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WORKING PAPER

GUIDANCE FOR CALCULATING WATER USE EMBEDDED IN PURCHASED ELECTRICITY

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EXECUTIVE SUMMARY

- Organizations increasingly quantify and report water use from their operations and supply chains, but there is limited information on how to measure water used in the generation of electricity that the organization purchases.
- This working paper proposes the first comprehensive approach to calculate water withdrawals and consumption associated with purchased electricity. It provides the first international country-level and U.S. subnational-level water use factors detailing the grid-average water withdrawal and consumption resulting from a unit of electricity consumption.
- The approach establishes accounting and reporting principles, helps identify and set reporting boundaries, and distinguishes reporting scopes by electricity production and distribution methods.
- The method allows organizations to measure water impacts, risks, and opportunities associated with purchased electricity.
- The resulting water use factors indicate high variability in average water consumption, from 4.91 U.S. gallons per kilowatt hour (kWh) in Brazil to 0.3 gallons in Malta, and in water withdrawal, from 3,912 U.S. gallons per kWh in Slovenia to 15 gallons in Cyprus. (The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per U.S. gallon.) The variability strengthens the call to action for organizations to assess and respond to water risks associated with their purchased electricity.

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Water use during electricity generation represents one of the largest sources of water withdrawals globally. In some places, such as the United States, water withdrawals for thermoelectric power are the largest source of water withdrawals in the country. Further, although accounting for water withdrawals and consumption is the first step toward identifying water risks and opportunities, there is limited information on how to account systematically for water use during the generation of purchased electricity.

In response, WRI and WSP propose accounting and reporting principles and a method to measure water use systematically during the generation of purchased electricity (also known as water use embedded in purchased electricity; here, it will be called embedded water use). The method is designed for all organizations interested in measuring water use and the impacts, risks, and opportunities associated with purchased electricity. It was developed by engaging key stakeholder groups and building on greenhouse gas reporting principles, relevant scientific research, and existing data.

This working paper provides, for the first time, a four-step approach to calculating embedded water use and a country and U.S. Emissions and Generation Resource Integrated Database data set on grid-average water withdrawal and consumption resulting from a unit of electricity consumption. The approach also establishes accounting and reporting principles, helps identify and set accounting and reporting boundaries, and distinguishes reporting scopes by electricity production and distribution methods.

ABBREVIATIONS

eGRID	Emissions & Generation Resource Integrated Database
ERCOT	Electric Reliability Council of Texas
gal	U.S. gallon
gal/kWh	gallons per kilowatt hour
GHG	greenhouse gas
GJ	gigajoule
GOs	guarantees of origin
GRI	Global Reporting Initiative
ISO	International Organization for Standardization
kWh	kilowatt hour
LCA	life cycle assessment
LCI	life cycle inventory
m^3	cubic meter
MWh	megawatt hour
OECD	Organisation for Economic Co-operation and Development
PPAs	power purchase agreements
PV	photovoltaic
RECs	renewable energy certificates
U.S. EPA	U.S. Environmental Protection Agency
WBSCD	World Business Council for Sustainable Development
WECC	Western Electricity Coordinating Council
WRI	World Resources Institute
WULCA	water use in life cycle assessment

INTRODUCTION

Global demands for freshwater are projected to more than double by 2050, which could result in more than 40 percent of the world's population living in areas of severe water stress (OECD 2012). The global water crisis is one of the largest threats facing the planet (World Economic Forum 2019), and organizations across sectors are spending billions to tackle the associated risks. In 2017, companies reporting to CDP Water committed US$23.4 billion to tackle water risks around the world (CDP Water 2017).

Measuring an organization's dependency on water is a first and critical step in any comprehensive approach to addressing water risks and opportunities (Ceres 2011). As such, an organization should quantify and report water use across its value chain, prioritizing parts of the value chain where water use is greatest. Despite ample available guidance to measure an organization's water use (CEO Water Mandate 2018), there is limited information on how to measure water withdrawals and consumption (water use) systematically during the generation of purchased electricity.

Standards are available to measure water use for products, services, and organizations, such as the International Organization for Standardization (ISO) 14046:2014 standard (ISO 2014) and the Global Water Footprint Assessment standard (Hoekstra et al. 2011). There are also methodologies to determine the impact of water use using a life cycle approach, such as the water use in life cycle assessment available water remaining method (Boulay et al. 2017). There are data sets documenting water use during electricity generation (Grubet and Sanders 2018), including water consumption of electricity from hydropower (Mekonnen and Hoekstra 2012), life cycle use of water in electricity generation (Meldrum et al. 2013; Fthenakis and Kim 2010), and average operational water consumption and withdrawal factors for electricity-generating technologies (Macknick et al. 2012). However, none of these provides a comprehensive, comparable, and scalable approach to measuring water use embedded in electricity generation from the perspective of the organization that is purchasing electricity. It is also possible to conduct a regional impact assessment after assessing water consumption as defined in ISO 14046. This goes beyond the scope of this document, but possible outcomes of such an assessment include enhanced understanding of region-specific risks associated with ensuring adequate electricity supplies if electricity generation relies on water. For example, power plants may be forced to reduce power production because of a lack of water (Luo et al. 2018).

Water use during electricity generation represents one of the largest sources of water withdrawals globally and is projected to grow by 140 percent by 2050 (OECD 2012). In the United States, for example, water withdrawals for thermoelectric power account for 45 percent of the total—the largest source of water withdrawals in the country—followed closely by water withdrawals for irrigation, which account for 38 percent of the total (Maupin et al. 2014). Water use embedded in electricity consumption may be much greater than operational water uses in some cases, and therefore be material to an organization or country. For example, a drought-induced water shortage in Zambia in 2015 forced power cuts that disrupted the country's mining industry, threatening output, jobs, and economic growth (Mfula 2015).

Electricity consumers have significant opportunities to reduce water use by reducing the electricity purchased from water-intensive energy sources. Quantifying water use by electricity source can help to build the case for alternative, less-water-intensive sources of electricity (Box 1), that may also provide other benefits, such as reduced greenhouse gas (GHG) emissions and operating costs.

Companies or organizations seeking to manage water-related risks may want to consider how the water embedded in energy affects their risk profile and evaluate the tradeoffs between various sources of energy. By including embedded water use in risk assessments, in evaluation of energy sources, and in resource allocation, organizations gain a more complete picture of their resource dependencies and a more nuanced understanding of the natural resource tradeoffs from an operational perspective.

The methods used to calculate water use during electricity generation can influence how an organization assesses water-related risks and opportunities associated with its electricity use, and what response actions will be prioritized. This guidance aims to enhance the relevance, completeness, consistency, transparency, and accuracy of accounting and reporting water use during the generation of electricity, and help organizations to evaluate three factors:

- **Dependence**—magnitude of the water withdrawals and consumption required to produce an organization's purchased electricity
- **Risk**—exposure to water-related risks associated with purchased electricity, such as operational disruptions caused by electricity generation disruptions stemming from water shortages
- **Opportunities**—water-related benefits and tradeoffs associated with different technologies or reducing purchased electricity

This guidance establishes accounting and reporting principles for embedded water use in purchased electricity. Information is also provided on how to identify and set the boundaries for accounting and reporting water use during electricity generation, including organizational boundaries, and how to distinguish reporting scopes by the electricity production and distribution methods.

All organizations interested in measuring water use, impacts, risks, and opportunities associated with purchased electricity should use this guidance (Box 2). In addition, energy suppliers, utilities, and grid operators should read this guidance to understand the type of information customers may be requesting to calculate water use from electricity generation. Government entities involved in regulating water use for electricity production should also be informed about this guidance.

This guidance was developed by WRI and WSP, building on GHG reporting standards and principles (Box 3), relevant scientific research, and existing data. WRI and WSP also engaged key stakeholder groups from businesses, nongovernmental organizations, reporting programs, electric utilities, government agencies, and academic institutions from around the world.

SETTING BOUNDARIES AND DEFINING THE SCOPE

Organizational Boundaries

An organization can choose between two consolidation approaches for defining its boundaries for the entire water use inventory and is recommended to use the same consolidation approach as the one it uses for its GHG inventory over time. These approaches are as follows:

Box 1 | **Case Study: Facebook Inc.**

Facebook Inc. quantifies water embedded in purchased electricity to understand the environmental impact of its wide-scale adoption of clean and renewable energy.

Facebook set a goal to source 100 percent clean and renewable energy by 2020 and to reduce its operational greenhouse gas emissions by 75 percent by 2020. By prioritizing clean and renewable energy, Facebook has been able to contribute to water savings. Clean and renewable energy sources, such as wind and solar, consume less water than other energy sources, such as coal.

To measure its contribution, Facebook quantified the water demand of clean and renewable energy sources by partnering with WRI to calculate the water embedded in purchased electricity at data centers, considering the energy mix and cooling technology at each data center. This project highlighted an aspect of the water–energy nexus that had previously not been well articulated and helped to understand the positive environmental impact of clean and renewable energy sources, particularly in water-stressed areas. By looking at the energy value chain through the lens of water, Facebook Inc. was able to identify cases where energy efficiency might go farther in achieving water efficiency, and helped the company better understand the impacts and tradeoffs of different energy sources. For example, at data centers that rely on hydropower, the analysis helped make the case for considering less-water-intensive renewable energy solutions.

This type of analysis added value to Facebook Inc. by allowing the company to consider broader environmental impacts beyond greenhouse gas emissions, resulting in a more nuanced understanding of the natural resource tradeoffs from an operational perspective, particularly in water-stressed regions.

For additional information, see "Facebook Sustainability Footprint" (https://sustainability.fb.com/our-footprint/) and "Facebook Sustainability Clean and Renewable Energy" (https://sustainability.fb.com/clean-and-renewable-energy/).

Source: Facebook Inc. 2019.

