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Electricity Consumption and Economic Growth: A New Relationship with Significant Consequences?

The growth rate of electricity consumption has important implications for business and public policy. This article describes altered trends in the relationship between growth in economic activity and electricity use and offers hypotheses to explain them. These new trends require utility system stakeholders to rethink old assumptions and prepare for a new reality of lower growth rates in electricity consumption.

Richard F. Hirsh and Jonathan G. Koomey

I. Introduction

The growth rate of electricity consumption has important implications for business and public policy. Increasing use of electricity usually boosts power producers' income, but construction of conventional generating plants to meet rising demand may add to pollution and other environmental woes. The traditional electric utility business model is predicated on continuously expanding usage of electricity, and if the rate of growth slows (or becomes negative), profits will decline, especially if companies build unneeded generating facilities.

Increasing consumption is also embedded as a key element in the

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Obama administration's Clean Power Plan. If the actual growth rate differs from the forecast amount, then perverse and unexpected outcomes can result. In particular, lower-than-predicted consumption growth would imply less-stringent environmental mitigation requirements than initially expected.[1]

This article explores the relationship between electricity use and economic activity since 1949. That relationship has been a major driver of electricity forecasts in the past, and it continues to hold sway today. But the relationship has changed significantly in the U.S.[2] At the time of the first oil shock in the early 1970s, the U.S. economy shifted from a period of electrification and increasing electricity intensity to one in which electricity use and gross domestic product (GDP) grew at comparable rates. Then, in the mid-1990s, the U.S. economy entered a period in which electricity consumption grew more slowly than the GDP. Finally, since 2007, the U.S. economy has generated GDP growth with almost no net growth in electricity demand. If this last trend continues, it will present fundamental challenges to how utilities operate in the U.S., with implications for the design of public policies that affect creation of new generation resources, energy efficiency, and compliance with environmental regulations.

II. Electricity Consumption and Economic Activity

Do electricity consumption and economic well-being go hand-in-hand? For decades, conventional wisdom (and data) answered this question with a resounding "yes." A 1960 article celebrating Thomas Edison's birthday observed, for example, that the power industry "is a growth industry in the fullest sense of that term! Electricity increasingly stimulates over-all economic growth in the United States. . ."[3] That belief held sway into the 1980s, as the solid connection between prosperity and electricity consumption implied that the economy "cannot grow at a rate much higher than the rate of increase in the electricity supply."[4] The U.S. Department of Energy and several electric utility organizations published a pamphlet in 2003 noting that the "use of electricity has grown dramatically over the last 30 years and mirrors the equally robust growth of the gross domestic product (GDP), the gauge of economic health in the United States."[5] In 2007, the Edison Electric Institute, a trade group of electric utility companies, observed in its publication (available online in 2011 or later), *Key Facts About the Electric Power Industry*, that "[e]lectricity is the lifeblood of the U.S. economy"[6] and that "[g]rowth in electricity use has coincided with growth in the GDP since the end of World War II."[7]

A solid connection between prosperity and electricity consumption implied that the economy 'cannot grow at a rate much higher than the rate of increase in the electricity supply.'

The apparently strong relationship between economic growth and electricity consumption often motivates the need for increased power-plant construction, at least in the eyes of some utility stakeholders. "Economic growth is good news for Virginia," noted Dominion Virginia Power's Web site in 2011, for example, "but it presents special challenges" due to the projected increase in electricity demand of almost 4,500 MW in the next decade that may result from the rising GDP. "A strong economy requires more energy to support its continued growth," the site declared. "The key issue confronting the Commonwealth is where the additional power will come from to sustain this growth."[8] For planning purposes, the company develops forecasts that correlate strongly with economic measures; its 2010 integrated resource planning document noted that the "forecast of the Virginia economy drove the Company's energy sales and load

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forecasts.''[9] More recently, the firm's 2014 plan, which uses several models and considers a host of variables, still notes that the ''forecast for the Virginia economy is a key driver in the Company's energy sales and load forecasts.''[10] And while it considers many factors, the PJM Interconnection, the regional grid operator for 13 states (and the District of Columbia), still employs projections of economic growth for determining load forecasts.[11]

One cannot dispute the notion that electricity use has yielded huge productivity enhancements that benefit the economy (and will likely continue to do so), nor that economic growth in the past has propelled increased electricity use. However, it appears that a one-to-one relationship between electricity consumption and GDP no longer holds.[12] In other words, the history of this relationship demonstrates that it has been more variable than people have assumed, especially since the mid-1990s. Moreover, though some interests may have a stake in claiming that a direct linkage between the two metrics exists, we are unaware of an empirical or theoretical justification for it.[13]

This article does not fully explore the relationship between electricity consumption and economic growth. Instead, it presents data suggesting a path of research to clarify the main question posed above, at least as it applies in the United States.[14] We suggest that a linear relationship between electricity consumption and the gross domestic product—GDP, the widely accepted (though flawed[15]) measure of economic activity—changed remarkably after the mid-1990s in the United States. Before then, starting in the early 1970s, the relationship between electricity consumption and GDP demonstrated a solid (almost one-to-one) correlation; after about 1996, that correlation appeared to have diverged significantly, requiring less electricity to produce each unit of GDP.

Utilities, regional grid operators, and other stakeholders must realize that long-term load projections based largely on the belief in a strong correlation between economic growth and electricity consumption may not be accurate.

Our contribution toward understanding the relationship between electricity and GDP growth will therefore focus on hypotheses for the correlation divergence since the mid-1990s. Further research will draw from these hypotheses and perhaps suggest ways to obtain greater economic value with less demand on electrical resources. That goal has merit since, even if one can generate electricity with renewable resources, the production of power (unless absolutely necessary) still has significant environmental, business, and policy impacts.

