

“Business implications of the falling cost of electricity”

AUTHORS	John C. Edmunds Charles Winrich
ARTICLE INFO	John C. Edmunds and Charles Winrich (2016). Business implications of the falling cost of electricity. <i>Environmental Economics</i> , 7(2), 9-18. doi: 10.21511/ee.07(2).2016.1
DOI	http://dx.doi.org/10.21511/ee.07(2).2016.1
RELEASED ON	Friday, 03 June 2016
JOURNAL	"Environmental Economics"
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”



NUMBER OF REFERENCES

0



NUMBER OF FIGURES

0



NUMBER OF TABLES

0

© The author(s) 2025. This publication is an open access article.

John C. Edmunds (USA), Charles Winrich (USA)

Business implications of the falling cost of electricity

Abstract

Sharp declines in cost per kilowatt-hour of electricity generated by wind turbines and solar panels have opened up major shifts in cost and supply of electricity. Using elasticity of price and income to analyze scenarios of much cheaper electricity reveals economic impacts well outside the range that has dominated the debate until now. The methods and computations give a wide span of impacts, and those methods led to unexpected and provocative implications.

Keywords: renewable energy, solar energy, wind energy, electricity price, elasticity of demand, energy intensive industries, competitiveness, comparative advantage, factor costs.

JEL Classification: Q21, P18, P28, P42, O14.

Introduction

Technological improvements in wind turbines and solar panels are making electricity much cheaper. Since 2009, the cost of generating electricity with wind turbines has fallen approximately by 50%¹. The turbines have become more efficient and new installations have used larger rotors. During the same time frame, the cost of solar has also fallen, because the cost of crystalline silicon photovoltaic panels has fallen dramatically. Production capacity outpaced demand, and there have also been improvements in semiconductor fabrication and economies of scale, as volume of production has grown.

The decline in cost per kilowatt-hour is predicted to continue, so it is useful to contemplate the business implications. The cost reductions have already reached “grid parity” in many regions² and, if cost reductions continue, the price of electricity coming from new installations might fall enough to have pervasive effects beyond the electric utility industry. Depending on the country and the region, these cost declines could alter the mix of economic activities that will be profitable; the cost declines can broaden the market for electricity, while shrinking the market for other forms of energy. In the electric utility industry, wind and solar are already supplanting older generating technologies. In regions where electricity has chronically been expensive and erratic, the adoption of new wind and solar generating facilities might complement existing generating facilities, before displacing them. And, in countries where electricity has been expensive and erratic, the advent of cheaper, more routinely available electricity might accelerate the obsolescence of capital

equipment in industrial sectors that seemed unlikely to be affected.

Most electricity still comes from burning hydrocarbons³. The shift from coal to natural gas has attracted attention in the financial press. The transition to renewables still seems decades away, but business leaders are becoming aware that wind and solar are no longer exotic technologies that depend on subsidies to be viable. Because progress has been so rapid, it is useful to consider what the most direct implications will be, as these alternate ways of generating electricity take market share away from traditional sources. It will also be worthwhile to speculate about the knock-on effects, as the cost reductions ripple through the broad economy. Many large-scale enterprises might suffer rapid downsizing; and some capital equipment might suddenly experience sharp increases in demand, or face abrupt obsolescence.

To frame this discussion, we posit four levels of cost per kilowatt-hour. These are 8 cents, 6 cents, 4 cents, and 2 cents. Those figures refer to cost at the busbar. Improvements in the distribution and delivery systems are occurring, but are not as dramatic as the improvements in generation. The 8-cent level has already been achieved in installations in Texas and New Mexico⁴. The 6-cent level has been announced in Texas, and so has a 4-cent cost. For wind farms, costs as low as 2.5 cents per kilowatt-hour have been announced. For the calculations presented here, we consider that the 4-cent and 2-cent levels are still in the future; but those levels and lower might be achieved in the near future, so investors, business leaders and government officials will need to be prepared for the implications. There will be direct and indirect employment effects, and also shifts in the kinds of economic activity that are profitable in each region.

© John C. Edmunds, Charles Winrich, 2016.

John C. Edmunds, D.B.A., Professor of Finance, Babson College, Wellesley, USA.

Charles Winrich, Ed.D., Director of Science, Babson College, Wellesley, USA.

¹ Cardwell, Diane. Solar and Wind Energy Start to Win on Price vs. Conventional Fuels, New York Times, 23 November 2014.

² Clover, Ian. Buffett strikes cheapest electricity price in US with, *PV Magazine*, 08 July 2015.

³ Patel, Tara. Fossil Fuels Losing Cost Advantage Over, *Bloomberg*, 31 August 2015.

⁴ Feldman, David, Galen Barbose and Robert Margolis. *Photovoltaic System Pricing Trends*. Presentation. 2014.

In order to conduct this analysis, we concentrate on electric power generation coming from the two sources, and exclude from our analysis electricity coming from other promising technologies. We also exclude liquid fuels from our analysis, except to note that reductions in demand for liquid fuels might occur as electricity from wind and solar gain market share.

In any discussion of energy, it is always difficult to strip away subsidies, taxes, penalties, and other distortions, to reach the true economic cost of each source. We acknowledge the difficulty and use a real-world test to infer when wind or solar become cheaper than fossil-fuel generating plants for specific locations in specific countries. Our test is when an electric utility makes a large investment in a new facility to generate electricity, we infer that the experts who decided which technology to adopt took all relevant calculations into account. Those calculations include political and environmental factors, so we do not conclude that one or two big investment decisions prove that one technology deliver cheaper electricity than another. But, as more decisions are made, and one team of experts after another chooses wind or solar, we infer that costs have shifted in favor of those two.