- **Equity share approach.** An organization accounts for embedded water use from operations according to its share of equity in the operation. The equity share reflects economic interest, which is the extent of rights an organization has toward the risks and rewards flowing from an operation.
- **Control approach.** An organization accounts for 100 percent of the embedded water use from operations over which it has control. It does not account for embedded water use from operations in which it owns an interest but has no control. Control can be defined in either financial or operational terms. When using the control approach to consolidate embedded water use, organizations shall choose either the operational control or financial control criteria:
  - Financial control. The organization has financial control over the operation if the former can direct the financial and operating policies of the latter with a view to gaining economic benefits from its activities.
  - Operational control. The organization has operational control over an operation if the former or one of its subsidiaries has the full authority to introduce and implement its operating policies at the operation.

Box 2 | **Case Study: Mars Inc.**

Mars Inc. calls for a standardized approach to measuring water use, impacts, risks, and opportunities associated with purchased electricity to help inform energy sourcing decisions.

In 2010, Mars Inc. committed to decarbonize its factories by moving to 100 percent renewable energy by 2040 to address the factories' climate-related impacts. As the company began to use solar photovoltaic power (PV), and to purchase renewable electricity from wind turbines at scale, Mars Inc. became increasingly aware that these energy sources have significantly lower water demands per unit of electricity produced than does the grid as a whole. This is particularly relevant in water-stressed areas, such as Pune, India, where a recent solar PV project at Mars Inc.'s confectionery facility reduced the facility's reliance on the local electricity grid and consequently its reliance on scarce freshwater resources. By quantifying the water demands of purchased electricity, Mars Inc. will be able to build a stronger business case for renewable projects, such as the one in Pune, and inform the company's purchase of grid electricity where the renewable energy program has not yet reached.

For additional information, see:

- Mars Inc. Sustainable in a Generation Plan (https://www.mars.com/global/sustainable-in-a-generation)
- Mars Inc. Climate Action Position Statement (https://www.mars.com/global/about-us/policies-and-practices/climate-action-position-statement)

Source: Mars Inc. 2019.

Defining Embedded Water Use

Embedded water use includes the water use associated with generating electricity, needed power that an organization purchases from a separate entity that generates electricity, either through a distribution grid or through a direct line connection to an on-site or off-site generation unit. Embedded water use includes water use (water withdrawals or consumption) during the generation of purchased or acquired electricity consumed by an organization and generated at discrete sources owned and operated by entities that generate power. For example, the cooling water used at a thermal power plant or the water stored in and evaporated from a hydroelectric reservoir both represent embedded water use.

Embedded water use excludes water use (water withdrawals or consumption) during electricity generation at an organization's facility. It also excludes water use during transmission, distribution, or activities upstream of electricity generation, such as water use during the extraction and processing of fuels.

In some instances, an organization may generate electricity at one of its facilities, sell excess generated electricity to the grid, and purchase grid electricity to meet additional demand at the generating facility. In these circumstances, embedded water use is quantified using the gross amount of electricity purchased from the grid, not the net purchase amount. Simply put, water use is quantified for total purchased electricity, which excludes any self-generation sold to a third party or to the grid. However, net purchases can be used to quantify embedded water use if there is no way to distinguish between gross and net purchases, such as when net metering is in effect and the utility bill reports only net purchases.

Box 3 | Relationship to the GHG Protocol *A Corporate Accounting and Reporting Standard* and *GHG Protocol Scope 2 Guidance*

This guidance builds on the principles outlined in the GHG Protocol *A Corporate Accounting and Reporting Standard* (WRI and WBCSD 2014) and establishes accounting and reporting principles for embedded water use in purchased electricity by adapting the *GHG Protocol Scope 2 Guidance* (WRI 2015).

The GHG Protocol *A Corporate Accounting and Reporting Standard* classifies an organization's GHG emissions into three scopes (Figure B3.1):

- Scope 1 emissions are direct emissions from owned or controlled sources.
- Scope 2 emissions are indirect emissions from the generation of purchased electricity, steam, heating, and cooling.
- Scope 3 emissions are all indirect emissions (not included in Scope 2) that occur in the value chain of the reporting organization, including both upstream and downstream emissions.

FIGURE B3.1. ACTIVITIES WITHIN SCOPES 1, 2, AND 3 AS DEFINED IN THE GHG PROTOCOL

SCOPE 3

- Purchased goods and services
- Capital goods
- Fuel and energy-related activities
- Transportation and distribution
- Waste generated in operations
- Business travel
- Employee commuting
- Leased assets

SCOPE 2

- Purchased electricity
- Steam
- Heating
- Cooling

SCOPE 1

- Company facilities
- Company vehicles

SCOPE 3

- Transportation and distribution
- Processing of sold products
- Use of sold products
- End-of-life of sold products
- Leased assets
- Franchises
- Investments

Source: Based on WRI and WBCSD 2014 and WRI 2015, modified by WRI and WSP.

Despite ample differences between accounting and reporting GHG emissions and water use, there are parallels between embedded water use and location-based Scope 2 GHG emissions. *Embedded water use* refers to the water use (withdrawn or consumed) during the generation of purchased electricity— for example, the cooling water used at a thermal power plant or the water evaporated from a hydroelectric reservoir.

The *GHG Protocol Scope 2 Guidance* defines methods for quantifying and reporting Scope 2 GHG emissions. It provides significant detail, examples, and guidance specific to the issues associated with GHG accounting. This embedded water use accounting guidance follows the same structure, applies the same general concepts, and uses many of the same terms as the GHG Protocol.

Following the principles outlined in the GHG Protocol *A Corporate Accounting and Reporting Standard*, embedded water use accounting and reporting should be based on the principles of relevance, completeness, consistency, transparency, and accuracy. These five principles help guide the implementation of embedded water use accounting guidance, particularly when application of the guidance in specific situations proves ambiguous. Organizations may encounter tradeoffs between principles when completing a water use inventory and should strike a balance between these principles based on their organizational goals. For instance, an organization may find that achieving the most complete water use inventory requires the use of less accurate data, compromising overall accuracy. Over time, as the accuracy and completeness of data increase, the tradeoff between these accounting principles will likely diminish.

Source: WRI 2015.

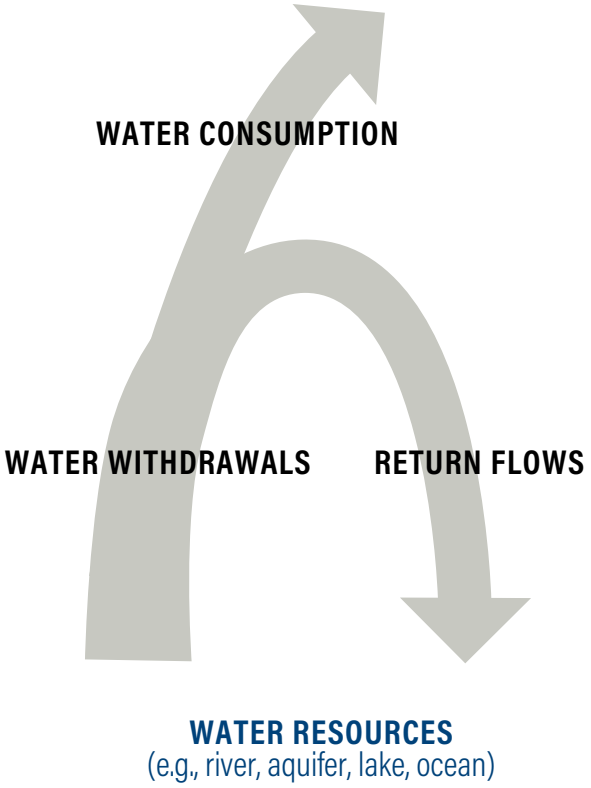
ACCOUNTING METHODS

The objective of embedded water use accounting is to quantify the water use during electricity consumption, and therefore applies to measures of water withdrawals and water consumption (Figure 1).

In Figure 1, "water withdrawals" refers to the water removed from its source for a specific use. A portion of the water withdrawals will be returned (return flows) and available for other uses. A portion will be consumed (water consumption) and permanently lost from its source and otherwise not available to other users.

Understanding both water withdrawal and consumption is critical to evaluating water risks properly. Measurements of water withdrawal indicate the level of competition and dependence on water resources. Water consumption estimates help to quantify the impact of water withdrawals on downstream availabilities and are essential to evaluating water shortage and scarcity (Gleeson 2017).

Figure 1 | **Water Withdrawals, Consumption, and Return Flows**



Source: WRI.

Following the convention defined for location-based Scope 2 GHG accounting, this guidance presents a method to quantify water withdrawals and consumption during electricity generation, reflecting the average water use of grids on which electricity consumption occurs. This method uses grid-average water use factors, calculated on the basis of statistical water use, distribution of electricity generation technologies, and electricity output, aggregated and averaged within a defined geographic boundary during defined time.

In GHG accounting, an electricity emission factor represents the quantity of GHG emissions associated with a unit of electricity consumption. This paper's accounting guidance for embedded water use proposes the concept of water use factors, representing the amount of water withdrawal or consumption expected to result from a unit of electricity consumption. The most significant of these uses are the evaporation of water from a reservoir serving a hydroelectric power plant and the cooling water used at a thermal or nuclear power plant.

These are generation-only factors. They do not include the water used during transmission, distribution, or activities upstream of electricity generation, such as water used during the extraction and processing of fuels.

The convention defined for market-based Scope 2 GHG accounting is not suitable to quantify water withdrawals and consumption during electricity generation for organizations purchasing renewable energy certificates (RECs) (also known as green tags, renewable energy credits, or tradable renewable certificates). That convention is excluded from this method.

Market-based Scope 2 GHG accounting is not suitable for water accounting because the purchase of RECs does not reduce the water withdrawals and consumption associated with electricity consumed from the grid. For that reason, any water savings associated with RECs cannot be attributed to their buyers or to the owners of the renewable technology if they continue to procure electricity from the grid. Further, any water savings associated with RECs should be accounted for by the grid-average water use factors; it would be double-counted if it were attributed separately using RECs. Organizations using RECs or investing in renewable energy to help reduce the water withdrawals or consumption associated with electricity production can provide a qualitative description of their activities and the associated water savings.