While more research to determine the causes of the divergence between electricity consumption and economic growth needs to be conducted, the identification of the deviation in itself yields an immediate policy contribution. Most importantly, this work suggests that utilities, regional grid operators, and other stakeholders must realize that long-term load projections based largely on the belief in a strong correlation between economic growth and electricity consumption (or on similar correlations embedded in regression-based forecasting models) may not be accurate. Since load projections often serve as the basis for planning of new generation plants and transmission facilities, while also affecting elements of pollution mitigation programs, their inaccuracy can have serious consequences.[16]

III. The Data

Before going further, let's examine historical trends on end-use electricity consumption, primary energy consumption, and inflation-adjusted GDP. The data, which come from the U.S. Department of Energy's Energy Information Administration, have been normalized, making each value equal to 100 in 1973.

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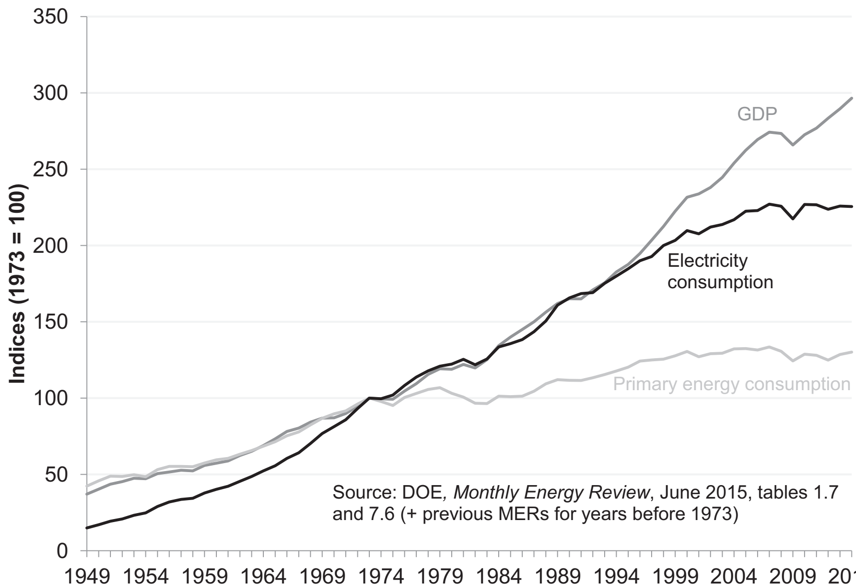

Figure 1: Indices of US Inflation-Adjusted GDP, Primary Energy Consumption, and Electricity Consumption Normalized to 1973 = 100

Note: Data from U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, June 2015, tables 1.7 and 7.6, downloaded as Excel files at http://www.eia.gov/totalenergy/data/monthly/index.cfm. Energy consumption consists of use of all primary energy sources, including fossil and nuclear fuels, renewable energy, and net electricity imports. Electricity consumption includes retail sales plus direct use of electrical energy. It is equivalent to net generation in the electric power, commercial, and industrial sectors plus net electrical imports, minus losses from transmission and distribution and unaccounted-for causes. This number includes power generated by combined heat-and-power plants and self-generated electricity. DOE/EIA converted GDP figures to inflation-adjusted 2009 dollars before we normalized them for our graphs.

Figure 1 highlights important trends. First, it shows that primary energy consumption grew 137 percent from 1949 to 1973 at a time when electricity usage jumped 573 percent. Meanwhile, GDP shot up 167 percent. In other words, the electricity intensity (electricity/unit of GDP) increased substantially during this period when the primary energy intensity (primary energy/unit of GDP) declined moderately (about 11 percent—a small amount compared to the overall growth).

To make the intensity story clearer, we offer **Figure 2**, which presents ratios of energy and electricity consumption per inflation-adjusted GDP, normalized to 1973 = 100.

The trend of electricity intensity appeared to change after the Arab oil embargo of 1973. From that year and for the next 23 years, electricity consumption seemed to grow in lockstep with the GDP, while overall energy consumption declined dramatically with respect to economic activity. From 1973 to 1996, the GDP grew 92 percent as electricity consumption jumped 90 percent. It seems, then, that GDP growth correlated with electricity consumption, but the relationship now appeared linear; in other words, the electricity intensity remained fairly uniform instead of increasing as it did before 1973.

Perhaps most strikingly, however, the correlation between electricity consumption and GDP expansion diverged after about 1996, when the GDP growth rate greatly exceeded the electricity consumption rate. Breaking the trend of equivalent growth in the two indicators that persisted for more than two decades, real GDP increased 41 percent between 1996 and 2007 while electricity consumption rose only 19 percent. Electricity usage appeared to follow the same path as primary energy growth in decoupling from GDP, only a few decades later.

Another graph highlights the correlation divergence more dramatically. **Figure 3** uses the same data as the previous graph, but focuses on the period after 1973, and it normalizes the measures to 100 in 1996. Electricity consumption growth and GDP growth occurred at a similar pace from 1973 to 1996; however, after 1996, the correlation deviated significantly.