In recent months, there have been high-profile announcements of new generating facilities and a vigorous debate that, taken together, focus attention on current designs and raise the question whether solar, wind, or natural gas generating facilities have lower costs per kilowatt-hour at the busbar. That debate is informative, and reveals that wind and solar are frequently winning when electric utilities are choosing what sort of new design will replace aging coal-fired plants.

As of 2013, the average retail price of electricity in the U.S. was almost exactly 10 cents per kilowatt-hour for all categories of users, including residential, commercial and industrial⁵. That is a convenient benchmark for our scenarios. For electricity costing 8 cents or 6 cents per kilowatt-hour, the implications will be for changes within the existing composition of industries and infrastructure. For the scenarios with costs per kwh of 4 cents and 2 cents, we conduct what physicists call a “thought experiment” and our experiment takes, as a starting assumption, that wind and solar become cheaper than power from traditional generating plants and, then, gain market share. The implications of such big declines in the price of electricity will be beyond the parameters of the existing composition of industry and infrastructure.

We note, in passing the widely-cited disadvantage, that both solar and wind are intermittent. Traditional plants fired by coal or natural gas can deliver conti-

nuous supply. Storing electricity is expensive and involves losses in storage. Batteries are still expensive, but are becoming cheaper, and the total amount of battery storage is growing⁶. For purposes of this analysis, the cost of cheap electricity from intermittent sources needs to be adjusted for the cost of storing it, so that it can be compared to the cost of power from traditional coal-fired and gas-fired plants. This will slow the transition, but will not stop it.

Our results cover a wide range and suggest that major shifts in business profitability might be coming soon. We acknowledge that the results may be inexact, or may not come to pass for reasons not contemplated in our analysis. We hope that our analysis draws attention to a major macroeconomic trend, and prompts business leaders to take appropriate actions to benefit their organizations and society at large.

Previous studies

For such an ambitious research project, there are many previous lines of research and scientific development that together provide the foundation materials for the present study. In the energy field, we cite Boltzmann’s entropy formula (1879) as the most elegant and decisive proof that energy must always have a cost. As a classic example of the potential cost reductions that can theoretically be achieved, we cite the optimistic period in the early 1950s when the “plutonium economy” appeared feasible, and could potentially make the cost of generating electricity so low that it would not be necessary or worthwhile to install meters to bill users for their consumption of kilowatt-hours. We acknowledge that there may have been a propaganda element to the optimistic forecasts about how much electricity could be produced by recycling spent fuel rods in fast breeder reactors, and how many thousands of years the earth’s U-238 could last. We also take note that, from time to time, inventors claim to have developed clever devices that can covert ordinary water into hydrogen and oxygen. The energy field is replete with visionaries, and also has its share of crackpots. We offer our analysis knowing that events will, probably, unfold in unexpected ways.

For the historical rates at which costs of generating electricity with wind turbines and solar panels have declined, we consulted multiple sources, and have also consulted forecasts of future declines in the costs of these two technologies. For solar cells, there is the debate about Swanson’s Law⁷, the observed decline in cost per watt of solar panels. We found a

⁵ http://www.eia.gov/electricity/annual/html/epa_01_01.html.

⁶ <http://gizmodo.com/teslas-new-battery-could-solve-one-of-solar-powers-bigg-1699555784>.

⁷ U.S. Energy Information Administration. *Total Electric Power Industry Summary Statistics*, 2013 and 2012. n.d. Webpage. 27-09-2015. http://www.eia.gov/electricity/annual/html/epa_01_01.html.

range of forecasts for future costs per kilowatt-hour, to take into account the cost trajectories that different expert analysts have put forward. All the cost trajectories that we found projected continuing cost declines.

To estimate how much more electricity might be demanded if the price per kilowatt-hour declines, we use the elasticity concept from neoclassical economics. This method has a long history and has well-known limitations. We use two variants of elasticity: price elasticity and income elasticity. Both use the method of comparative statics, a mainstay of neoclassical economic analysis.

Elasticities and income growth projections allow computing future demand in kilowatt-hours from an initial rate of consumption and an initial price per kilowatt-hour. For price to consumers and industrial users, we use EIA data⁸, and we use EIA data for the beginning amount of consumption.

Scope and methods of analysis and forecasts

Our analysis covers two ranges of price reductions. The first range is price reductions of 20% and 40% of the current local price the users are paying. These percentages correspond to price declines to 8 cents and 6 cents per kilowatt-hour. The second range is price reductions of 60% and 80%, which correspond to price declines to 4 cents per kilowatt-hour and 2 cents per kilowatt-hour.

The effects of price reductions can induce more use of electricity and can also alter the profitability or viability of broad categories of economic activity. We address both possibilities in our analysis and here is how we do that. To compute the effects of the first range of price reductions, we use an elasticity approach.

There are many studies of the elasticity of demand for electricity⁹. Most focus on changes in demand that would occur in the industrial countries. Their results can be relevant to assessments of demand in the higher income emerging countries.

In neoclassical economics, elasticity of demand is measured with respect to price and also with respect to income. The elasticity of demand is reported as a negative number, e.g., -0.3, meaning that when the price rises by 1%, the demand falls by 0.3%. The price elasticity of demand estimates how much more of a product or service a user would demand, if the price falls 1%, and how much less the user would

demand, if the price rises by 1%. The income elasticity of demand is a similar metric, which estimates how much more or less of a product a user would demand, if the user's income rises or falls by 1%.