Calculations

Once the organizational and scope boundary has been established, organizations can calculate their embedded water use following four steps.

Step 1. Identify sources of embedded water use

Organizations should first identify all purchased or otherwise acquired electricity from an entity outside the organization, from utility bills or meters within the inventory boundaries, measured in megawatt hours (MWh) or kilowatt hours (kWh). This will typically be the same activity data that the organization may have already gathered to quantify its GHG emissions.

Step 2. Collect activity data

To determine activity data, metered electricity consumption or utility bills specifying consumption in MWh or kWh units often provide the most precise information. In some cases, these data sources may not be available (e.g., in a shared space without electricity metering), and estimates may be used to allocate electricity usage among tenants (e.g., on the basis of the organization's square footage and the building's occupancy rate) (Table 1).

Table 1 | **Examples of Activity Data per Facility**

ACTIVITY DATA		
FACILITY	LOCATION	QUANTITY OF ELECTRICITY (KWH)
Facility 1	San Francisco, CA	500,000
Facility 2	New York, NY	1,000,000
Facility 3	Munich, Germany	2,500,000
Facility 4	Tokyo, Japan	4,000,000
Facility 5	Lima, Peru	5,000,000

Source: WRI and WSP.

Step 3. Determine water use factors

Organizations should use the most appropriate, accurate, precise, and highest-quality water use factors available. The availability of water use factors is currently much more limited than the availability of GHG emission factors. The recommendations in this guidance make provisions for this situation. As more factors become available, the accounting approaches can be applied more completely.

Factors are provided for water withdrawal and water consumption, both of which are commonly quantified and reported in water accounting. Understanding both water withdrawal and consumption is critical to evaluate water risks properly. Measurements of water withdrawal indicate the level of competition and dependence on water resources. Water consumption estimates help to quantify the impact of water withdrawals on downstream availabilities and are essential to evaluate water shortage and scarcity (Gleeson 2017).

Embedded water use is calculated with grid-average water use factors representing all electricity production occurring in a defined grid distribution region or geographical area (Table 2). Organizations should use regional or subnational grid-average factors (Appendix 1) when available; if they are not available, organizations can use national grid-average factors (Appendix 2).

Factors include only the water use that is specifically used during electricity generation. They exclude other upstream water uses related to electricity generation, such as the extraction and processing of fuels.

Step 4. Calculate water use

To calculate embedded water withdrawals or consumption for a specific facility, organizations should multiply the activity data (e.g., MWh or kWh of purchased electricity) of each facility by the water withdrawal or consumption factor. Table 3 provides examples.

Scope 2 water withdrawals = $\sum$ (activity data × water withdrawal factor)

Scope 2 water consumption = $\sum$ (activity data × water consumption factor)

To report total embedded water withdrawals, water consumption, or both, an organization can summarize embedded water use from all facilities within the organizational boundaries. This process should be planned carefully to minimize the reporting burden, reduce the risk of errors, and ensure all facilities are collecting information on an approved, consistent, and comparable basis. Organizations have an opportunity to achieve this by integrating embedded water use accounting with existing reporting processes, such as that for GHG emissions, and take advantage of any relevant data already collected and reported.

Recommended Disclosures

The GHG Protocol *A Corporate Accounting and Reporting Standard* recommends that companies make a number of disclosures (WRI and WBCSD 2014):

- **Total annual embedded water withdrawals.** Companies should report total embedded water withdrawals in purchased electricity.
- **Total annual embedded water consumption.** Companies should report total embedded water consumption in purchased electricity.
- **Total annual embedded water withdrawals from areas with high water stress** (Box 4). When possible, companies should report total embedded water withdrawals in purchased electricity from areas with high water stress.
- **Total annual embedded water consumption from areas with high water stress** (Box 4). When possible, companies should report total embedded water consumption in purchased electricity from areas with high water stress.
- **Embedded water withdrawals and consumption disaggregated by country.** This can improve transparency.
- **Avoided water withdrawals and consumption estimation.** Companies may separately report an estimation of water withdrawals and consumption avoided from a project or action. This quantification should be based on project-level accounting, with methodologies and assumptions documented (documentation of what the reduction is being compared with). See *The GHG Protocol for Project Accounting* (WRI and WBCSD 2005) and *Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects* (WRI 2007) for examples of methodologies.
- **Embedded water use calculated by other methods.** If companies are subject to mandatory corporate reporting requirements for facilities in a region or nation that specify methodologies other than those outlined here, these companies may report these results separately.

WATER USE FACTORS

WRI and WSP developed grid-average water use factors, modeled with the life cycle assessment software GaBi® and the life cycle inventory databases available in the software produced by thinkstep AG (thinkstep AG 2018a).

Table 2 | **Examples of Water Use Factors**

ACTIVITY DATA				WATER USE FACTORS	
FACILITY	LOCATION	QUANTITY OF ELECTRICITY (KWH)	GRID REGION	WATER WITHDRAWAL FACTOR (GAL/KWH)	WATER CONSUMPTION FACTOR (GAL/KWH)
Facility 1	San Francisco, CA	500,000	CAMX (WECC California)	213	1.37
Facility 2	New York, NY	1,000,000	NYCW (NPCC NYC/ Westchester)	18	0.49
Facility 3	Munich, Germany	2,500,000	Germany	375	0.51
Facility 4	Tokyo, Japan	4,000,000	Japan	490	0.61
Facility 5	São Paulo, Brazil	5,000,000	Brazil	236	4.91

Source: WRI and WSP.

These factors include the following:

- Subnational grid-average water use factors: for subregions of the U.S. electricity grid, as defined by the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID) (U.S. EPA 2018). See Figure 2, Figure 3, and Appendix 1.
- National grid-average water use factors for a select number of countries. See Figure 4, Figure 5, and Appendix 2.

Factors include only the water use that is specifically associated with electricity generation. They exclude other upstream water uses related to electricity generation, such as from the extraction and processing of fuels.

Data Sources and Method

Modeling was conducted using the GaBi® modeling software program, version 8.6.0.20, with the use of the life cycle inventory extension database II: Energy 2018 (thinkstep AG 2018b). Specifically, the direct electricity grid mix processes available in this database were used to model the water withdrawn and consumed in the generation of electricity at the country and U.S. eGRID regional level.

Water footprinting or life cycle assessments often report consumption of blue water, which is water sourced only from surface water and groundwater and excludes seawater. In this guidance, however, the water withdrawal and consumption factors represent total water from all sources, including seawater. This approach most comprehensively quantifies the water use during electricity generation and is in alignment with the Global Reporting Initiative (GRI) 303: Water and Effluent standard. Seawater's impact on the factors is insignificant.

The database develops these factors on the basis of water use for each electricity-generating technology (Appendices 3 and 4), and the mix of generating technologies operating in each country or region (Appendices 5 and 6), including the import of electricity from adjacent countries or regions. The mix of generating technologies will change over time, and therefore it is envisioned that factors will also be updated in the future to reflect those changes.

The GaBi® electricity generation models consider two cooling technologies for thermal power plants: once-through cooling and recirculation cooling (with a cooling tower). Country-specific mixes of these two technologies are used in the models where data are available. For the United States and all subregions, 68 percent of thermal plants are modeled as recirculation cooling and 32 percent as once-through cooling (Kenny et al. 2009). The main data sources for power plant cooling technologies for other countries is the WaterGAP model (Alcamo et al. 2013). For a description of uncertainty in the GaBi® data, please refer to the GaBi® modeling principles (Kupfer et al. 2017).

Table 3 | **Examples of Embedded Water Calculations**

ACTIVITY DATA				WATER USE FACTORS		CALCULATED EMBEDDED WATER USE	
FACILITY	LOCATION	QUANTITY OF ELECTRICITY (KWH)	GRID REGION	WATER WITHDRAWAL FACTOR (GAL/KWH)	WATER CONSUMPTION FACTOR (GAL/KWH)	EMBEDDED WATER WITHDRAWALS (U.S. GALLONS)	EMBEDDED WATER CONSUMPTION (U.S. GALLONS)
Facility 1	San Francisco, CA	500,000	CAMX (WECC California)	213	1.37	106.5 million	685,000
Facility 2	New York, NY	1,000,000	NYCW (NPCC NYC/Westchester)	18	0.49	18 million	490,000
Facility 3	Munich, Germany	2,500,000	Germany	375	0.51	937.5 million	1.275 million
Facility 4	Tokyo, Japan	4,000,000	Japan	490	0.61	1 billion	1.2 million
Facility 5	São Paulo, Brazil	5,000,000	Brazil	236	4.91	1.18 billion	24.55 million
TOTAL						**4.202 billion**	**29.44 million**

Source: WRI and WSP.

The water withdrawal factors are significantly greater than the consumption factors. This is caused by the nature of water use by common electricity generation technologies, such as the following:

- **Hydropower:** Water withdrawals are calculated by using the sum of the water that is needed for turbine operation of the hydropower plant, and water consumption is determined on the basis of evaporative losses from the reservoir. Studies have demonstrated that an average of 1.5 cubic meters (m^3) (400 gallons) of water can be lost to evaporation per gigajoule (GJ) of electricity produced, but this water loss can range from 0.01 to 53 m^3 (3 to 14,000 gallons) of water per GJ of electricity (Mekonnen and Hoekstra 2012), although this depends on how the hydropower dam is managed (Lampert et al. 2015). Even though hydropower water withdrawal and consumption intensities are usually orders of magnitude larger than other types and likely to skew overall regional averages, it is important to include hydropower in the factors to show not only the power sector's dependency on water but also its vulnerability to water shortages. Droughts have been crippling hydropower production and raising power prices all around the world, from Brazil (Goy 2015) to Norway (Karagiannopoulos 2018) and the Balkans (Zuvela 2017) to India (Ved 2019).
- **Thermoelectric power generation:** It commonly uses once-through cooling systems, in which water is withdrawn from a water source, passed through a power plant's cooling system once, and returned to the water source, resulting in a high rate of withdrawal but a low rate of consumption. Thermal electricity generation, using fuels such as coal, natural gas, or nuclear, uses water to produce steam to move turbines and to provide cooling. Water use for these technologies is far lower than that of traditional hydropower.
- **Solar PV and wind:** These technologies use no water to generate power; their water use factors are zero.