Figures 1 and 3 also show that electricity consumption has remained flat from 2007 to 2014, even as real GDP grew 8 percent. This surprising trend, if it continues, would represent yet another fundamental shift in the relationship between electricity use and GDP. Astute observers of the utility industry would do well

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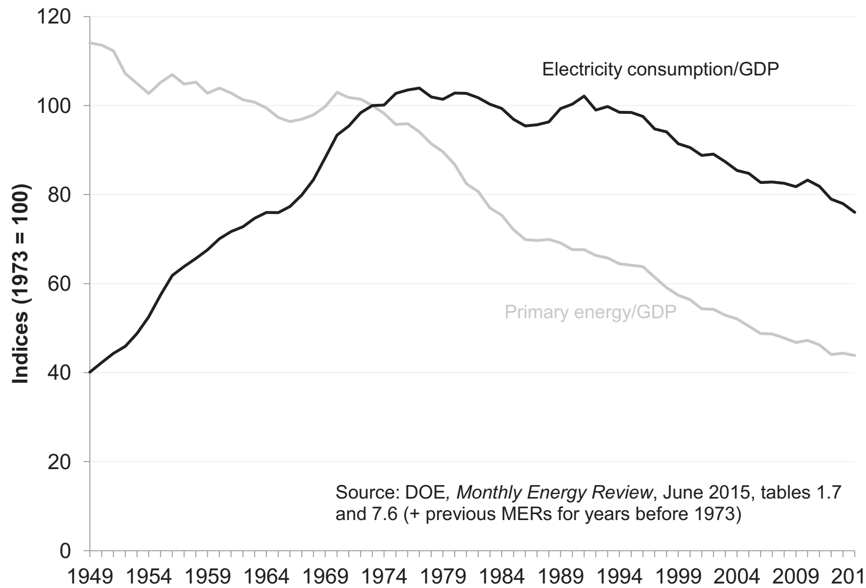

Figure 2: Indices of Ratios of US Primary Energy Consumption and Electricity Consumption to Inflation-Adjusted GDP, Normalized to 1973 = 100
Note: Data from **Figure 1**.

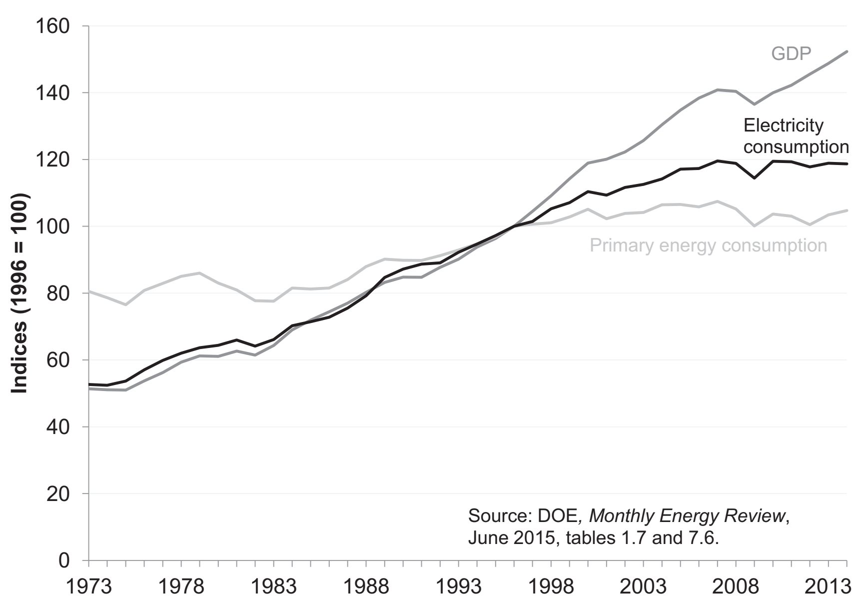

Figure 3: Indices of US Inflation-Adjusted GDP, Primary Energy Consumption, and Electricity Consumption Normalized to 1996

to consider this trend as they formulate business strategy in the future.

Figure 4 shows annual changes in U.S. electricity demand since 1950, and it tells a story of declining consumption growth over time. The linear trend line associated with these data goes below zero in about 2010, which indicates that declines in absolute electricity consumption could become a reality in the years ahead, assuming recent trends continue. If nothing else, the data suggest that the heady growth rates of past decades (which had both positive and negative impacts) may not repeat themselves soon, if ever.[17]

IV. Electricity and GDP: Some Hypotheses

The National Academy of Sciences (NAS) in 1986 sponsored a study that examined the relationship between electricity use and economic activity, noting that major structural changes in the American economy since the early 1970s contributed to the overall lowering of the electricity intensity.[18] It also found that ''electricity use and gross national product have been. . . strongly correlated,''[19] with stable linear relationships between the two measures over long periods of time.[20] Shifts in the slope of the linear relationships occurred during the Great Depression and after World War II.[21] Perhaps most interestingly (for our purposes), the NAS researchers observed that electricity intensity had begun to decline into the mid-1980s. Whether the trend would continue remained uncertain to the NAS authors, who observed that the ''post-embargo years are still too few to provide definitive answers about trend shifts.''[22]

The data presented in this article, of course, suggest that the modest declines in electricity intensity observed in the mid-1980s were reversed in the late 1980s, so that intensities

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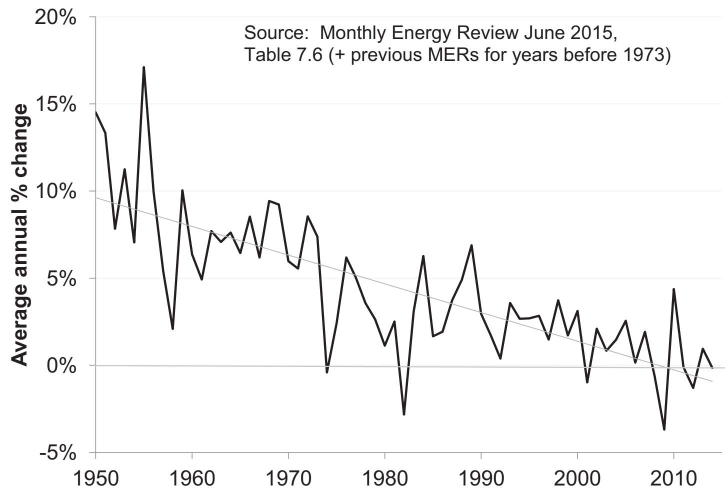

Figure 4: Annual Change in Electricity Demand for the US, 1950 to 2014

remained roughly flat until the mid-1990s. After that time the electricity intensity started to decline. What happened to cause the mid-1990s correlation divergence? Here are some plausible hypotheses—hypotheses that will require further testing.