There are carefully done studies of price and income elasticity of demand for electricity. It is tempting to use the estimates for the price and income elasticities to compute the amounts in kilowatt-hours of electricity that would be demanded if the price falls. We attempted to use estimates of elasticity to forecast changes in kilowatt-hours demanded, but the weather played such a big role that its effect swamped the influence of price and income. That result, which we report in Appendix 1, should not be surprising, and does not undermine the logic of the elasticity method. It should be noted that the elasticity measure is accurate only in the narrow price range that existed when the study was done, and only when other factors are held constant. For the large price reductions that we are considering here, the elasticity estimates are no more than a good beginning. Moreover, the *ceteris paribus* assumption – i.e., that other variables do not change – excludes, at least, two major influences from the computation. Those are the effects of the economic cycle (i.e., recession or prosperity) and the weather, as measured by degree-days.

It is also important to note that, in the short run, users cannot adjust their pattern of use as much as they can in the long run. For that reason, studies of elasticity distinguish between short-run elasticity and long-run elasticity. For example, if the price of gasoline rises sharply, commuters keep driving to work, if they live far from public transportation. But, if the price rises and stays high, commuters can move to houses or apartments that are nearer to public transportation.

The studies we cite here find that, the demand for electricity is price-elastic, in the long run, but inelastic, in the short run. That is, when the price drops, the increase in demand, in the short run, is only about -0.2, but, in the long run, is about 0.3¹⁰. Understandably, it takes time for users to react. So, if the price to the user falls by 1%, the user's response is to consume 0.2% more immediately, and 0.3% more in the following year.

Estimates of income elasticity are of similar magnitude, but positive – higher income is associated with higher consumption, but not in the ratio of 1:1. In the short run, changes in income do not lead to such large increases in consumption, as they do in the long run.

⁸ Ibid.

⁹ Wilder, Ronald, P., Joseph E Johnson and R. Glenn Rhyne. (1992). Income Elasticity of the Residential Demand for Electricity, *The Journal of Energy and Development*, pp. 1-13.

Borenstein, Severin. (2009). To What Electricity Price Do Consumers Respond? Residential Demand Elasticity Under Increasing-Block Pricing, *NBER*, pp. 1-37.

¹⁰ Ibid.

With these figures and with the limitations of neoclassic methods in mind, we compute the following increases in demand related to reductions in price.

Table 1. Electricity demand changes from price reductions

20% reduction in price implies	6% increase in demand	3,725,103 *0.06 millions of kwh
40% reduction in price	12% increase in demand	3,725,103*0.12 millions of kwh

To continue the elasticity analysis for the first range of price reductions, we use 0.4 as the income elasticity of demand, and we assume that the Gross Domestic Product grows at 2%.

20% reduction in price implies	8% increase in demand	3,725,103 *0.08 millions of kwh
40% reduction in price	16% increase in demand	3,725,103*0.16 millions of kwh

These magnitudes imply major shifts in infrastructure needs. Some inputs will not be required in the amounts that used to be the norm. Other inputs will be required in far greater amounts. These shifts in primary demand cause knock-on effects, “derived demand” in economists’ terminology, and those knock-on effects need to be thoroughly examined. Here we make two attempts to characterize the knock-on effects.

Before discussing the effects on other sectors of the economy, we offer forecasts of the increase in demand for electricity for bigger declines in the retail price. These are for two time horizons: immediately after the price falls, and over a longer period of time, when users have had time to replace their old capital equipment with new equipment that is adapted to the new lower price of electricity.

To calibrate the magnitude of these increases in demand for electricity, we express the increase in terms of how many new gigawatt-scale power plants would be needed to generate that amount. Of course, the capacity increases will not take the form of new gigawatt plants, but it will be useful to calibrate the amounts of electricity in that way. Using cost estimates from the U.S. Energy Information Administration, it is possible to estimate how many billions of capital investment would need to be financed. From those estimates, business analysts can forecast demand for each input, and can estimate associated needs for transporting and installing the new equipment that would be used, including wind turbine components and solar panels.

Table 2. Cost of building a new gigawatt-scale generating plant

Cost of building a new gigawatt-scale generating plant		
	Generating capacity per unit & number of units	“Overnight” construction cost (i.e., no finance charges) in 2012

Case 1: gasified coal, combined cycle plant	600 MW per unit (2 units needed)	\$4.54 M
Case 2: natural gas, combined cycle	620 MW per unit (2 units needed)	\$1.14 M
Case 3: offshore wind	*EIA calculated cost of a 400 MW wind farm, so three such facilities would be needed.	\$7.48 M

The cost of new power plants varies greatly by the technology. However, given the forecasts above about the change in electricity demand, we consider the costs associated with building those new facilities in Table 3.

Table 3. Range of estimated number of plants needed for each drop in the price of electricity

20% cost reduction	~30,000 new power plants	\$150 billion
40% cost reduction	~60,000 new power plants	\$300 billion

Implications for other sectors of the economy

To organize the discussion of the business implications, we use two time horizons. The first is immediately after the price drop, and the second is longer term, meaning five years or more. That is why, for the price drops to 4 cents and 2 cents per kilowatt-hour, we forecast the immediate increases in demand and the long-run increases in demand. Our “thought experiment” does not compute shifts in market share of the kinds of generating plants. These shifts have already been computed by the IEA. Business analysts might accelerate the shifts to highlight the businesses that will benefit and the ones that will suffer. The key question for analyzing the shift in market share of the kinds of generating plants sources is to observe what happens when a coal-burning plant reaches the end of its economic life and is replaced. Most will not be replaced by new coal-burning plants. Instead, some will be replaced by natural gas-burning facilities, and others will be replaced by wind and solar, possibly, in conjunction with storage facilities.