Box 4 | **Defining Water Stress**

Water stress measures the level of competition for available water and estimates the degree to which freshwater availability is an ongoing concern.

Exposure to water stress can be determined using the baseline water stress indicator available in the Aqueduct Water Risk Atlas (https://www.wri.org/aqueduct).

Baseline water stress and similar withdrawal-to-availability indicators are widely used in scientific and policy literature to identify regions experiencing water stress. Baseline water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and nonconsumptive uses. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users. Metadata and methodology are available here: https://www.wri.org/publication/aqueduct-30.

The baseline water stress indicator is widely used and recommended in disclosure, management, and reporting standards, including the following:

- Alliance for Water Stewardship Standard Guidance Version 2.0 (Alliance for Water Stewardship 2019)
- CDP General Water Questionnaire (CDP 2019)
- Financial Stability Board Task Force on Climate-Related Financial Disclosures (Task Force on Climate-Related Financial Disclosures 2017)
- GRI 303: Water and Effluents (GRI 2019)
- Sustainability Accounting Standards Board (Sustainability Accounting Standards Board 2019)

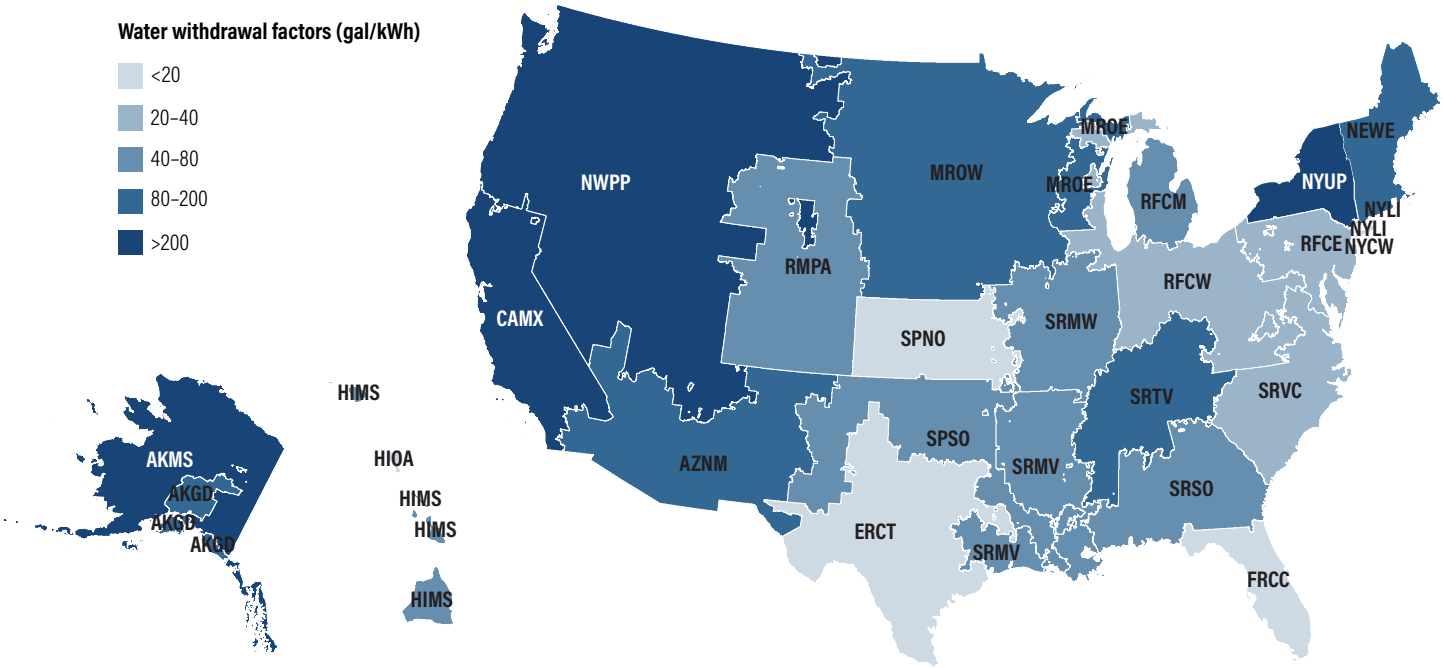
Source: WRI.

Limitations

Limitations of the embedded water use factors include the following:

- Water use factors are estimated on the basis of geographical averages and not on the basis of data reported from individual power plants.
- The data currently available in the GaBi® databases do not include air-cooling technology because of its limited implementation. Updates to the GaBi® databases will consider including air-cooling technology.
- There are sources of uncertainty associated with the characterization of hydropower because of different methodological assumptions in calculated results. The approach here is conservative, in that it assigns 100 percent of water consumption from evaporated losses to electricity generation, in alignment with other assessments of water consumed for hydropower (Grubet and Sanders 2018), despite the following:
  - Reservoirs can be used for more than just electricity generation; for example, for flood control, irrigation, or recreation.

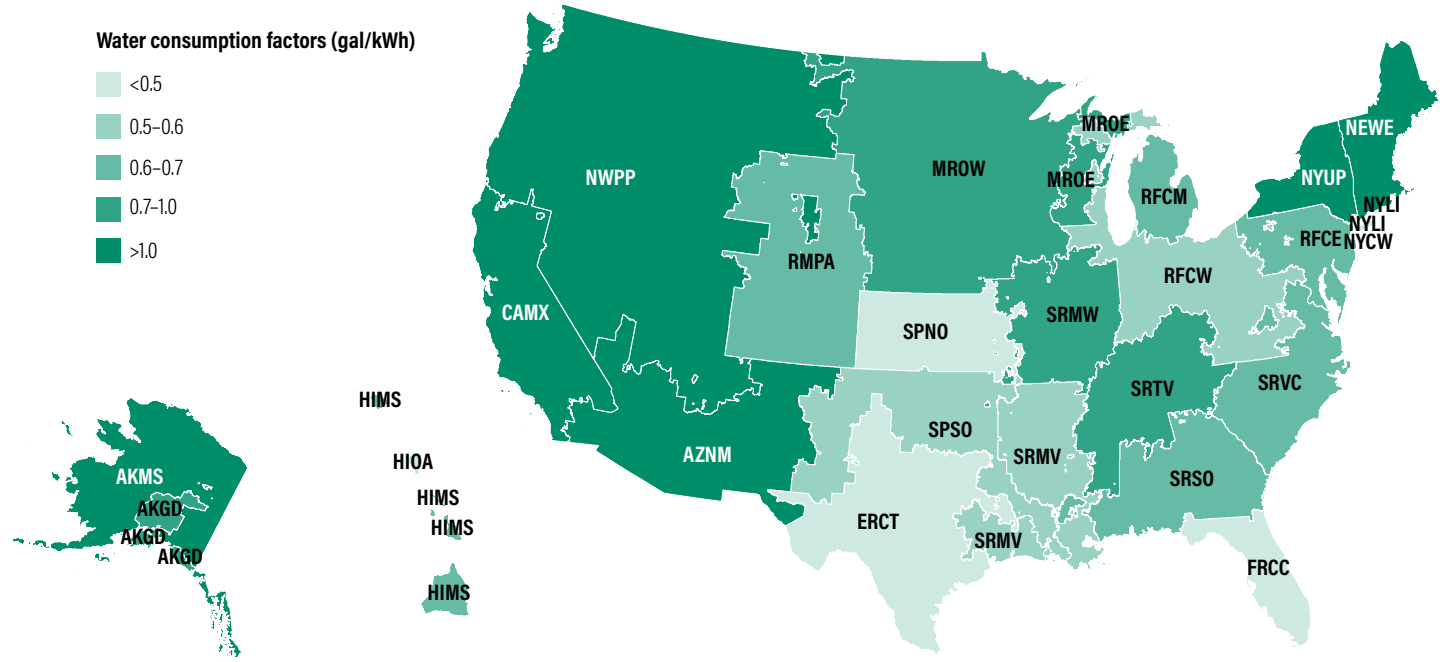
Figure 2 | U.S. Subnational Grid-Average Water Withdrawal Factors



Note: Appendix 1 includes the acronyms explained

Source: Based on raw data from thinkstep AG 2018a, aggregated by WRI and WSP.