Hypothesis 1: Cumulative impact of electrical energy-efficiency efforts. Starting with the Arab oil embargo in 1973, governments, utilities, private businesses, and individuals made significant efforts to do more with less energy. In particular, governments (especially trend-setting California) began establishing incentives for energy efficiency and standards for energy consumption in buildings, equipment, and appliances (such as refrigerators, air conditioners, dehumidifiers, lighting, and windows),[23] with the federal government passing national energy-efficiency standards in 1987, 1992, and 2005.[24] Since so much energy is used in buildings (about 40 percent of total energy and three quarters of all electricity use in 2014),[25] these energy efficiency gains (along with those from utility efficiency programs) had a major impact on overall electricity consumption growth rates.[26]

Likewise, starting in the 1970s, regulators in some states adopted policies that forced electric utilities to pursue more efficiency.[27] The cumulative impact of these efforts, especially as electricity-hogging equipment purchased in the 1970s began seeing replacement in the 1990s (refrigerators, for example, typically have lives of 15 or more years) may have contributed significantly to the correlation divergence in the mid-1990s.[28] If nothing else, the overall efficiency efforts may have already had an impact by contributing to the declining growth rate of electricity consumption: in the post-war years to the beginning of the energy crisis (late 1940s to 1973), electricity use grew about 8 percent annually. From 1996 to 2007 it grew about 1.6 percent per year, and from 2007 to 2014, electricity consumption growth dropped to zero.[29]

Hypothesis 2: Increased use of information and communications technologies (ICT). The greater employment of the Internet and electronic technologies to conduct business may have also contributed to lower electricity intensity. Enabling people and businesses to communicate with others more efficiently, these technologies yielded great economic productivity with relatively little electricity consumption. In a 2008 study, the American Council for an Energy-Efficient Economy argued that much of the improvement in the overall energy intensity decline since the mid-1990s appears to draw from the use of such technologies.[30] Moreover, the 1990s witnessed a period of increasing business investment (as a percent of GDP), much of which went into information and communications technologies (ICT). (In 1992, the gross private domestic investment in ICT stood at about 11.9 percent of GDP; it rose to 15.6 percent by 2002, though it has remained at that rate during much of the 2000s.[31]) Some of this investment may have been motivated by concerns of the heavily promoted Y2K problem, in which people worried about failing computers as the clock ticked into the new century, and

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businesses purchased new computers and other ICT in a way that enhanced productivity without greatly pushing up demand for electricity. Finally, subtle effects in the service sector may have been prominent in the 1990s and thereafter. For example, the financial services sector—a large user of productivity-enhancing ICT—grew from 14.7 percent of the GDP in 1973 to 19.0 percent in 1995 and 21.5 percent in 2009.[32] In short, the application of these technologies throughout the economy may have had a significant impact on the relationship between the nation's electrical consumption and GDP.

Hypothesis 3: Higher prices for electricity in some states and regions. In much of the country, customers have seen prices for electricity increase modestly. Nationally, average prices (for all sectors) increased in inflation-adjusted terms by just 11 percent from 2001 to 2014.[33] This modest increase of average prices around the country (and among all customer classes) may mask large regional price hikes, especially in states that experienced an end of price caps as part of deregulation efforts beginning in the late 1990s.[34] As prices increase, customers seek to curtail use of electricity through behavioral changes and through efforts to increase electrical energy efficiency, such as purchases of new, energy-stingy equipment (Hypothesis 1). For Hypothesis 3 to hold, electricity customers must respond asymmetrically to price hikes and price decreases, or alternatively customers must have a threshold change above which they are more price sensitive. It is unclear if either of those conditions holds in practice, and ultimately, empirical analysis comparing state data will be required to assess this hypothesis.

Hypothesis 4: The U.S. may be entering a new stage of economic

development, characterized by structural changes in the economy. As some industries move from the U.S. to other countries, the relationship between electricity use and GDP could be affected, an explanation suggested by researchers who conduct detailed decompositions of changes in the energy economy over time.[35] Industries may also be transforming themselves to produce GDP growth in less electricity-intensive ways (which may be related to Hypothesis 2). High-level data suggest that such structural shifts are unlikely to have caused the changes observed in electricity demand growth beyond 1996, because changes of consumption patterns in residential and commercial buildings constituted the primary drivers of the decline in total electricity demand growth starting in the mid 1990s.[36] However, these data may be hiding structural shifts between different industrial sectors inside the U.S., and only more empirical analysis will be needed to untangle that potential complexity.

Hypothesis 5: The electricity consumption data may be biased because of measurement issues. The most important omitted factor consists of generation of electricity by residential and commercial customers using small rooftop photovoltaic (PV) systems. Because the modest power production of these systems remains ''behind the meter,'' the Department of Energy's Energy Information Administration does not track them. While PV systems were not numerous enough to have caused the correlation divergence in 1996, they have become much more common in recent years—especially in several states that have provided incentives for their installation[37]—and no doubt some of the reduced growth in electricity demand in the EIA data results from increased penetration of such rooftop PV systems. This hypothesis is ripe for empirical testing.