We can now identify two obvious implications of the shift in sources. One is the transition away from coal and the other is the slower transition away from gasoline and diesel-powered cars. Railroads will transport less tonnage of coal, and the stock market has already marked down the shares of the major U.S. railroads to adjust for the reduced traffic. The shares of CSX, for example, fell from \$35 per share in November 2014 to \$26 in September 2015¹¹. That has already been amply reported in the financial press. As an example of a knock-on effect, companies that manufacture railroad cars and locomotives will already have been affected, and can expect fe-

¹¹ New York Stock Exchange.

wer orders in the future. For the transition away from gasoline and diesel-powered cars, the stock market might have taken note of the outlook, but there are too many countervailing and confounding influences. So, the share prices of refinery stocks have declined, but not in synchronization with the shift toward electric cars. The share prices of refinery stocks appear to move in response to changes in refiners' profit margins, and those margins are the result of complication regulations interacting with the falling price of crude oil. As another example of a knock-on effect, coal mining towns and regions face a bleak future, and the financial press has reported that those towns and regions have been stagnating and losing population for many decades. The knock-on effect for towns that depend on oil refining has been reported as cyclical, but now it might be more accurate to view their bleak outlook as secular stagnation, not as cyclical.

As an example of another industry that will be affected, consider bauxite and aluminum production. Bauxite is abundant in the earth's crust, but it needs to be accessible for mining to be cost-effective. The places where it is easiest to mine do not happen to be near places where electricity is cheap. In consequence, the aluminum industry moves large tonnage of ore to smelters, and, then, moves the aluminum ingots to places where fabrication and consumption are located. If electricity can be produced cheaply near bauxite mines, the tonnage to be moved falls sharply, because the bauxite would be smelted in the immediate vicinity. The transport cost component of aluminum would drop. The implications are for a relative drop in the price of aluminum, and a much steeper drop in the demand for ships that carry ore. The ships that carry aluminum ingots would still be needed in approximately the same amounts, because the bauxite smelters would still be a long distance away from the factories that transform the aluminum into finished products.

To complete our examples of industry sectors that would be profoundly affected by the transition to cheaper electricity coming from these two sources, we cite cement and glass, two of the most energy-intensive industry sectors, in the United States and also, in the case of cement, in India. These would experience transformational restructuring, with profound repercussions for transport companies. It has been cheaper to bring limestone, clay and sand to places where energy is cheap, make the cement or glass there, and, then, transport the finished product. What if the cement and glass can be made at the source of the heaviest ingredient? The total shipping required to move from raw materials to delivery of the finished products would be sharply reduced, and the bulk carriers would be most affected.

And hiding in plain sight is the energy industry itself, which is, not surprisingly, the biggest user of energy. The energy industry is a big part of the macroeconomy, so it can be expected to use large amounts of energy, but it uses more than its proportional share of GDP. The energy sector is, indisputably, the largest user of energy, if we include all stages of extraction, transport, refining, wholesaling, and retailing. The effects of the inroads that solar and wind have made are co-mingled with the more sudden impact of the September 2014 oil price collapse. The sector most affected in the fourteen months since that headline-grabbing plunge has been the heavily indebted U.S. independent oil producers who went headlong into fracking. The companies fail, and go into bankruptcy court, but the wells they developed continue to operate, until their incremental costs of production rise above the market price of crude oil.

Implications of bigger declines in retail electricity prices

It is challenging to consider the implications of even lower prices for electricity, but decision makers in business and government need to take the possibilities seriously, because entire industries would be transformed or eclipsed by price declines of the magnitudes in our second range. Those who have had contact with the electronic industry have grown almost blasé about a product's three to five year life cycle from expensive experiment to commercial commodity. Wind and solar power have crept quietly into the mainstream, because the cycle has taken more than fifty years! But that leisurely pace is accelerating, and now the data on solar and wind performance and consumer adoption are coming in so rapidly that financial reporting and the perceptions of informed people have not fully registered the new information. Policy discussion is still framed in terms of "alternate" and "renewable" when "alternate" is becoming "conventional". The fragmentary data coming in are beyond skepticism. Major solar installations in such locations as south and central Texas are generating electricity in volume on a sustained basis at less than 8 cents per kilowatt-hour. There are also reports of utility-scale installations in comparable locations of 6 cents per kw/hr¹², and anecdotal reports of solar generation at 4 cents per kw/hr. Wind energy reports significant production at 2.5 cents per kilowatt-hour, but necessarily not on a fully sustained basis. All of this is down from 10 to 15 cents per kilowatt-hour recently as 2012¹³. At

¹² Feldman, David, Galen Barbose and Robert Margolis. (2014). *Photovoltaic System Pricing Trends*. Presentation.

Proctor, Cathy. (2014). Solar power prices are dropping fast, NREL says, *Denver Business Journal*, 20 October 2014.

¹³ Ibid.

prices as low as 4 to 5 cents per kilowatt-hour – sustained and in volume – wind and solar are fully competitive with fossil-generated (coal, natural gas, diesel, propane) power, independent of subsidies, both hidden and overt, and geopolitical or environmental concerns. New houses in cloudy New England increasing have solar panels on the roof, even if the house is shaded by tall trees. These installations are partially subsidized, but, nevertheless, the cost effectiveness of these panels has shifted, profoundly and permanently, even in regions that do not receive very much sunlight.

