

Micropower Database: Methodology 2014

Introduction

This paper summarizes the methodology behind the data in Rocky Mountain Institute's database of global micropower, posted at <http://www.rmi.org/micropower-database> and maintained by RMI's technical staff. The purpose of the database is to present a clear, rigorous, and independent assessment of the global capacity and electrical output of micropower. With minor exceptions, this information is based on bottom-up, transaction-by-transaction equipment counts reported by the relevant suppliers and operators, cross-checked against assessments by reputable governmental and intergovernmental technical agencies.

Following *The Economist*'s convention, "micropower" is defined here as the electricity-producing portion of combined-heat-and-power (known in the U.S. as "cogeneration"), plus all renewable sources of electricity except big hydroelectric stations (which are defined as units bigger than 50 MWe). The term "micropower" occasionally confuses novices, and we recognize that some cogeneration units and some aggregations of wind turbines, photovoltaics, etc. are relatively large. "Micropower," however, is not confined to tiny units on your roof or in your backyard, but generically embraces many kinds of generators that are not large central thermal (or hydro) stations. Micropower's generating units are distinguished by having relatively short lead times and gaining their principal economies from production scale rather than from unit scale. Other terms such as "decentralized" or "distributed" generation are discussed on pp. 2–67 (especially around p. 43) of *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 2002, www.smallisprofitable.org), an *Economist* book of the year that describes micropower's economics.

For each of the electricity generation technologies, this methodology document describes how the values in the Micropower Database were calculated.

All years are calendar years. Each year is assumed to have 8,766 hours, smoothing out the quadrennial effect of Leap Day. For all micropower technologies for which no generation data were available, we have accounted for rapid growth by calculating annual output in a way that doesn't assume all the capacity installed by year-end was installed and commissioned by the beginning of the same year. Rather, assuming continuous exponential growth, we assumed that a quarter of the new year's capacity was effectively available for full-year electricity generation in that year.

RMI's Micropower Database is currently maintained by this July 2014 version's author:

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All generators

Due to data limitations, we report all capacity and generation data as gross, not net of the plants' own consumption. Since that autoconsumption is generally greater for thermal stations than for renewables, this convention tends to overstate nuclear and cogeneration net output to the grid (typically by an amount on the order of 5–8%) relative to renewable net output to the grid.

Nuclear

New connections:

New connections are displayed on page 20, table 7, of the 2014 “Nuclear Power Reactors in the World” report by the International Atomic Energy Agency (IAEA), available here: http://www-pub.iaea.org/MTCD/Publications/PDF/rds-2-34_web.pdf.

Shutdowns, uprates:

Nuclear reactor shutdowns are displayed in the same “Nuclear Power Reactors in the World” report, by country, not chronologically. The numbers in our analysis have been derived from this report, with the help of Mycle Schneider of Mycle Schneider Consulting LLC (Paris), principal author of the *World Nuclear Industry Status Report*.

Cumulative capacity, electrical output:

Both use IAEA's PRIS database, data 1995–2013 available at:

<http://www.iaea.org/PRIS/WorldStatistics/WorldTrendNuclearPowerCapacity.aspx> for capacity (GWe) and

<http://www.iaea.org/PRIS/WorldStatistics/WorldTrendinElectricalProduction.aspx> for electrical output (TWh). BP's *Statistical Review of World Energy 2013* was used as a comparative source for electricity gross generation data, available here:

<http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf>. Note the negligible differences in electricity output between these sources.

Inferred capacity factor:

The inferred capacity factor is calculated by dividing the actual output by the theoretical output—the product of gross nameplate capacity times 8,766 hours per average year. The inferred capacity factor indicates what percentage of the time the technology is generating, on average, at its rated gross capacity. As noted above, net energy sent out to the grid will be less because of the station's own consumption.