V. Next Steps and Conclusions

Clearly, further research needs to be performed to understand

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better why the correlation divergence occurred in the mid-1990s, why electricity intensity continues to decline, and whether electricity demand will remain flat even as GDP growth continues. Statisticians and others can use their special skills to test the above hypotheses or to propose others. (We don't claim to have exhausted the possibilities.)

Even without fully understanding the reasons for declining electricity intensity, however, our observations still yield an important implication. Namely, one should avoid making long-term forecasts of electrical loads based largely on predictions of correlations with the gross domestic product (or variations of this measure for metropolitan and other geographical regions). As noted, while the growth of electricity consumption closely paralleled the increase in the GDP from 1973 to the mid-1990s, that linkage appears to have been broken in the past two decades.

Planners need to remain aware of the divergence in the growth rates of the GDP and electricity consumption. Within the PJM region, for example, an error that yields a 1 percent increase in projected economic growth translates to an approximately 1,000 MW miscalculation in peak load projection based on existing capacity—an amount equivalent to the output of a large fossil-fuel or nuclear generating unit.[38] Such an error in a hugely capital-intensive industry would have grave financial implications. It would also incur large environmental and political consequences for entities seeking to build new (and ultimately unnecessary) facilities. At the same time, consumers in states that retain traditional regulation would bear a portion of the costs associated with overly high

forecasts (and construction of unused facilities) while also suffering because their demand response and energy-efficiency efforts would have less monetary value.[39]

A recent example of how forecasts can affect public policy is embedded in the Obama Administration's Clean Power Plan, which relies on forecasts from the Energy Information Administration's National Energy Modeling System (NEMS) to determine one path for meeting emissions targets in different states. As some investigators have recently noted, NEMS has historically overestimated electricity sales, which implies that the emissions targets will not be nearly as stringent as expected.[40] More generally, any public policy measures that rely on forecasted electricity growth for their compliance method likely will be subject to slower increases in coming years.

Of course, even if planners stop employing forecast models that correlate load growth with economic activity, new construction of power generation facilities will remain likely in the future. Existing power plants cannot last forever, and they will need replacement. And if the nation seeks to address climate change concerns, it will likely need to replace fossil-fuel-burning plants with less polluting plants (combined, of course, with a large dose of energy efficiency) and with transmission lines that link load centers to renewable energy facilities.

Homeowners and businesses may also increase their use of distributed generation facilities—everything from on-site, small-scale gas generators to plug-in hybrid vehicles that send power into the grid when they are not used, to greater use of home photovoltaic systems. Such investments (and those in battery storage, which increases the value to the grid of variable natural resource-based generation systems) would reduce utility-produced electricity consumption even further and create additional pressure on companies' rate design and profitability.[41] (Countering such

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drops in consumption, of course, could be increased sales to electric vehicles away from homes or those at home without distributed generation on site.) With retail sales from utilities remaining steady, declining, or only growing slowly, the demand for power in the future may not increase in parallel with the robust economic growth that planners hope for.

That conclusion has serious consequences for many stakeholders: environmental advocates may celebrate the reduced pressure to build new conventional (and polluting) power plants and draw instead from renewable power systems used in distributed generation configurations. Utility managers and financial planners may appreciate the reduced need to enter capital markets and borrow money (or float stock issues) for new generation and transmission facilities, but they may have to become more creative in obtaining new sources of revenue (perhaps by purchasing and then leasing renewable energy systems on customers' premises). They will also benefit from working with regulators and legislative bodies to deal with self-generating customers who still depend on utilities for backup power and who force fixed and variable costs to be shared among fewer kilowatt-hours (with higher unit prices as the result). And they will need to ensure that policies dependent on forecasts of electricity demand growth take into account these recent trends. In other words, utility stakeholders must rethink old assumptions and prepare for what appears to be a new reality of lower growth rates in electricity consumption.

Appendix. People Used to Think that Energy and GDP Also Had a One-to-One Correspondence

The discussion in this article of the relationship between electricity growth and economic growth mirrors a similar one held in the 1960s and later concerning the correlation between overall energy use and economic prosperity. Since the nation's early years and into the mid-20th century, per capita and gross energy consumption exploded: Americans consumed a total of about 2.4 quadrillion (10^{15}) BTUs in 1850 and 40.8 quadrillion BTUs in 1955; per capita consumption more than doubled in the same period.[42] As economic growth accompanied increased energy use, many observers believed that material well-being depended on increased energy consumption.[43] Interestingly, some people also felt that social progress also correlated with growth in energy use: the American anthropologist Leslie A. White wrote in 1947, for example, that ''[c]ulture advances as the amount of energy harnessed per capita increases. . .'' thus yielding an objective measure for ''the evaluation of cultures.''[44] But serious scholars in the 1950s tested an element of this belief using econometric data derived from the 1880s, finding that the ratio of energy consumption per unit of economic activity (energy intensity) rose from 1880 to 1920 only to fall thereafter at a rate of about 1.2 percent annually.[45] Moreover, since the 1973 energy crisis, this declining trend accelerated, largely due to higher energy prices and new policy initiatives that encouraged energy efficiency, as government, industry, and the general public made efforts to use energy more wisely.[46] The President's Council on Environmental Quality observed in 1979 that energy intensity continued to decline at a rapid pace, suggesting ''that the means are available to wring far more consumer goods and services out of each unit of fuel that we use, whether it be a barrel of oil or a ton of coal or uranium.''[47] In general, that trend has continued, such that in 2014, Americans produced a dollar's worth of GDP with 44 percent of the energy needed in 1973.[48]