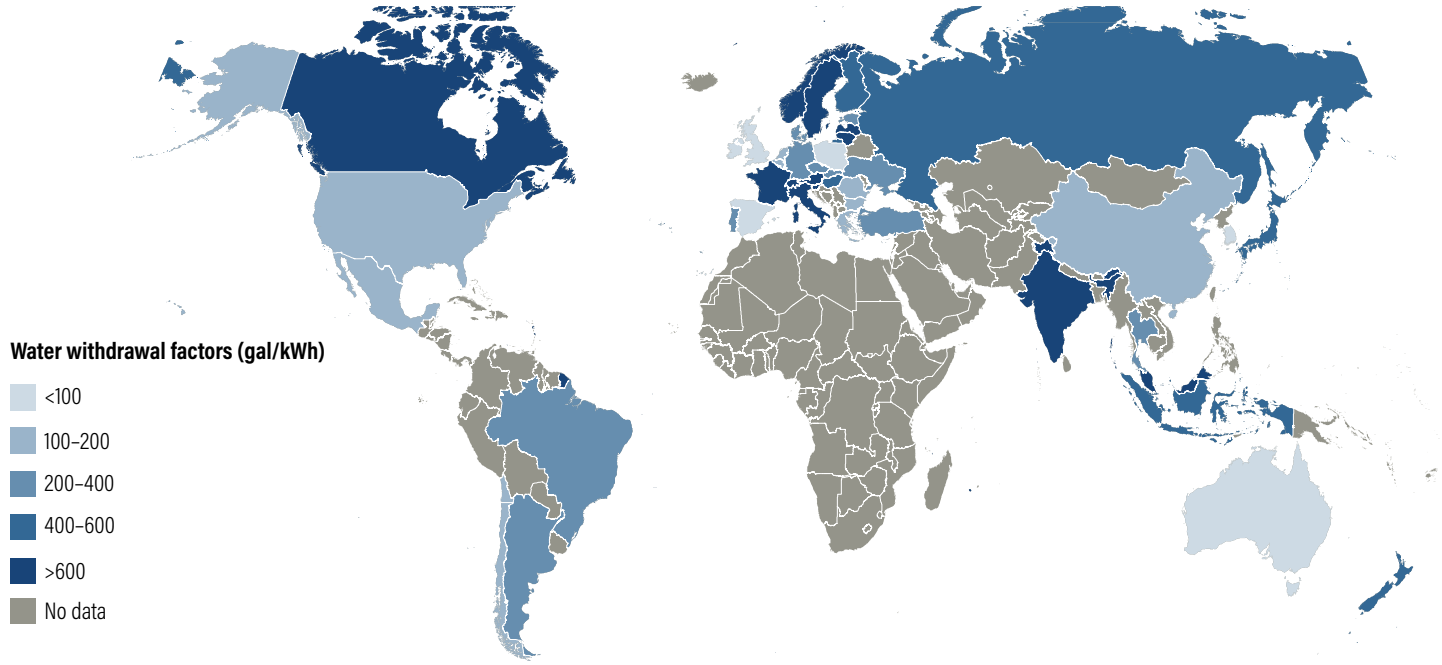
Figure 3 | U.S. Subnational Grid-Average Water Consumption Factors



Note: Appendix 1 includes the acronyms explained

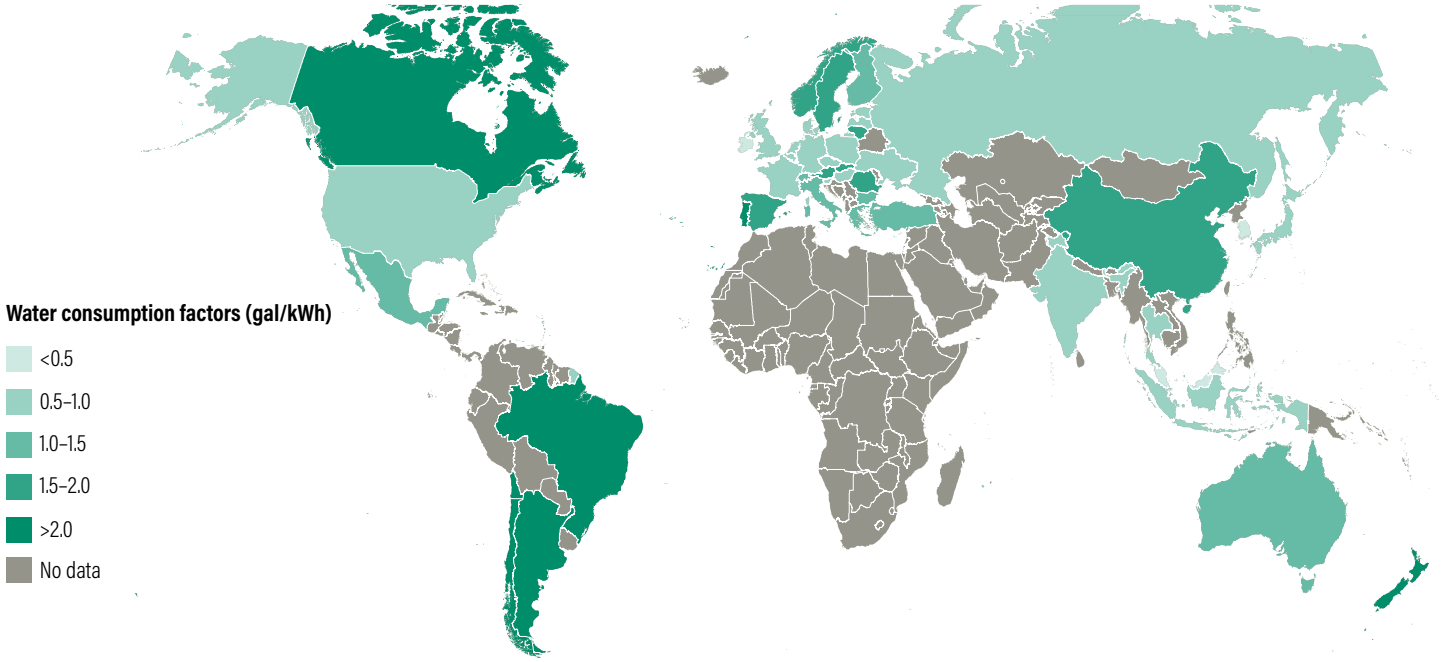
Source: Based on raw data from thinkstep AG 2018a, aggregated by WRI and WSP.

Figure 4 | National Grid-Average Water Withdrawal Factors



Source: Based on raw data from thinkstep AG 2018a, aggregated by WRI and WSP.

Figure 5 | Map of National Grid-Average Water Consumption Factors



Source: Based on raw data from thinkstep AG 2018a, aggregated by WRI and WSP.

- Water consumption from evaporated losses of hydropower is sensitive to how a hydropower plant is managed, as has been documented in some cases where the more electricity a hydropower plant generates, the less-water-intensive it is (Lampert et al. 2015).

- Water used in maintenance of renewable power, including washing solar panels, was not included in the system boundary.

Results

On the basis of data available in the GaBi® databases, WRI and WSP calculated water withdrawal and consumption factors for all U.S. eGRID regions (Figure 2; Figure 3; Appendix 1) and 47 countries (Figure 4; Figure 5; Appendix 2). For countries included in the analysis, weighted by total electricity generation (Appendix 7), the global average water withdrawal factor is 315 gallons per kilowatt hour (gal/kWh), and the average consumption factor is 1.27 gal/kWh, as shown in Table 4. The results indicate high variability in average water consumption, from 4.91 U.S. gal/kWh in Brazil to 0.3 in Malta, and in average water withdrawal, from 3,912 U.S. gal/kWh in Slovenia to 15 in Cyprus, strengthening the call to action for organizations to assess and respond to water risks associated with their purchased electricity. (The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per U.S. gallon.) For example, country average hydropower water withdrawal factors range from 46 to 9,946 gal/kWh, and average thermoelectric power withdrawal factors vary between 1 and 59 gal/kWh (Appendix 3).

Table 4 | **Summary Statistics of Country-Level Power Generation Water Use Intensity (gal/kWh)**

	GLOBAL AVERAGE WATER USE (WEIGHTED BY GENERATION)	GLOBAL MAXIMUM USE	GLOBAL MINIMUM USE
Withdrawal	315	3,910	15
Consumption	1.27	4.91	0.30

Source: Based on data from thinkstep AG 2018a, aggregated by WRI and WSP.

The five countries with the lowest water withdrawal factors (i.e., the lowest dependence on water to produce electricity) are Cyprus, Malta, Australia, the United Kingdom, and Ireland, mostly because of limited use of hydropower. Cyprus and Malta do not rely on hydropower and obtain 90 percent of their power from fossil fuel generation. In Australia, the United Kingdom, and Ireland, less than 10 percent of generation comes from hydropower. The five countries with the lowest water consumption factors (i.e., the lowest impact on water availability) are Malta, Cyprus, Ireland, Malaysia, and South Korea, also mostly driven by limited use of hydropower. Furthermore, Ireland and Malaysia do not rely on nuclear or lignite power generation and on only small amounts of biomass power production. Nuclear, lignite, and biomass are some of the most water-intensive fuel types.

Of the countries assessed, 36 out of 48 (75 percent) are high-income countries according to the World Bank's 2018 income classification (World Bank 2019). The remaining 25 percent include nine upper-middle-income and three lower-middle-income countries. High-income countries have an average water withdrawal factor of 665 gal/kWh, more than twice as much as upper- and lower-middle-income countries, mostly because of higher reliance on hydropower generation. On the other hand, water consumption factors do not vary significantly between high- and middle-income countries, most likely because high-income countries have relatively high reliance on hydropower but less production of hard coal and lignite power compared with middle-income countries.

Almost all countries facing high levels of water stress have relatively low water consumption factors, except Spain, where hydropower and nuclear power production account for roughly 36 percent of the country's total generation. On the other hand, countries such as Brazil, New Zealand, and Luxembourg, with low levels of water stress, have the highest water consumption factors, with electricity production mostly driven by hydropower. This guidance lays out a method for calculating the water impacts associated with electricity use and could serve as a first-step screening tool for understanding the dependence of power on water and the associated potential risk exposures. Future iterations of this guidance could integrate water stress indicators to better understand these risks.

CONCLUSION

As global demand for water increases because of multiple competing uses, it is important that organizations consider the water embedded in electricity generation. Previously, systematic guidance and a set of factors for quantifying water required for an organization's electricity use were not available. It is hoped that this guidance allows a more comprehensive understanding of an organization's water impacts to inform decision-making.

Further study is recommended, as is production of a journal article or white paper that relies on such explorations and on comparison of the GHG emissions from different electricity generation technologies in the same countries and regions to illuminate tradeoffs between different environmental impacts from electricity generation technologies. This could include an analysis of the multiple uses for hydropower dams and exploration of the allocation of water withdrawal and consumptive burdens to these multiple uses.