To assess the full implications, we recall two universally accepted, yet, frequently misunderstood economic laws:

- ♦ Any commodity in a free market prices itself on the marginal unit of supply and demand. No one can pretend that, in a world dominated by OPEC, and a daunting tangle of regulations in each region, energy is a truly free market commodity, yet we have seen repeatedly how small changes in supply can produce or augment radical fluctuations in price.
- ♦ Energy is hard to store, and the demand for it is price-insensitive, in the short run. The huge fluctuations in oil prices we have seen repeatedly have been reinforced by the fact that all the oil tanks on the East Coast can only hold three weeks supply. The shortage of oil tanks, and the obstacles to building new tank farms, have given wind and solar an important – and largely unpublicized – boost. The disadvantage of inadequate and costly storage is being overcome by advances in battery technology. Tesla Motors, in the short run, expects to earn more money from its giant in-construction battery factory than from selling cars. So, if soon a user can store solar power longer than oil in the tank, solar becomes the risk averse preference.

Add these two together shows how it can happen that relatively small changes in the percentage of electricity generation provided by wind and solar may wreak havoc on oil prices. Meanwhile, improvements in reliability and cost of battery storage could undercut OPEC's already shaky prospects for sustaining oil prices look even worse. So, OPEC might become an anachronism, an ineffective defender of an oligopoly that was dominant in a bygone era.

Yet, even more profound questions arise. One way of framing these questions is to imagine that existing

buildings, roads, ports, and industrial plants do not exist, and, then, think of how today's decision makers would lay out the roads, the industrial clusters, the housing areas, and the parks, in response to the new relative prices of inputs and the preferences of the people who would live and work in each region.

That mental exercise would be difficult, because it requires conceptualizing from zero, from the most fundamental starting point. The results of this exercise could be surprising. For example, if electricity costs 2 cents per kilowatt-hour, it might not be cost-effective to insulate a house, even if the house is located where winters are cold. It might be less expensive to heat the house with electricity.

These estimates are enough to show how profound the implications might be. We ignore many dynamic effects, though we acknowledge that those can be large enough to lift demand far above the forecasts that we have presented here. There are famous cases of forecasts that were so inaccurate that the forecaster looked foolish. One such forecast was often attributed to Thomas Watson, the head of IBM, who allegedly said in 1943 that there would only be demand for four or five computers. If he really said that, he must have been thinking that automating Hollerith card data processing systems would be uneconomical. And he must have completely overlooked the possible applications of a machine that can perform fast, accurate floating-point calculations.

These estimates that we have presented here ignore possible future changes in subsidies, taxes, and other government policies that accelerate or retard the rates of adoption of new technologies in generating electricity.

Conclusion

Our scenarios hopefully draw attention to the coming shift in market share of wind and solar energy with the attendant implications for related sectors of the economy. Our scenarios also indicate which unrelated sectors of the economy will be affected positively or negatively. There will also be implications for geographical shifts – some activities will become profitable in places where they historically have not been located. We cannot hope that our scenarios will give forecasts for every sector and for every geographic region, and we cannot claim that our forecasts are precise, but we publish them, because they are timely and will contribute to analyses that others will do.

References

1. Arshad, Aameena, Muhammad Zakaria and Xi Junyang. (2016). Energy prices and economic growth in Pakistan: A macro-econometric analysis, *Renewable & Sustainable Energy Reviews*, pp. 25-33.