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The observation that a unit of GDP could increase with less energy input disputed the notion that economic growth depends on increasing energy consumption. After all, the economy continued expanding at respectable rates over many years without using as much energy per unit as in earlier years. Of course, analysts appropriately attributed part of this reduction in energy intensity to the changing structure of the American economy, as we note above. As the economy moved more from manufacturing (which contributed 21.9 percent to the GDP in 1973 but only 11.2 percent in 2009[49]) and into services, one could expect less energy input per unit of GDP. The decline in energy intensity appears to have become a long-term fixture of the American economy.■

Endnotes:

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2. In developing countries, by contrast, energy (and especially electricity) use and economic activity remain linked. ''All else equal,'' notes a Department of Energy discussion, ''a growing economy leads to greater energy and electricity use. However, in developed countries like the United States, the relationship has been changing for some time. . .'' U.S. DOE, ''US economy and electricity demand growth are linked, but relationship is changing,'' March 22, 2013, at http://www.eia.gov/todayinenergy/detail.cfm?id=10491, obtained June 15, 2015. A recent study demonstrating the ''bidirectional causality between economic growth and electricity consumption'' is Bayar, Y. Özel, H.A., 2014. Electricity consumption and economic growth in emerging economies. J. Knowl. Manag. Econ. Inform. Technol. 4 (April (2)), 1–18. At the same time, shortages of energy in developing nations clearly hamper economic activity and social justice, as noted by the United Nations. The ''lack of modern energy services stifles

income-generating activities and hampers the provision of basic services such as health care and education.'' ''Achieving Universal Energy Access,'' United Nations Foundation, http://www.unfoundation.org/what-we-do/issues/energy-and-climate/clean-energy-development.html, obtained July 6, 2015.

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7. Ibid., 1. Similar claims abound. The American Electric Power Company claimed on its Web site (until 2012, available on the Internet Archive, http://web.archive.org) that ''[i]f the GDP goes up, it means people are doing better, generally, in their lives. The U.S. electricity line [in the accompanying graph]. . . goes up with the GDP line . . . because electricity is used to make lots of products and provide services.'' American Electric Power, 2011. Energy: Past, Present, and Future, at http://www.aep.com/environmental/education/solar/powerPie/energy.aspx, obtained July 25, 2011, now available at http://web.archive.org. In another realm, investment analysts typically note that ''[c]hanges in demand for electricity closely follow the rate of economic growth.'' Scott, T., 2010. University of Iowa Tipple School of Management, Henry Fund Research. Electr. Util. (February), 5–6.

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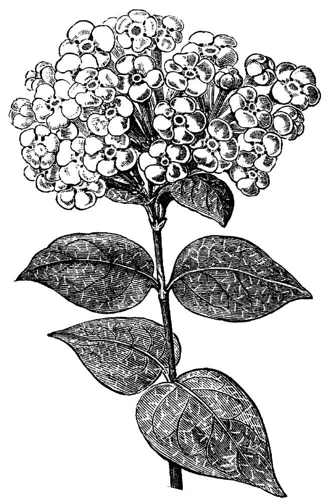
10. Dominion North Carolina Power's and Dominion Virginia Power's Report of its Integrated Resource Plan. Public Version, filed Aug. 29, 2014, 20, at https://www.dominionresources.com/corporate/what-we-do/electricity/generation/integrated-resource-planning, obtained June 26, 2015.

 http://dx.doi.org/10.1016/j.tej.2015.10.002

11. In its summary of ''Forecast Model Overview'' for 2015, the PJM notes that its planning model ''uses anticipated economic growth and historical weather patterns to estimate growth in peak load and energy use.'' PJM, Manual 19: Load Forecasting and Analysis, revision 27, March 26, 2015, 9, at https://www.pjm.com/~/media/documents/manuals/m19.ashx, obtained July 6, 2015. In this and earlier load forecasts, the PJM employed forecasts of the ''Gross Metropolitan Product'' of cities in its region. This metric is functionally comparable (within the geographical area) to the GDP nationally. See Wilson, J.F., 2009. PJM long-term load forecasting methodology: proposal regarding economic forecast. In: Presentation to PJM Planning Committee, Aug. 12, 2009, at http://www.pjm.com/~/media/committees-groups/subcommittees/las/20090825/20090825-load-forecast-economic-forecast-proposal.ashx, obtained 26 July 2011, now available at http://web.archive.org. In written testimony to the Virginia State Corporation Commission, Mr. Wilson noted that ''there is only a single driver of future peak load growth in PJM's forecasting model—economic growth.'' ''Direct Testimony of James F. Wilson on Behalf of Commission Staff, Application of PATH Allegheny Virginia Transmission Corporation,'' SCC Case no. PUE-2009-00043, p. 8. Mr. Wilson argued that the PJM should use other measures for forecasting rather than the GMP. Of course, electricity consumption in kilowatt-hour units is not the same as generating capacity, measured in kilowatts (kW) or megawatts (MW), but they are related. A utility needs to maintain enough capacity (plus a reserve margin) so it can meet the maximum consumption at any time. Planners often use electricity usage to determine peak demand through the concept of the load factor—the ratio of the average generating capacity over a period of time compared to the peak demand. Changing expectations about load factor can influence peak load projections, though (as noted in a 1983 study) ''growth in consumption remains the more important variable.'' U.S. Department of Energy, Office of Policy, Planning and Analysis, ''The Future of Electric Power in America: Economic Supply for Economic Growth,'' DOE/PE-0045, June 1983, 3-82 to 3-86.

12. A linear relationship suggests that an increment of growth in the GDP occurs with a proportional (though constant) increase in electricity consumption. In a recent PJM projection, the linear constant was 0.64 or 64 percent. Hence, a projected



growth of one percent in regional GDP meant a growth of about 0.6 percent in projected load growth. Wilson, ''Direct Testimony,'' 23.