APPENDICES

Appendix 1. U.S. Subnational Grid-Average Water Use Factors (gal/kWh)

U.S. EGRID SUBREGION	WATER WITHDRAWAL FACTOR	WATER CONSUMPTION FACTOR
AKGD (ASCC Alaska Grid)	150	0.90
AKMS (ASCC Miscellaneous)	824	4.06
AZNM (WECC Southwest)	184	1.31
CAMX (WECC California)	213	1.37
ERCT (ERCOT All)	9	0.34
FRCC (FRCC All)	12	0.39
HIMS (HICC Miscellaneous)	51	0.63
HIOA (HICC Oahu)	9	0.38
MROE (MRO East)	85	0.81
MROW (MRO West)	87	0.82
NEWE (NPCC New England)	200	1.09
NWPP (WECC Northwest)	474	2.51
NYCW (NPCC NYC/Westchester)	18	0.49
NYLI (NPCC Long Island)	16	0.43
NYUP (NPCC Upstate NY)	392	2.14
RFCE (RFC East)	37	0.61
RFCM (RFC Michigan)	44	0.66
RFCW (RFC West)	31	0.59
RMPA (WECC Rockies)	64	0.68
SPNO (SPP North)	13	0.46
SPSO (SPP South)	41	0.54
SRMV (SERC Mississippi Valley)	48	0.59
SRMW (SERC Midwest)	44	0.71
SRSO (SERC South)	46	0.61
SRTV (SERC Tennessee Valley)	104	0.96
SRVC (SERC Virginia/Carolina)	39	0.63

Note: The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per gallon.

Source: thinkstep AG 2018a.

Appendix 2. National Grid-Average Water Use Factors (gal/kWh)

COUNTRY	WATER WITHDRAWAL FACTOR	WATER CONSUMPTION FACTOR
Argentina	341	3.03
Australia	41	1.25
Austria	3,737	1.51
Belgium	164	0.69
Brazil	236	4.91
Bulgaria	100	1.22
Canada	753	2.16
Chile	121	2.78
China	160	1.59
Cyprus	15	0.34
Czech Republic	209	0.85
Denmark	363	0.84
Estonia	202	0.58
Finland	571	1.20
France	651	0.97
Germany	375	0.51
Great Britain	44	0.62
Greece	137	1.36
Hungary	403	0.97
India	627	0.91
Indonesia	424	0.60
Ireland	56	0.39
Italy	931	1.28
Japan	490	0.61
Latvia	1,988	0.67
Lithuania	806	1.56
Luxembourg	368	3.38
Malaysia	653	0.44
Malta	23	0.30
Mexico	124	1.40

Appendix 2. National Grid-Average Water Use Factors (gal/kWh) (Cont'd)

COUNTRY	WATER WITHDRAWAL FACTOR	WATER CONSUMPTION FACTOR
Netherlands	184	0.91
New Zealand	460	3.95
Norway	2,189	1.76
Poland	57	0.66
Portugal	389	2.53
Romania	120	1.94
Russia	546	0.91
Slovakia	273	1.53
Slovenia	3,912	0.79
South Korea	68	0.50
Spain	78	1.64
Sweden	998	1.59
Switzerland	2,201	1.50
Thailand	220	0.76
Turkey	363	1.30
Ukraine	249	0.56
United States	102	0.83

Notes: The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per U.S. gallon.
See Appendix 6 to review the underlying mix of electricity-generating technologies per country.

Source: thinkstep AG 2018a.

Appendix 3. Water Withdrawal Factors by Country and Electricity-Generating Technology (gal/kWh)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Argentina	X	X	X	X	X	30	1,114
Australia	2	3	3	X	3	3	520
Austria	23	13	21	X	13	9	7,100
Belgium	5	14	15	X	17	6	2,613
Brazil	27	17	23	X	23	24	348
Bulgaria	22	13	X	X	16	6	640
Canada	29	31	X	X	30	29	1,287
Chile	X	7	X	X	23	22	345
China	X	10	8	X	5	6	824
Cyprus	3	X	X	X	X	16	X
Czech Republic	2	2	2	X	2	3	5,685
Denmark	0	0	X	X	1	1	9,715
Estonia	11	7	X	X	32	32	9,715
Finland	1	1	3	X	1	1	2,238
France	8	13	11	X	9	3	5,074
Germany	8	14	11	2	11	10	7,200
Great Britain	7	7	10	X	5	9	215
Greece	1	X	X	X	1	1	303
Hungary	33	42	38	X	8	26	9,946
India	13	18	13	X	9	10	6,071
Indonesia	69	56	X	2	28	26	6,021
Ireland	4	4	X	X	3	4	1,415
Italy	8	14	11	2	10	9	3,418
Japan	X	1	1	2	1	1	5,810
Latvia	2	3	X	X	2	1	9,919
Lithuania	12	8	X	X	X	10	152
Luxembourg	5	4	X	X	X	X	43
Malaysia	44	44	X	X	26	17	6,934
Malta	34	X	X	X	X	24	X
Mexico	X	X	X	X	X	30	818
Netherlands	7	19	16	X	15	10	9,715
New Zealand	23	21	26	2	19	22	816
Norway	26	37	29	X	29	29	2,306
Poland	7	11	18	X	10	5	185

Appendix 3. Water Withdrawal Factors by Country and Electricity-Generating Technology (gal/kWh) (Cont'd)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
X	19	39	X	0	X	X	0
5	3	X	X	0	X	X	0
X	3	X	X	0	X	23	0
X	5	30	X	0	X	23	0
36	20	39	X	0	X	X	0
25	3	31	X	0	X	X	0
31	20	45	X	0	X	5	0
X	15	X	X	0	X	X	0
X	3	8	X	0	X	23	0
X	X	X	X	0	X	X	0
3	1	4	X	0	X	23	0
X	0	X	X	0	X	23	0
45	13	X	4	0	X	23	0
X	0	3	1	0	X	23	0
X	3	14	X	0	X	23	0
12	4	20	X	0	X	X	0
X	3	9	X	0	X	23	0
1	1	X	X	0	X	23	0
37	8	46	X	0	X	23	0
9	7	11	X	0	X	23	0
25	21	X	X	0	X	23	0
X	2	X	4	0	X	23	0
11	4	X	X	0	X	23	0
X	1	1	X	0	X	37	0
X	1	X	X	0	X	X	0
X	7	44	2	0	X	23	0
X	11	X	X	0	X	23	0
X	25	X	X	0	X	23	0
X	X	X	X	0	X	X	0
X	18	39	X	0	X	X	0
X	4	27	X	0	X	23	0
22	12	X	X	0	X	X	0
X	12	X	X	0	X	23	0
14	5	X	X	0	X	23	0

Appendix 3. Water Withdrawal Factors by Country and Electricity-Generating Technology (gal/kWh) (Cont'd)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Portugal	19	30	X	2	14	10	1,345
Romania	15	10	21	X	11	9	346
Russia	X	7	8	2	7	10	3,209
Slovakia	12	19	6	X	15	8	1,839
Slovenia	3	3	X	X	3	16	9,846
South Korea	8	X	X	X	X	X	3,936
Spain	13	14	11	X	13	10	309
Sweden	0	0	0	X	0	0	2,209
Switzerland	13	14	X	X	X	6	4,561
Thailand	X	X	X	X	X	X	6,010
Turkey	5	10	15	2	7	8	2,265
Ukraine	X	X	X	X	X	X	4,171
United States	14	13	8	2	12	9	1,264

Notes: X means not available. The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per U.S. gallon.
When read as a PDF, we recommend our readers turn on the "Two Page View" and "Show Cover Page in Two Page View" options.

Source: thinkstep AG 2018a.

Appendix 4. Water Consumption Factors by Country and Electricity-Generating Technology (gal/kWh)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Argentina	X	X	X	X	X	0.26	8.22
Australia	0.47	0.55	0.58	X	0.55	0.56	9.62
Austria	0.37	0.26	0.35	X	0.24	0.16	1.02
Belgium	0.10	0.36	0.32	X	0.39	0.12	3.15
Brazil	0.24	0.27	0.28	X	0.30	0.29	7.22
Bulgaria	0.41	0.29	X	X	0.33	0.12	6.48
Canada	0.24	0.36	X	X	0.27	0.24	3.53
Chile	X	0.11	X	X	0.28	0.25	8.35
China	X	1.10	0.80	X	0.56	0.63	6.05
Cyprus	0.06	X	X	X	X	0.37	X
Czech Republic	0.35	0.42	0.46	X	0.44	0.56	2.20
Denmark	0.14	0.06	X	X	0.26	0.44	0.00
Estonia	0.07	0.09	X	X	0.22	0.20	0.00
Finland	0.29	0.14	0.78	X	0.26	0.32	2.94
France	0.41	0.70	0.57	X	0.45	0.13	3.34
Germany	0.26	0.52	0.39	1.89	0.39	0.33	1.17

Appendix 3. Water Withdrawal Factors by Country and Electricity-Generating Technology (gal/kWh) (Cont'd)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
X	5	X	X	0	X	23	0
12	4	18	X	0	X	X	0
8	7	17	6	0	X	35	0
21	3	26	X	0	X	23	0
10	1	12	X	0	X	23	0
X	3	12	X	0	X	X	0
13	5	19	X	0	0	23	0
X	0	2	0	0	X	23	0
X	1	17	X	0	X	23	0
X	X	X	X	0	X	X	0
10	3	X	X	0	X	23	0
X	X	X	X	0	X	X	0
12	5	17	X	0	0	5	0

Appendix 4. Water Consumption Factors by Country and Electricity-Generating Technology (gal/kWh)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
X	0.17	0.45	X	0.00	X	X	0.00
0.94	0.49	X	X	0.00	X	X	0.00
X	0.05	X	X	0.00	X	1.70	0.00
X	0.11	0.50	X	0.00	X	1.70	0.00
0.47	0.25	0.45	X	0.00	X	X	0.00
0.48	0.06	0.52	X	0.00	X	X	0.00
0.29	0.16	0.36	X	0.00	X	1.51	0.00
X	0.16	X	X	0.00	X	X	0.00
X	0.36	0.72	X	0.00	X	1.88	0.00
X	X	X	X	0.00	X	X	0.00
0.57	0.26	0.74	X	0.00	X	1.70	0.00
X	0.08	X	X	0.00	X	1.70	0.00
0.31	0.08	X	0.05	0.00	X	1.70	0.00
X	0.01	0.74	0.24	0.00	X	1.70	0.00
X	0.16	0.64	X	0.00	X	1.70	0.00
0.44	0.14	0.60	X	0.00	X	X	0.00