Wind

Net new capacity, cumulative capacity:

Cumulative capacity data for 1990–1995 is taken from the European Wind Energy Association's *Current Status of the Wind Industry (2005)*

(http://www.ewea.org/documents/factsheet_industry2.pdf). Annual new capacity for 1990–1995 is derived from these data. Data for the period 1995–2013 are taken from the Global Wind Energy Council (GWEC) Global Wind 2013 Report, available here: <http://www.gwec.net/publications/global-wind-report-2/global-wind-report-2013/>

Nominal capacity factor, nominal capacity-factor-based output:

Our underlying spreadsheet includes a calculation that does not contribute to our reported findings but is described here in case it is of interest. EWEA's *Wind Force 12* estimates the 2003 average capacity factor to be 24%, rising to 28% by 2011. From 2004–2010 we interpolated capacity factors based on a linear trend, and extended this back to 1990. GWEC's *Wind Energy Outlook 2008* shows the global wind capacity factor reaching 30% by 2036. For 2013 we interpolated one year of a linear trend from 2012 through 2036. To calculate electric generation from capacity, we assumed for a given year on average previous year's capacity plus a quarter of the capacity added in that year, multiplied by the nominal capacity factor. However, some countries or their wind-industry associations do publish output data. For example, the U.S. Energy Information Administration (EIA)'s *Monthly Energy Review* wind generation data for 2013 show 167.7 TWh—in reasonable agreement with the 169.4 TWh derived from BP's generation data.

Electrical output:

Our reported findings instead simply use BP's *Statistical Review of World Energy 2014*, available here: <http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf>. For comparison, we also show data from EIA's International Energy Statistics, available here:

<http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=6&pid=37&aid=12&cid=regions&syid=1990&eyid=2012&unit=BKWH>. Note the large discrepancy (more than 10 percent) between output data from BP and EIA and the higher output estimated from nominal capacity factor. This probably reflects some combination of lags between sales and installation and between installation and operation, as well as a time distribution of installations over the year different than the smooth exponential growth we assumed. Output data for some countries other than the U.S. may also be estimated rather than measured.

Inferred capacity factor:

See nuclear.

PV

Cumulative installed capacity:

1990–1999: We first found the 1989 cumulative PV production by subtracting the 1990 production from the 1990 cumulative total. Using the assumption that all PV panels produced in 1989 or before were installed by the end of 1990, we then added the annual installations in following years. We assumed the generally accepted 25-year lifespan of the modules (some modern modules now come with a 25-year *warranty*). Therefore, in 1996 we start retiring the first PV modules, which were made in 1971.

2000–2013: Cumulative installed capacity data for 2000–2013 were taken from EPIA's 2014 PV market report, page 17, available here:

http://www.epia.org/fileadmin/user_upload/Publications/EPIA_Global_Market_Outlook_for_Photovoltaics_2014-2018_-_Medium_Res.pdf.

Nominal capacity factor, nominal capacity-factor-based output:

Our underlying spreadsheet includes a calculation that does not contribute to our reported findings but is described here in case it is of interest. The International Energy Agency (IEA)'s *World Energy Outlook (2005)*

(<http://www.iea.org/textbase/npsum/weo2005sum.pdf>) contains predictions of PV capacity and output for 2010. From these we were able to calculate IEA's implicit PV capacity factor of 0.17. We assume 0.17 was IEA's observed capacity factor in 2004 when the *World Energy Outlook (2005)* was written, and we use it for 1990–2004. IEA's *International Energy Outlook (2009)* (<http://www.iea.org/weo/2009.asp>) assumes a 0.21 capacity factor for 2012. We assume the IEA observed 0.21 in 2008 when *International Energy Outlook (2009)* was written, and we drew a linear trend from 2004 to 2008.

Professor Mark Jacobson of Stanford confirmed to us that this is a reasonable assumption. He used the same 0.21 capacity factor in his paper *Evaluating the Feasibility of Meeting all Global Energy Needs with Wind, Water and Solar Power* (2010)

(<http://www.stanford.edu/group/efmh/jacobson/PDF%20files/JDEnPolicy24Jan2010.pdf>). We held capacity factor constant at 0.21 through 2015 to be conservative; actual utility-scale PV capacity factors have lately ranged from about 15% to 27% without tracking, or up to 30+% with tracking (p. 12, LBNL-6408E, September 2013). These estimates seem reasonable for the U.S., where average insolation (averaged over all states of the Earth's rotation and orbit) is $\sim 180 \text{ W/m}^2$. Given the rapid growth of PV capacity in low-latitude countries, and an average insolation of $\sim 230 \text{ W/m}^2$ worldwide, this should be conservative as a global trend.

The annual electrical generation calculated by multiplying installed capacity with capacity factor is much higher than the electrical generation reported by BP. We could not determine whether this was due to sales/installation/operation lags or to other causes.

Electrical output:

Our reported electrical output of solar photovoltaics is taken from BP's *Statistical Review of World Energy 2014*, available here: <http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf>.