2. Bernstein, M.A. and J., Griffin. (2006). *Regional Differences in the Price-Elasticity of Demand for Energy*. U.S. Department of Energy Report. Santa Monica: National Renewable Energy Laboratory.
3. Blake, Clayton. (2014). The Case for Allowing U.S. Crude Oil Exports, *Renewing America – Council on Foreign Relations*, July.
4. Bordoff, Jason and Trevor Houser. (2015). *Navigating the U.S. Oil Export Debate*. New York: The Center on Global Energy Policy – Columbia University.
5. Borenstein, Severin. (2009). To What Electricity Price Do Consumers Respond? Residential Demand Elasticity Under Increasing-Block Pricing, *NBER*, pp. 1-37.
6. Cardwell, Diane. (2014). Solar and Wind Energy Start to Win on Price vs. Conventional Fuels, *New York Times*, 23 November 2014.
7. Clover, Ian. (2015). Buffett strikes cheapest electricity price in US with, *PV Magazine*, 08 July 2015.
8. De Vroey, Michel and Pierre Malgrange. (2009). From The Keynesian Revolution to the Klein-Goldberger Model: *Alternative approaches to the building of economic dynamics in the years of high theory workshop* - Sienna University.
9. Denholm, Paul and Paul Margolis. (2008). Supply Curves for Rooftop Solar PV-Generated Electricity for the United States, US Department of Energy Report.
10. Devadoss, Stephen and Martin Kuffel. (2010). Is the U.S. Import Tariff on Brazilian Ethanol Justifiable? *Journal of Agricultural and Resource Economics*, pp. 476-488.
11. Federal Reserve Bank FRED Economic Data. (2009). *Consumer Price Index for all Urban Consumers*. n.d. Webpage. 27.09.2015. Available at: <https://research.stlouisfed.org/fred2/series/CPIAUCNS#>.
12. —. *Personal Income and Outlays: Personal Income and Its Disposition*. n.d. Webpage. 27 09 2015. Available at: <https://research.stlouisfed.org/fred2/release/tables?rid=53&eid=42509>.
13. Feldman, David, Galen Barbose and Robert Margolis. (2014). *Photovoltaic System Pricing Trends*. Presentation.
14. Filippini, Massimo and Shonali Pachauri. (2002). Elasticities of Electricity Demand in Urban Indian Households. *Swiss Federal Institutes of Technology: Centre for Energy Policy and Economics*, Electronic.
15. Henderson, James M. and Richard E. Quandt. (1971). *Microeconomic Theory - A Mathematical Approach*, New York: McGraw-Hill. Book.
16. Katz, Cheyl. (2014). Will New Technologies Give Critical Boost to Solar Power? *Yale Environment* 360, 11 December 2014.
17. Krozer, Yoram. (2013). Cost and benefit of renewable energy in the European Union, *Renewable Energy: An International Journal*, February, pp. 68-73.
18. Mulder, Machiel and Bert Scholtens. (2013). The impact of renewable energy on electricity prices in the Netherlands, *Renewable Energy: An International Journal*, September, pp. 94-100.
19. National Grid U.S. *Heating Degree Days*. n.d. Webpage. 27.09.2015. Available at: https://www.nationalgridus.com/niagaramohawk/energy_supplier/gas_hdd.asp.
20. Patel, Tara. (2015). Fossil Fuels Losing Cost Advantage Over, *Bloomberg*, 31 August 2015.
21. Price, Catherine Waddams. (2008). The Future of Retail Energy Markets, *Energy Journal*, April, pp. 125-147.
22. Proctor, Cathy. (2014). Solar power prices are dropping fast, NREL says, *Denver Business Journal*, 20 October 2014.
23. Samuelson, Paul Anthony. (1947). *Foundations of Economic Analysis*. Cambridge: Harvard University Press, Book.
24. Swift, Kenton D. (2013). A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States, *Renewable Energy: An International Journal*, September, pp. 137-143.
25. Trivich, Dan. (1953). Photovoltaic Cells and Their Possible Use as Power Converters for Solar Energ, *Ohio Journal of Science*, pp. 300-314. Electronic. Available at: <http://hdl.handle.net/1811/4070>.
26. U.S. Energy Information Administration. *Total Electric Power Industry Summary Statistics, 2013 and 2012*. n.d. Webpage. 27.09.2015. Available at: http://www.eia.gov/electricity/annual/html/epa_01_01.html.
27. U.S. Energy Information Administration. *Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants*. April 2013. Web. 20.11.2015. Available at: http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf.
28. van Sark, Wilfried, G.J.H.M., Peter Muizebelt, Jadranka Cace, Arthur de Vries and Peer de Rijk. (2014). Price development of photovoltaic modules, inverters, and systems in the Netherlands in 2012, *Renewable Energy: An International Journal*, November, pp. 18-22.
29. Wilder, Ronald, P., Joseph E. Johnson and R. Glenn Rhyne. (1992). Income Elasticity of the Residential Demand for Electricity, *The Journal of Energy and Development*, pp. 1-13.
30. Wilson, Lindsay. What's The Average Price of Electricity In... 30.09.2013. *Clean Technica*. Webpage. 28.09.2015. Available at: <http://cleantechnica.com/2013/09/30/average-electricity-prices-around-world/>.

Appendices

Appendix 1. Evidence of declining cost solar power and reasons for the decline

There are many ways to convey how rapidly the cost of solar panels has fallen. Our favorite is that panel prices per watt generated fell 86% from in 1996 to 2013¹⁴ – and have fallen another 12% between 2013 and 2015¹⁵. The long-awaited threshold of \$1 per watt has been crossed, and the lowest-priced panels are quoted at 42 cents per watt. And a well-regarded engineer predicts that prices per watt will fall yet 40% more in the next two years.

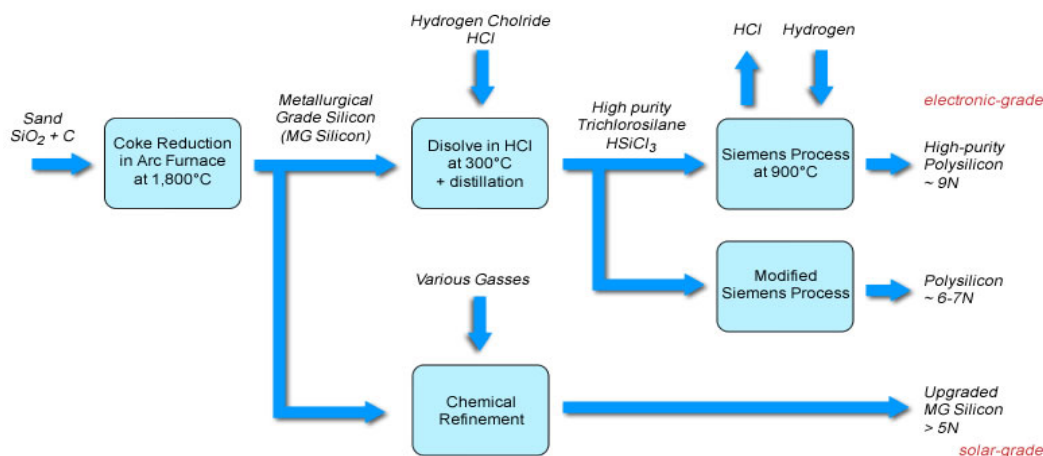
To explain this precipitous drop, we cite well-known phenomena in the field of industrial engineering, the learning curve; and economies of scale. Adding to those, we cite breakthroughs in coatings applied to the solar panels. These coatings capture more of the available spectrum of light that falls on the surface of the panel. With better coatings, the panel absorbs more of the light and reflects less.

It is also argued that solar panel production ramped up in anticipation of subsidies to owners of buildings and land who install solar panels. The world economy went into recession in the second half of 2008, and the recession proved deeper and longer than any recession since the Great Depression. As the recession continued, manufacturers cut the prices of the panels as they scrambled for a market that was shrinking. Serendipitously, as they cut the prices, they made utility-scale installations viable in many regions where previously natural gas and coal plants had produced electricity more cheaply.