Appendix 4. Water Consumption Factors by Country and Electricity-Generating Technology (gal/kWh) (Cont'd)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Great Britain	0.60	0.63	0.88	X	0.50	0.81	4.51
Greece	0.72	X	X	X	0.59	0.68	8.38
Hungary	0.26	0.46	0.30	X	0.10	0.21	0.00
India	0.99	1.41	0.99	X	0.66	0.76	3.10
Indonesia	0.42	1.01	X	1.89	0.45	0.38	1.89
Ireland	0.55	0.54	X	X	0.45	0.51	2.11
Italy	0.34	0.67	0.48	1.89	0.47	0.40	4.45
Japan	X	0.54	0.45	1.89	0.46	0.42	2.55
Latvia	0.17	0.38	X	X	0.28	0.16	0.00
Lithuania	0.11	0.12	X	X	X	0.09	4.40
Luxembourg	0.03	0.12	X	X	X	X	4.38
Malaysia	0.58	0.71	X	X	0.37	0.23	1.41
Malta	0.21	X	X	X	X	0.31	X
Mexico	X	X	X	X	X	0.34	8.95
Netherlands	0.14	0.46	0.34	X	0.33	0.22	0.00
New Zealand	0.47	0.51	0.53	1.89	0.41	0.46	6.39
Norway	0.16	0.34	0.18	X	0.21	0.18	1.79
Poland	0.21	0.41	0.57	X	0.35	0.16	5.14
Portugal	0.54	0.97	X	1.89	0.43	0.30	7.63
Romania	0.09	0.43	0.82	X	0.45	0.36	5.83
Russia	X	0.31	0.33	1.89	0.29	0.41	3.62
Slovakia	0.27	0.51	0.13	X	0.38	0.18	4.17
Slovenia	0.21	0.22	X	X	0.22	0.95	0.00
South Korea	0.49	X	X	X	X	X	2.68
Spain	0.46	0.57	0.39	X	0.47	0.34	8.53
Sweden	0.12	0.11	0.06	X	0.09	0.06	2.86
Switzerland	0.49	0.61	X	X	X	0.21	1.39
Thailand	X	X	X	X	X	X	2.75
Turkey	0.32	0.66	0.90	1.89	0.48	0.47	6.20
Ukraine	X	X	X	X	X	X	4.18
United States	0.55	0.58	0.33	1.89	0.48	0.36	5.99

Notes: X means not available. The recommended conversion factor to convert U.S. gallons to liters is 3.785 liters per U.S. gallon.
When read as a PDF, we recommend our readers turn on the "Two Page View" and "Show Cover Page in Two Page View" options.
Source: thinkstep AG 2018a.

Appendix 4. Water Consumption Factors by Country and Electricity-Generating Technology (gal/kWh) (Cont'd)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
X	0.28	0.73	X	0.00	X	1.70	0.00
0.67	0.43	X	X	0.00	X	1.70	0.00
0.32	0.07	0.35	X	0.00	X	1.70	0.00
0.67	0.48	0.69	X	0.00	X	1.88	0.00
0.40	0.32	X	X	0.00	X	1.88	0.00
X	0.25	X	0.54	0.00	X	1.70	0.00
0.48	0.19	X	X	0.00	X	1.70	0.00
X	0.38	0.78	X	0.00	X	2.87	0.00
X	0.06	X	X	0.00	X	X	0.00
X	0.06	0.39	0.40	0.00	X	1.70	0.00
X	0.07	X	X	0.00	X	1.70	0.00
X	0.33	X	X	0.00	X	1.88	0.00
X	X	X	X	0.00	X	X	0.00
X	0.20	0.41	X	0.00	X	X	0.00
X	0.09	0.53	X	0.00	X	1.70	0.00
0.48	0.24	X	X	0.00	X	X	0.00
X	0.08	X	X	0.00	X	1.70	0.00
0.47	0.15	X	X	0.00	X	1.70	0.00
X	0.13	X	X	0.00	X	1.70	0.00
0.47	0.13	0.63	X	0.00	X	X	0.00
0.36	0.27	0.63	0.25	0.00	X	2.48	0.00
0.51	0.08	0.55	X	0.00	X	1.70	0.00
0.60	0.06	0.66	X	0.00	X	1.70	0.00
X	0.16	0.66	X	0.00	X	X	0.00
0.47	0.18	0.59	X	0.00	0.00	1.70	0.00
X	0.00	0.75	0.09	0.00	X	1.70	0.00
X	0.04	0.61	X	0.00	X	1.70	0.00
X	X	X	X	0.00	X	X	0.00
0.62	0.21	X	X	0.00	X	1.70	0.00
X	X	X	X	0.00	X	X	0.00
0.50	0.21	0.61	X	0.00	0.00	1.51	0.00

Appendix 5. U.S. Subnational Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source)

U.S. EGRID SUBREGION	COAL	OIL	GAS	ANOTHER FOSSIL	NUCLEAR	HYDRO	BIOMASS	WIND	SOLAR	GEO-THERMAL	OTHER UNKNOWN/ PURCHASED FUEL
AKGD (ASCC Alaska Grid)	12.6	9.2	61.9	0.0	0.0	12.6	0.9	2.9	0.0	0.0	0.0
AKMS (ASCC Miscellaneous)	0.0	24.6	7.9	0.0	0.0	65.4	0.0	2.1	0.0	0.0	0.0
AZNM (WECC Southwest)	29.5	0.1	39.8	0.0	19.5	3.5	0.4	1.2	2.8	3.2	0.0
CAMX (WECC California)	4.3	0.1	48.4	0.7	9.4	12.1	2.9	7.0	10.6	4.1	0.2
ERCT (ERCOT All)	25.9	0.0	48.2	0.5	10.8	0.3	0.3	13.7	0.2	0.0	0.2
FRCC (FRCC All)	16.0	1.2	66.6	0.0	12.8	0.1	2.4	0.0	0.1	0.0	0.7
HIMS (HICC Miscellaneous)	0.2	61.7	0.0	0.0	0.0	3.3	4.3	14.8	2.1	9.5	4.1
HIOA (HICC Oahu)	20.7	68.7	0.0	0.9	0.0	0.0	6.1	3.2	0.4	0.0	0.0
MROE (MRO East)	64.5	0.6	20.5	0.1	0.0	6.8	5.3	2.0	0.0	0.0	0.1
MROW (MRO West)	52.7	0.2	6.7	0.0	12.8	5.0	1.3	21.1	0.0	0.0	0.2
NEWE (NPCC New England)	2.4	0.6	49.8	0.1	30.4	5.3	8.2	2.5	0.7	0.0	0.1
NWPP (WECC Northwest)	22.5	0.2	15.3	0.3	3.4	47.2	1.3	8.6	0.5	0.7	0.1
NYCW (NPCC NYC/ Westchester)	0.0	0.4	64.6	0.0	34.1	0.0	0.9	0.0	0.0	0.0	0.0
NYLI (NPCC Long Island)	0.0	2.7	88.5	0.0	0.0	0.0	8.0	0.0	0.8	0.0	0.0
NYUP (NPCC Upstate NY)	2.1	0.2	27.7	0.0	31.4	31.6	2.1	4.7	0.1	0.0	0.0
RFCE (RFC East)	17.6	0.2	38.0	0.2	39.7	0.9	1.9	1.0	0.4	0.0	0.0
RFCM (RFC Michigan)	41.5	0.9	31.4	1.9	17.5	0.0	2.0	4.8	0.0	0.0	0.0
RFCW (RFC West)	49.8	0.4	16.7	0.7	27.6	0.9	0.6	3.2	0.1	0.0	0.1

Appendix 5. U.S. Subnational Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source) (Cont'd)

U.S. EGRID SUBREGION	COAL	OIL	GAS	ANOTHER FOSSIL	NUCLEAR	HYDRO	BIOMASS	WIND	SOLAR	GEO-THERMAL	OTHER UNKNOWN/ PURCHASED FUEL
RMPA (WECC Rockies)	51.3	0.0	20.2	0.0	0.0	12.1	0.3	15.1	0.8	0.0	0.1
SPNO (SPP North)	57.9	0.1	9.5	0.0	12.4	0.3	0.1	19.8	0.0	0.0	0.0
SPSO (SPP South)	34.8	1.9	40.7	0.2	0.0	3.6	1.5	17.1	0.1	0.0	0.1
SRMV (SERC Mississippi Valley)	14.0	1.1	58.7	1.4	21.2	1.4	1.8	0.0	0.0	0.0	0.4
SRMW (SERC Midwest)	71.4	0.1	8.3	0.0	15.1	1.2	0.1	3.5	0.0	0.0	0.2
SRSO (SERC South)	28.9	0.1	47.0	0.0	18.2	2.0	3.5	0.0	0.3	0.0	0.0
SRTV (SERC Tennessee Valley)	43.7	0.6	23.4	0.0	25.1	6.4	0.8	0.0	0.1	0.0	0.0
SRVC (SERC Virginia/ Carolina)	24.9	0.2	29.5	0.1	39.6	1.5	2.8	0.2	1.1	0.0	0.1

Source: U.S. EPA 2018.