13. For a discussion of problems from assuming that social and economic systems are as predictable and constant as physical systems, see Scher, I. Koomey, J., 2011. Is accurate forecasting of economic systems possible? Clim. Change 104(3). Also see Why we can't accurately forecast the future, 2012. In: Koomey, J.G., Cold Cash, Cool Climate: Science-based Advice for Ecological Entrepreneurs. Analytics Press, Burlingame, CA, http://www.analyticspress.com/cccc.html (Chapter 4).

14. Studies of the relationship between economic growth and electricity consumption in other countries have yielded equivocal results. For a summary of such studies, see Yoo, S.-H., Lee, J.-S., 2010. Electricity consumption and economic growth: a cross-country analysis. Energy Policy 38, 622–625. One can also do an Internet search using terms such as ''economic growth'' and ''electricity'' to retrieve scores of studies dealing with the relationship in various countries.

15. An excellent example of the deficiencies of the GDP in measuring economic value is presented in Brynjolfsson, E., Saunders, A., 2009. What the GDP Gets Wrong (Why Managers Should Care). MIT Sloan Manag. Rev. 51 (1), 95–6. Nobel Prize winner Joseph Stiglitz expounded on problems with the GDP in a presentation he made in 2008, found on YouTube at http://www.youtube.com/watch?v=QUaJMNtW6GA, obtained July 28, 2011.

16. The focus here remains on long-term forecasting-projections that drive decisions about building new capacity, for example. Incredibly important as well, short-term forecasting focuses on planning for months, days, or hours ahead of events, enabling utility organizations to meet fluctuating demand due to weather extremes, equipment outages, and other causes.

17. The benefits of electricity growth through the 1960s and reasons for the decline and loss of those benefits is explored in Hirsh, R.F., 1989. Technology and Transformation in the American Electric Utility Industry. Cambridge University Press, New York.

18. National Academy of Sciences, Committee on Electricity in Economic Growth, 1986. Electricity in Economic Growth. National Academies Press, Washington, DC, at http://www.nap.edu/catalog.php?record_id=900, xx.

19. Ibid., 15.

20. Ibid., 16.

21. See graph in Op. Cit, note 18, 20.

22. Ibid., 49.

23. See California's Appliance Efficiency Program, at http://www.energy.ca.gov/appliances/, obtained July 27, 2011.

 1040-6190/, http://dx.doi.org/10.1016/j.tej.2015.10.002

24. National Appliance Energy Conservation Act of 1975, National Appliance Energy Conservation Act of 1987, Energy Policy Act of 1992, and Energy Policy Act of 2005.

25. US DOE. 2015, April 14. Annual Energy Outlook 2015, with Projections to 2040. Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA-0383(2015). http://eia.doe.gov/oiaf/aeo/.

26. Koomey, J.G., Mahler, S.A., Webber, C.A., McMahon, J.E., 1999. Projected regional impacts of appliance efficiency standards for the U.S. residential sector. Energy: Int. J. 24 (January (1)), 69–84. Meyers, S., Williams, A., Chan, P., Price, S., 2015, March. Energy and Economic Impacts of U.S. Federal Energy and Water Conservation Standards Adopted From 1987 Through 2014. Lawrence Berkeley National Laboratory, Berkeley, CA. LBNL-6964e. https://ees.lbl.gov/sites/all/files/lbnl-6964e.pdf, obtained Sept. 17, 2015. For building codes see Livingston, O.V., Cole, P.C., Elliott, D.B., Bartlett, R., 2014, March. Building Energy Codes Program: National Benefits Assessment 1992–2040. Pacific Northwest National Laboratory, Richland, WA. PNNL-22610 Rev1. https://www.energycodes.gov/building-energy-codes-program-national-benefits-assessment-1992-2040-0, obtained 17 September 2015. For a summary view of impacts from utility programs and equipment standards, see Figure 18 on page 22 and Figure 19 on page 23 of Steven, N., Elliott, N., Langer, T., 2015, June. Energy Efficiency in the United States: 35 Years and Counting. American Council for an Energy Efficient Economy (ACEEE), Washington, DC. http://aceee.org/energy-efficiency-united-states-35-years-and.

27. See Hirsh, R.F., 1999. Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System. MIT Press, Cambridge, MA (Chapter 9).

28. Afsah, S., Limodio, N., Salcito, K., 2015, March 19. Did Energy Efficiency Break the Electric Utilities' Business Model? CO2 Scorecard, Bethesda, MD. Available from http://www.co2scorecard.org/home/researchitem/32, obtained June 20, 2015.

29. Calculations based on data in Figure 1.

30. John A. ''Skip'' Laitner, J.A., Ehrhardt-Martinez, K., 2008, February. Information and Communication Technologies: The Power of Productivity; How ICT Sectors are Transforming the Economy While Driving Gains in Energy Productivity. ACEEE Report E081, at http://www.aceee.org/sites/default/files/publications/researchreports/E081.pdf obtained July 27, 2011. Full disclosure: Richard Hirsh was a reviewer of the original manuscript of this document. This report has been updated and extended in John A. ''Skip'' Laitner, J.A., McDonnell, M.T., Ehrhardt-Martinez, K., 2014, November. The Energy Efficiency and Productivity Benefits of Smart Appliances and ICT-Enabled Networks: An Initial Assessment. ACEEE Report F1402, at http://aceee.org/research-report/f1402, obtained Sept. 15, 2015.

31. Percentages calculated from U.S. Department of Labor, Bureau of Labor Statistics, at http://www.bls.gov/emp/ep_table_405.htm, obtained Sept. 15, 2015.

32. U.S. Department of Commerce, Bureau of Economic Analysis. Gross-Domestic-Product-by-Industry Accounts, at http://www.bea.gov/industry/gpotables/gpo_action.cfm, obtained July 27, 2011.