The price war caused a shakeout in the solar panel industry. That is not surprising; but what is surprising is that the solar panel producers who have survived are able to make profits at the low prices that currently prevail. An industry analyst reported that Chinese producers shipped 48 gigawatts of panels in 2014 and 61 gigawatts in 2015. The producers took in revenues of \$31 billion and \$38 billion in those two years. The price per watt was \$0.64 in 2014 and \$0.62 in 2015. That is a 3% decline, a smaller decline than the preceding years – but the producers' gross margin increased from 7% to 13%¹⁶.

That results suggests that the price war has lowered the prices enough so that solar panels are finding much more mainstream applications. And it also suggests that the installed capacity of the solar panel industry is no longer so much larger than the demand. That results suggest that the price war has lowered the prices enough so that solar panels are finding much more mainstream applications. If the producers were able to survive with gross margins of 7%, they are profitable now with gross margins at 13%, and no longer passing on all the cost reductions to customers. And it also suggests that the installed capacity of the solar panel industry is no longer so much larger than the demand.

The cost of producing silicon for solar panels is much lower than silicon for CPU chips. The required purity is only 99.999%, whereas the required purity for CPU chips is 99.9999999%. Diagram 1 shows the production techniques for both types of silicon, and shows that the two techniques would have entirely different cost profiles. Business-oriented readers can appreciate how different the two processes are, and can also infer that an oversupply of one type of silicon will not affect market conditions for the other type of silicon.



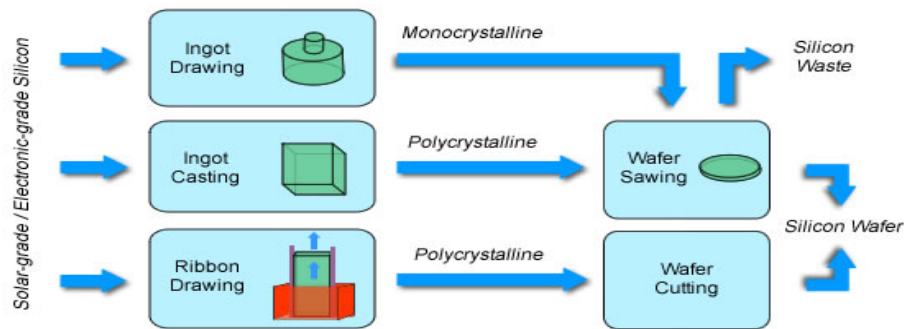
Source: Green Rhino Energy.

Fig. 1. Making silicon for solar panels

¹⁴ ReVista, Harvard Review of Latin America, Fall 2015 issue on Energy, p. 41.

¹⁵ Computed from <http://www.solarreviews.com/news/top-chinese-manufacturers-will-produce-solar-panels-for-42-cents-per-watt-in-2015/>.

¹⁶ http://www.pv-magazine.com/news/details/beitrag/ihs--module-gross-profits-to-double-in-2015_100019362/#axzz3pcj0n3Fl.



Source: Green Rhino Energy.

Fig. 2. Making silicon for CPU chips

The implication of these trends is that the price war shook out many producers, and also that there can soon be another round of price cuts, as the surviving producers try to defend their market share. Every price war, when it happens, drives another round of struggle for market share, not only within the solar panel industry, but also competing for utility-scale installations against natural gas and nuclear power plants.

Appendix 2. Evidence of declining cost wind power and reasons for the decline

Improvements in wind turbines have been incremental, and knowledge about choosing locations and heights has also improved incrementally. These unspectacular, but steady improvements have made wind turbines the most successful new technology to be implemented since the Fukushima nuclear reactor accident in 2011. Total megawatts of wind turbines installed in the U.S. were 25,741,039 from 2011 to 2015. But total megawatts of solar panels installed surpassed wind turbines for 2013 and 2014¹⁷. The data indicate that these two technologies are running neck and neck, without competing directly with each other, because the success of one does not imply the rejection of the other.

If wind turbines have become more conspicuous, it is because of the key relationship between the length of the rotors and the power the turbine can generate. As the rotor becomes longer, the power increases as the square of the length. So a turbine with 20-meter-long rotors generates four times as much power as a turbine with 10-meter-long rotors. For that reason, designers are advocating 120 meter towers, in contrast to the 85 meter towers that were the dominant design.

There are other factors that influence how much electricity a wind turbine can produce. These include the design of the blades, the gearboxes to transfer the mechanical energy to the generator, and the location of the towers. Offshore wind blows more steadily, with no hills to break it into turbulent cross-currents; but offshore towers are more expensive to build, even if the water is shallow. So, the preferred locations are on ridges in zones where the wind speed and consistency are favorable.

Appendix 3. Sample calculations illustrating price and income elasticity

In the literature of neoclassical economics, it is customary to compute the income elasticity of demand and the price elasticity of demand separately, and then combine them, ignoring second-order interactions between the two. We follow that convention here. As starting points for computations, world electricity consumption in 2014 was 20,450 billion kilowatt-hours; and U.S. consumption in 2013 was 3,725,103 million kilowatt-hours. The weighted average retail price that we use is \$0.1007 as reported by the EIA.

To work with those starting figures, we need annual projections of income growth. We use nominal rates of 2%, 3%, and 4%. These include inflation, and the target rate of inflation is 2%, so the real growth rates that we use are 0%, 1% and 2%.