Inferred capacity factor:

See nuclear.

Hydroelectricity

Only small hydro is included in the definition of "Micropower". In a previous version of this analysis, we set the limit at $\leq 10 \text{ MW}$ (although small hydro in China includes $\leq 50 \text{ MW}$ and in India $\leq 30 \text{ MW}$). Because our primary capacity source, Bloomberg New Energy Finance, provides data for $\leq 50 \text{ MW}$, in 2014 we have retroactively reset the definition for small hydro in all years to include all hydropower $\leq 50 \text{ MW}$.

Cumulative capacity, small hydro:

Data from Bloomberg New Energy Finance (to which RMI is a subscriber).

Capacity factor, small hydro:

According to ESHA (<http://www.esha.be/>) analysis, 13.5 GW of installed ≤ 10 MW capacity in Europe generated 48,783 GWh/year. This translates to a capacity factor of 41.4%, which is logically lower than large-scale hydro (large hydro operations are able to rely on their reservoir capacity to smooth power distribution through the season.) We assumed that this capacity factor is a good estimate for all years, smoothed over hydrological variations, as small hydro technology is reasonably mature. Since the equipment is very durable and many once-abandoned sites are being redeveloped, we assume that this trend and the upgrading of old equipment offsets any retirements. We think an assumption of a 40% capacity factor is probably conservative.

Large hydro electrical output:

Total generation comes from BP's *Statistical Review of World Energy 2014*.

Geothermal

Cumulative capacity:

Data from Bloomberg New Energy Finance. In previous versions of this analysis, total capacity was based on data provided by the *International Geothermal Association* (http://www.iea-gia.org/documents/FridleifssonetalIPCCGeothermalpaper2008FinalRybach20May08_000.pdf) and a linear trend covering missing years (2001–2002), we calculated annual installations for 2000–2008 by simply subtracting each year's global capacity from the following year's. Navigant Consulting provided an annual installation number for 2000 and BP's *Statistical Review of World Energy 2010* provides a 2009 total capacity number. These earlier data are in good agreement with the latest BNEF data we used.

Capacity factor:

Both the 2002 and 2010 capacity factors were calculated from IEA's capacity and output for these years, 72% and 78% respectively. For intermediate years, we simply assumed a linear increase from 2002 to 2010. Capacity factors for 2000 and 2001, and from 2011 to 2015 were extrapolated using the same linear trend.

Biomass-fueled generation (distinct from production of liquid biofuels for mobility)

Capacity additions, cumulative capacity:

Primary data source is Bloomberg New Energy Finance. For previous versions of this analysis, Navigant Consulting (<http://www.navigantconsulting.com>, <http://www.acore.org/pdfs/Frantzis.pdf>) kindly provided data on capacity additions for 2000–2002. We used IEA's 2002 total global capacity from the *World Energy Outlook 2004* as a reference value and worked backward and forward to find yearly total capacities. Our 2004–2006 and 2008–2009 capacities came from REN21's *Global Renewable Status Report* (www.ren21.net). We drew linear trends between 2002 and 2004, and between 2006 and 2008, to fill in missing data. We did not explicitly account for retirements and renewals of equipment, simply assuming that the process's generally favorable economics will tend to keep old capacity running or renovated (though the global distribution of the plants is shifting; for example, ~3 GW (2005) of bagasse cogeneration is a key to the profitability of Brazil's major sugar-cane ethanol industry).

Much biomass-fueled generation is in the forest-products industries such as pulp-and-paper and furniture-making; for example, EIA's *Annual Energy Review 2008* preliminarily reports that in 2008, U.S. industry (excluding the commercial sector) generated 27.9 TWh from wood and 0.7 TWh from "waste" (which after 2000 excludes non-biogenic wastes and tires), plus 548 and 16 trillion BTU of useful thermal energy, respectively. However, considerably more wood and waste was consumed by electricity-only (non-CHP) plants. EIA has recently begun reporting in detail all U.S. industrial and commercial CHP and its fuel sources.

IEA provided two global scenarios: a reference scenario (where biomass electricity generation reaches 407 TWh in 2015) and an alternate policy scenario (where it reaches 511 TWh in 2015). We averaged these 2015 generation projections to arrive at a 459 TWh figure, then, based on linear growth and a 70% capacity factor, back-calculated annual installations for 2009–2015.