33. Raw electricity price data from U.S. Department of Energy, at http://www.eia.gov/electricity/data/browser/#/topic/ obtained June 29, 2015, and the GDP deflator from Table 1.1.4 from the U.S. Bureau of Labor Statistics at http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=1&isuri=1, obtained June 29, 2015.

34. In Illinois, for example, the freeze on prices expired in January 2007, and rates exploded 26 percent and 55 percent for customers of two of the state's utilities. Customers in Maryland and Massachusetts experienced similar rate shocks. Davidson, P., 2007, August 10. Shocking Electricity Prices Follow Deregulation. USA Today, http://www.usatoday.com/money/industries/energy/2007-08-09-power-prices_N.htm, obtained Aug. 15, 2007. Also see Weil, M., 2006, March 8. Electricity Bills in Maryland May Rise: Legislators Attack Plans for Increases of up to 72 Percent. Washington Post, D1.

35. For example, see Schipper, L.J., Murtishaw, S., Unander, F., 2001. International comparisons of sectoral carbon dioxide emissions using a cross-country decomposition technique. Energy J. 22 (2), 35–75.

36. Annual electricity demand growth for the US industrial sector was at or slightly below zero from 1998 to 2013, and it didn't vary much. Demand growth for buildings fell from 3 to 4%/year to about zero in that same period. See Exhibit 5 in Afsah et al. 2015, Op. Cit. Note 31.

37. As of Sept. 2, 2015, the California Energy Commission and California Public Utilities Commission reported 3,220 MW of solar projects installed in the state. http://www.gosolarcalifornia.ca.gov/, obtained Sept. 6, 2015.

38. Wilson, ''PJM Long-Term Load Forecasting Methodology,''

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presentation, p. 2. Mr. Wilson noted that, as a rule of thumb, ''1% growth in RTO GMP [regional transmission operator gross metropolitan product] → approx. 1,000 MW growth in forecast RTO peak load.'' Using Mr. Wilson's methodology, in which he saw a correlation between gross metropolitan product and electricity consumption of about 0.64 and the PJM RTO's 2009 internal capacity at about 167,000 MW, a 1 percent growth rate would, indeed, yield about 1,000 MW. The 0.64 correlation factor, to be fair, dealt with the Mid-Atlantic region of the PJM, not the entire RTO. See Wilson, ''Direct Testimony,'' p. 23. PJM data from 2009 to 2010 from PJM, ''2010/2011 RPM Base Residual Auction Results,'' table 2, p. 3, at https://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/20080201-2010-2011-bra-report.ashx, obtained Aug. 24, 2015.

39. Wilson, J.F., 2010. Reconsidering resource adequacy, Part 2. Public Util. Fortn. (May), 41–47.

40. Op. Cit. Note 1, Wara et al. 2015.

41. The use of distributed generation has recently stirred much controversy, with some utilities seeking (and gaining) extra payments from customers who self-generate as a way to buffer other customers from the putative higher average costs incurred. For a general review of these actions, see Warrick, J., 2015, March. Utilities Wage Campaign Against Rooftop Solar. Washington Post. Available from: http://www.washingtonpost.com/national/health-science/utilities-sensing-threat-put-squeeze-on-booming-solar-roof-industry/2015/03/07/2d916f88-c1c9-11e4-ad5c-3b8ce89f1b89_story.html, obtained Aug. 24 2015.

42. Schurr, S.H., Netschert, B.C., 1960. Energy in the American Economy, 1850–1975: An Economic Study of Its History and Prospects. Johns Hopkins Press, Baltimore, pp. 35, 151.

43. See, for example, White, L.A., 1943. Energy and the evolution of culture. Am. Anthropol. 45, 335–356. ''On a common-sense basis, one might expect that the relationship between the growth in energy use and the growth in the country's total output of goods and services (the GNP) would show a high order of regularity,'' noted economists Sam Schurr and Bruce Netschert in 1960. After all, ''[e]nergy is so pervasive an ingredient in the production of all goods that it seems reasonable to expect that energy use should move in unison with overall production. Schurr, *Energy in the American Economy*, 16.

44. White, L.A., 1947. Evolutionary stages, progress, and the evaluation of cultures. Southwestern J. Anthropol. 3 (Autumn (3)), 187 (article runs from 165 to 192).

45. Ibid., 15,16. It should be noted that Schurr and Netschert used gross national product (GNP) as a measure of economic activity rather than GDP. GNP is often defined as the value of products and services produced by a nation's residence, regardless of their location. Hence, an American who works abroad to produce goods or services contributes to the GNP. GDP, by contrast, counts only contributions made by people residing in the United States, including those made by foreigners. Since 1991, the U.S. Department of Commerce's Bureau of Economic Analysis has used GDP as the primary indicator of economic value. U.S. Department of Commerce, Bureau of Economic Analysis, ''Gross Domestic Product as a Measure of U.S. Production,'' *Survey of Current Business* (August 1991), 8.

46. A review of changes in energy trends in the 1970s and early 1980s consists of Hirst, E., et al., 1983. ''Recent changes in US Energy Consumption: what happened and why.'' Annu. Rev. Energy 8 (1), 193–245.

47. U.S. Council on Environmental Quality, 1979. Environmental Quality—1979. U.S. Government Printing Office, Washington, DC, 323 and iii.

48. U.S. Department of Energy, Annu. Energy Rev., http://www.eia.gov/emeu/aer/overview.html.

49. Data from U.S. Department of Commerce, Bureau of Economic Analysis. Gross-Domestic-Product-by-Industry Accounts, at http://www.bea.gov obtained July 27, 2011.

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