Appendix 6. National Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Argentina	0.0	2.0	0.3	0.0	2.5	13.8	29.2
Australia	0.7	0.8	0.0	0.0	42.6	2.0	7.4
Austria	0.9	5.3	3.0	0.0	4.5	0.9	68.5
Belgium	1.3	3.6	3.0	0.0	3.1	0.3	2.1
Brazil	0.1	7.7	1.4	0.0	1.8	6.0	63.3
Bulgaria	0.1	0.3	0.0	0.0	4.9	0.4	10.9
Canada	0.2	0.6	0.0	0.0	1.4	1.2	58.5
Chile	0.1	7.2	0.0	0.0	35.4	6.2	31.5
China	0.0	0.8	1.3	0.0	71.1	0.2	18.7
Cyprus	1.2	0.0	0.0	0.0	0.0	92.7	0.0
Czech Republic	3.0	2.3	0.9	0.0	6.0	0.0	3.4
Denmark	1.4	9.2	0.0	0.0	34.4	1.0	0.1
Estonia	0.2	5.9	0.0	0.0	0.1	0.4	0.2
Finland	0.5	16.2	0.7	0.0	11.7	0.4	19.8
France	0.3	0.3	0.4	0.0	1.7	0.3	12.3
Germany	5.0	1.9	1.7	0.0	19.0	0.9	4.1
Great Britain	2.4	4.1	0.3	0.0	29.8	0.5	2.6
Greece	0.4	0.0	0.0	0.0	0.0	11.0	9.1
Hungary	1.0	5.8	0.4	0.0	0.0	0.3	1.0
India	0.1	1.8	0.1	0.0	59.3	1.8	10.2
Indonesia	0.3	0.1	0.0	4.4	0.0	11.3	6.6
Ireland	0.8	1.0	0.0	0.0	15.3	0.7	3.8
Italy	4.5	1.4	1.1	2.1	15.2	5.1	21.6
Japan	0.0	2.8	3.7	0.3	29.8	11.2	8.4
Latvia	6.8	6.2	0.0	0.0	0.0	0.0	38.8
Lithuania	1.9	7.1	0.0	0.0	0.0	3.9	26.2
Luxembourg	2.1	0.7	0.0	0.0	0.0	0.0	39.4
Malaysia	0.0	0.4	0.0	0.0	37.9	2.4	9.1
Malta	3.0	0.3	0.0	0.0	0.0	96.7	0.0
Mexico	0.1	0.4	0.1	2.0	11.1	11.0	12.9
Netherlands	1.0	2.0	2.8	0.0	28.6	1.9	0.1
New Zealand	0.6	0.9	1.4	16.7	3.0	0.0	55.9
Norway	0.0	0.0	0.1	0.0	0.0	0.0	96.2
Poland	0.5	5.8	1.3	0.0	47.9	1.0	1.7
Portugal	0.5	4.8	0.0	0.4	22.6	2.6	31.1
Romania	0.1	0.7	0.1	0.0	0.4	0.7	29.4
Russia	0.0	0.0	0.4	0.0	8.6	1.0	16.7
Slovakia	1.8	3.4	1.8	0.0	3.5	1.1	16.4
Slovenia	0.8	0.7	0.0	0.0	2.3	0.2	36.5
South Korea	0.2	0.1	3.9	0.0	38.2	3.2	1.5

Appendix 6. National Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source) (Cont'd)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
0.0	47.6	4.1	0.0	0.0	0.0	0.0	0.5
18.6	21.9	0.0	0.0	2.0	0.0	0.0	4.1
0.0	8.3	0.0	0.0	1.2	0.0	1.5	5.9
0.0	26.7	46.6	0.0	4.0	0.0	2.9	6.4
1.3	13.7	2.6	0.0	0.0	0.0	0.0	2.1
40.0	4.5	33.4	0.0	2.6	0.0	0.0	2.8
8.5	9.4	16.5	0.0	0.3	0.0	0.0	3.5
0.0	17.0	0.0	0.0	0.7	0.0	0.0	2.0
0.0	2.0	2.3	0.0	0.5	0.0	0.2	2.8
0.0	0.0	0.0	0.0	1.9	0.0	0.0	4.2
41.5	4.2	35.3	0.0	2.5	0.0	0.2	0.6
0.0	6.5	0.0	0.0	1.9	0.0	5.0	40.6
82.8	4.7	0.0	0.4	0.0	0.0	0.6	4.9
0.0	8.1	34.8	5.0	0.0	0.0	1.2	1.6
0.0	2.3	77.6	0.0	1.1	0.0	0.7	3.1
24.9	10.0	15.5	0.0	5.8	0.0	2.2	9.2
0.0	29.7	18.8	0.0	1.2	0.0	1.2	9.5
51.0	13.4	0.0	0.0	7.5	0.0	0.2	7.3
20.4	14.4	53.4	0.0	0.2	0.0	0.9	2.2
15.6	4.9	2.8	0.0	0.4	0.0	0.1	2.9
52.7	24.6	0.0	0.0	0.0	0.0	0.0	0.0
0.0	49.1	0.0	9.4	0.0	0.0	0.5	19.5
0.3	33.5	0.0	0.0	8.0	0.0	1.7	5.4
0.0	40.4	0.0	0.0	2.4	0.0	0.6	0.5
0.0	45.5	0.0	0.0	0.0	0.0	0.0	2.7
0.0	42.1	0.0	0.0	1.8	0.0	1.7	15.4
0.0	48.9	0.0	0.0	3.2	0.0	3.0	2.7
0.0	50.1	0.0	0.0	0.2	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	57.0	3.2	0.0	0.1	0.0	0.0	2.1
0.0	49.9	4.0	0.0	0.8	0.0	3.4	5.6
0.0	16.3	0.0	0.0	0.0	0.0	0.0	5.1
0.0	1.8	0.0	0.0	0.0	0.0	0.3	1.6
33.6	3.4	0.0	0.0	0.0	0.0	0.0	4.4
0.0	12.9	0.0	0.0	1.2	0.0	0.9	22.9
26.6	12.3	17.8	0.0	2.5	0.0	0.0	9.4
5.7	50.1	17.0	0.1	0.0	0.0	0.3	0.0
7.0	5.9	56.8	0.0	2.2	0.0	0.2	0.0
19.3	2.1	36.5	0.0	1.5	0.0	0.0	0.0
0.0	23.7	28.4	0.0	0.5	0.0	0.1	0.2

Appendix 6. National Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source) (Cont'd)

COUNTRY	BIOGAS	BIOMASS	COAL GASES	GEO-THERMAL	HARD COAL	HEAVY FUEL OIL	HYDRO
Spain	0.3	1.4	0.5	0.0	14.7	5.1	15.4
Sweden	0.0	5.9	0.3	0.0	0.2	0.2	41.6
Switzerland	0.4	0.4	0.0	0.0	0.0	0.1	55.3
Thailand	0.3	4.4	0.0	0.0	11.7	1.0	3.2
Turkey	0.4	0.0	0.8	0.9	14.6	0.9	16.2
Ukraine	0.0	0.1	0.5	0.0	38.0	0.1	5.1
United States	0.3	1.1	0.1	0.4	37.3	0.9	6.5

Note: When read as a PDF, we recommend our readers turn on the "Two Page View" and "Show Cover Page in Two Page View" options.
Source: thinkstep AG 2018a.

Appendix 7. National Annual Electricity Generation in 2016 (GWh)

COUNTRY	2016 NATIONAL ELECTRICITY GENERATION
Argentina	147,220
Australia	256,563
Austria	68,336
Belgium	85,008
Brazil	578,498
Bulgaria	45,243
Canada	667,302
Chile	79,308
China	6,217,907
Cyprus	4,887
Czech Republic	83,213
Denmark	30,522
Estonia	12,176
Finland	68,486
France	555,620
Germany	647,231
Great Britain	339,399
Greece	54,438
Hungary	31,781
India	1,477,564
Indonesia	248,613
Ireland	30,418
Italy	289,032
Japan	1,036,528

Appendix 6. National Mix of Electricity-Generating Technologies (Percentage of Total Mix by Source) (Cont'd)

LIGNITE	NATURAL GAS	NUCLEAR	PEAT	PHOTOVOLTAIC	SOLAR THERMAL	WASTE	WIND
1.1	17.0	20.6	0.0	3.0	2.0	0.5	18.7
0.0	0.3	42.2	0.1	0.0	0.0	1.9	7.3
0.0	0.7	38.4	0.0	1.2	0.0	3.4	0.1
10.0	68.3	0.0	0.0	0.8	0.0	0.2	0.2
14.9	47.9	0.0	0.0	0.0	0.0	0.0	3.4
0.0	7.0	48.4	0.0	0.2	0.0	0.0	0.6
2.1	26.8	19.2	0.0	0.5	0.1	0.5	4.2

Appendix 7. National Annual Electricity Generation in 2016 (GWh) (Cont'd)

COUNTRY	2016 NATIONAL ELECTRICITY GENERATION
Latvia	6,425
Lithuania	3,996
Luxembourg	2,196
Malaysia	156,660
Malta	856
Mexico	320,353
Netherlands	114,976
New Zealand	42,974
Norway	149,333
Poland	166,568
Portugal	60,280
Romania	65,103
Russia	1,090,973
Slovakia	26,934
Slovenia	16,500
South Korea	561,317
Spain	274,671
Sweden	156,010
Switzerland	63,175
Thailand	191,321
Turkey	273,695
Ukraine	164,494
United States	4,316,460

Source: International Energy Agency 2019.

Glossary

Embedded water use: Water use (withdrawn or consumed) during the generation of purchased electricity.

Energy generation facility: Any technology or device that generates energy for consumer use, including everything from utility-scale fossil fuel power plants to rooftop solar panels.

Energy supplier: Also known as an electric utility, this is the entity that sells energy to consumers and can provide information regarding the water intensity of delivered electricity.

Water consumption: The volume of water used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea. (Source: Adapted from Water Footprint Network)

Water risk: The possibility of an entity experiencing a water-related challenge (e.g., water scarcity, water stress, flooding, infrastructure decay, drought). Water risk is felt differently by every sector of society and the organizations within them and thus is defined and interpreted differently (even when they experience the same degree of water-related challenges). (Source: UN Global Compact CEO Water Mandate)

Water use factors: The amount of water withdrawal or consumption expected to result from a unit of electricity consumption.

Water withdrawal: The volume of water abstraction from the sea, surface, or groundwater. Part of the water withdrawal will evaporate; another part will return to the catchment from where it was withdrawn and yet another part may return to another catchment or the sea. (Source: Water Footprint Network)

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