Capacity Factor:

Both the 2002 and 2010 capacity factors were calculated from IEA's capacity and output for these years. As the capacity factors were identical at 70%, we adopted this value for all previous, intermediate, and future years.

Electrical output:

Electrical output of biomass generation is taken from BP's *Statistical Review of World Energy 2014*, available here: <http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf>.

Cogeneration

Cumulative capacity:

A report by the International Energy Agency, *Combined Heat and Power: Evaluating the Benefits of Greater Global Investment*, (http://www.localpower.org/documents/reporto_iea_chpwademodel.pdf), estimates the 2006 global level of CHP (regardless of its fuel) to be 300 GWe. Actually, the 2006 level may have been higher since the country-level data that this figure aggregates range from 2004 to 2006. Nonetheless, we use this 300-GWe figure as an "anchor" for global CHP capacity, then add and subtract actual and expected annual installations to establish a 1999–2013 trend. There are indications that at least in the United States, official data on installed cogeneration capacity may be understated: CHP was not included in official statistics until recently, so data-gathering techniques and reporting compliance are still maturing.

Capacity additions:

From 2003 to 2005, the World Alliance for Decentralized Energy (WADE)—the umbrella global trade organization for distributed generation—published an *Annual Survey of Decentralized Energy* (www.localpower.org) presenting, among other things, an analysis of annual global CHP installations. Engine- and motor-based CHP data were extracted from the authoritative industry compendium *Diesel Gas Turbine Worldwide (DGTW) Annual Power Generation Survey*, a supplier-industry compilation of reported

equipment sales (<http://www.dieselgasturbine.com/surveys.asp>). Steam-based CHP data were based on interviews conducted by WADE with its trade-association, vendor, customer, and other partners throughout the world. From 2009 onwards, *DGTW* published data on steam turbines sold.

While WADE no longer published its survey after 2006, *DGTW* continues to publish its survey and to include more useful data each year, so we have switched to directly using *DGTW*'s summary of its bottom-up transaction-by-transaction equipment-sales database. Employing WADE's methodology for extracting engine- and motor-based CHP, we returned to WADE's primary data source and created a trend for 2006–2009 based on the *DGTW* survey. This survey contains data on diesel, dual-fuel, and gas engine orders, and gas turbine power generator orders. For all years up to and including 2013, the survey gathered data on orders placed between June and May, e.g., June 2012 through May 2013. We assumed that orders during this period were installed over the course of the latter year.

DGTW tables show the total capacity of all orders for a given output range, and within that output range, how many units were standby, peaking, and continuous. Assuming a constant capacity across generating service types, we omit all standby and peaking capacity from our total CHP number as a major conservatism, since these capacities are large and most could be (and some have probably been) made dispatchable by grid operators. Following WADE's methodology, we include 100% of engines between 0.5 and 30 MW in our overall CHP number, and 60% of engines over 30 MW. For gas turbines, we include 100% of units between 1 and 30 MW, 75% of units between 30.01 and 60 MW, 10% of units between 60.01 and 120 MW, and 5% of units over 120 MW. This methodology ends up concluding that 12–21% of all engine and turbine orders are used in CHP applications. These assumptions were unofficially validated, within proprietary constraints, by Brent Haight, publisher of *DGTW* in June 2014,

Biomass adjustments:

Since a small percentage of decentralized cogeneration runs on biomass, and all biomass-fired generation is listed separately, biomass-fired CHP must be subtracted from our CHP total to avoid double-counting. It was hard to establish a firm number for the percentage of biomass-fueled cogeneration. In a 2006 personal communications, Michael Brown, director of WADE, estimated that the current biomass-fueled fraction of global generation was 3–5%, potentially rising to 6–8% by 2012. Brent Haight, publisher of *DGTW*, unofficially confirmed this as reasonable in June 2014. We therefore subtracted from the total decentralized cogeneration 4% of capacity in 2004, rising to 7% in 2013, to reach a reasonable estimate of non-biomass cogeneration.

Capacity factor:

Having neither electrical output nor capacity factors from any traditional sources, we again turned to help of Michael Brown of WADE. He provided an estimated average capacity factor in terms of hours per year: “7000–7500, possibly more.” Running 7,250 hours per year equates to a capacity factor of 82.8%, which we applied uniformly to all years under consideration. Brent Haight, publisher of *DGTW*, unofficially confirmed this estimate in June 2014. Fragmentary data from other sources suggest it may be conservative, but detailed field surveys appear not to have been conducted.