secondary User *(from List - if applicable)***	**Metrics Tense *(Lagging/ Leading)***	**Applicable to Valuation Project *(Yes/No)***	**Data Available? (Yes/No)**	**Geospatial Resolution *(from list)***	**Temporal Frequency of Data Reporting *(from list)***	**Citation/Data Source Reference #**	**Potential Issues/ Comments**
25	Electricity	Sustainability	Generation central	Electric sector SO_2, NOx, mercury emissions from EIA's AEO	Absolute SO_2, NOx, and mercury emissions as compiled by the EIA's AEO	To provide independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding	Short Tons SO_2, NOx, Mercury	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Leading	Yes	Yes	National	Annually	SUS8	
26	Electricity	Sustainability	Generation central	All sector SO_2, NOx, PM2.5 and heavy metals from EPA's National Emissions Inventory	All sector SO_2, NOx, PM2.5 and heavy metals from EPA's National Emissions Inventory	To provide independent and impartial emissions information to promote sound policymaking, efficient markets, and public understanding	Short tons or lb of criteria pollutants and heavy metals	Absolute	Outcome	Learning, Decision-making, Accountability, Demonstration	Consumers	Policy makers	Lagging	Yes	Yes	Plant	Varies	SUS12	

A.1.2 References

Citation/ Data Source Ref #	Citation/Data Source
SUS1	https://www.epa.gov/ghgreporting/ghg-reporting-program-data-sets
SUS2	https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014
SUS3	https://www.epa.gov/energy/egrid
SUS4	https://ampd.epa.gov/ampd/
SUS5	http://www.eia.gov/totalenergy/data/monthly/#environment
SUS6	http://www.eia.gov/electricity/annual/
SUS7	http://www.eia.gov/forecasts/steo/
SUS8	http://www.eia.gov/forecasts/aeo/
SUS9	SASB. 2018. Sustainability Accounting Standard - Infrastructure Sector. Electric Utilities & Power Generators Sustainability Accounting Standard, Version 2018-10. Available at: http://www.sasb.org/
SUS10	http://www.eia.gov/electricity/annual/html/epa_a_03.html
SUS11	EPA. 2013. 40 CFR Part 98, Subpart C, Table C-1 to Subpart C of Part 98 - Default CO2 Emission Factors and High Heat Values for Various Types of Fuel. Latest revision available at https://www.gpo.gov/fdsys/pkg/FR-2013-11-29/pdf/2013-27996.pdf#page=48
SUS12	https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

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http://gridmodernization.labworks.org/