Using 0.30 as the income elasticity of demand, the income-driven component of demand growth per year for electricity will be

$+0.30\% \times 2\% = +0.60\%$
$+0.30\% \times 3\% = +0.90\%$
$+0.30\% \times 4\% = +1.2\%$

For income growth of 2%, 3%, and 4% respectively.

These increases would be (for the world) 122, 184 and 245 billion kilowatt-hours.

The price-driven component will be much greater, even for the smallest of the price declines we are considering here.

To consider a 20% price decline from current levels, the price elasticity of -0.28 would give the following increases in demand:

For the world $20,450 \times (-0.2 \times -0.28) = 1,145$ billion kwh.

¹⁷ <http://www.seia.org/sites/default/files/Q4%202014%20SMI%20Fact%20Sheet.pdf>.

Adding the two components of the increase in demand gives 1267 to 1390 billion kwh of increased consumption in the first year.

Appendix 4. A more detailed elasticity computation illustration for the U.S.

The U.S. Energy Information Administration Total Electric Power Industry Summary Statistics data indicate that total U.S. electricity retail sales to residential, commercial, industrial and transportation uses was 3,725,103 thousands of megawatt-hours for 2013. For 2012, the figure was 3,694,650, so the figure for 2013 was 0.8% higher than the amount purchased in 2012. We illustrate the method of using elasticities by decomposing the total increase in consumption into a component that is attributed to change in income and a component that is due to change in price.

To begin the calculation, we obtain the change in price per kilowatt hour and the change in personal income. These figures come from the Energy Information Administration and the Federal Reserve of St. Louis Economic Data site. During the time interval 2012 to 2013 the weighted average price of electricity to all classes of users went up 2.3%. That aggregate figure lumps together regions where prices rose more and regions where prices rose less, but the scope of this analysis is broad, so we use the average price increase knowing that regional differences and pricing schemes might be important for smaller regions or for particular climate zones. For the change in income, we use the data for U.S. personal income adjusted for inflation. Real (i.e., inflation-adjusted) personal disposable income declined 1.4% from 2012 to 2013 in the United States. Disposable personal income, not adjusted for inflation, rose 1.1% from 2012 to 2013. The two figures for income are consistent with the Federal Reserve's calculation of inflation for the time interval. The Federal Reserve reports an array of inflation indicators, each using different inputs and assigning different weights, or excluding food and energy. We give, as an example, the Consumer Price Index including food and energy. That rose 1.6% during the time period, so there is a small disparity between the inflation-adjusted income figure of -1.4% and the income figure in current dollars, which rose 1.1%. We do not attempt to reconcile these differences, and we acknowledge that other data measuring income in the U.S. indicate slightly different changes from 2012 to 2013. We chose to use personal income because it is a measure of what people perceive and see coming in, so it would affect their decisions to purchase electricity if the elasticity arguments applies to such purchases.

Next we obtained estimates of price and income elasticity of demand for electricity. These are in the range of -.3 for price elasticity and +0.25 for income elasticity. These estimates are for short-run elasticities. For longer periods of time, classical microeconomics argues that elasticities are larger because in the longer run people have time to change the equipment they use, relocate their businesses, or relocate to housing in other places. Specifically, for gasoline, a well-regarded study found that the short-run price elasticity is -0.28 and the long-run price elasticity is -0.58. That is a big difference, and will be useful to keep in mind when we consider large declines in the price of electricity.

Long-run income elasticity of demand for electricity is very important for this study, because, in poor countries, households acquire more appliances and use more electric lighting as their income grows. The study by Massimo Filippini and Shonali Pachauri for India found that income elasticity of demand was approximately 0.7, taking into account differences between winter and summer and regional disparities. We use their figure to illustrate the elasticity method applied to a long run projection.

To illustrate the elasticity method used here, we begin with the 2012-2013 annual increase in electricity purchases cited above. The increase was 0.8%. The procedure is to attribute this increase to higher income and the depressing effect of higher price. The ceteris paribus assumption, i.e., holding all influences unchanged except for one, allows taking each elasticity and applying it, to compute the total effect. The Slutsky equation of microeconomic theory formalizes this procedure. In the case of 2012-2013 for the United States, the short run income elasticity should have contributed a 0.33% increase in demand. That uses 0.3 as the figure for short-run income elasticity and 1.1% as the increase in personal income, so $0.3 \times 1.1\% = 0.33\%$. Using the figure -0.28 as the short run price elasticity, and the price increase of 2.3%, sales of electricity should have decreased by 0.64%. The combined effect should have been

$$+0.33\% - 0.64\% = -0.31\%.$$

This figure does not match the +0.8% increase that happened. The combined effects of the elasticities missed the correct figure for many reasons. There are many factors that this computation leaves out. Most notably, variations in climate influence consumption. Degree-days, a metric of how cold the winter is, were 20.7% higher for 2013 than for 2012. The coefficient for climate, according the study by Bernstein and Griffin, is 0.246, so that increase in degree-days should have accounted for an increase in consumption of $20.7\% \times 0.246 = 5.1\%$. Taking that into account gives

$$+0.33\% - 0.64\% + 5.1\% = +4.79\%.$$

That figure, once again, does not match the +0.8% increased that happened.

These computations illustrate the method and also show that it does not give reliable results in specific situations and also intentionally does not take into account other influences that can have large effects. We do not include climate variations or factors other than income and price, because the scope of analysis is macro and long-term, and macro studies using long-term data do show that demand for electricity is responsive to price and income.

You can use the following link to access the Table: www.johncedmunds.com/articles/BusinessImplications-TABLE.pdf.