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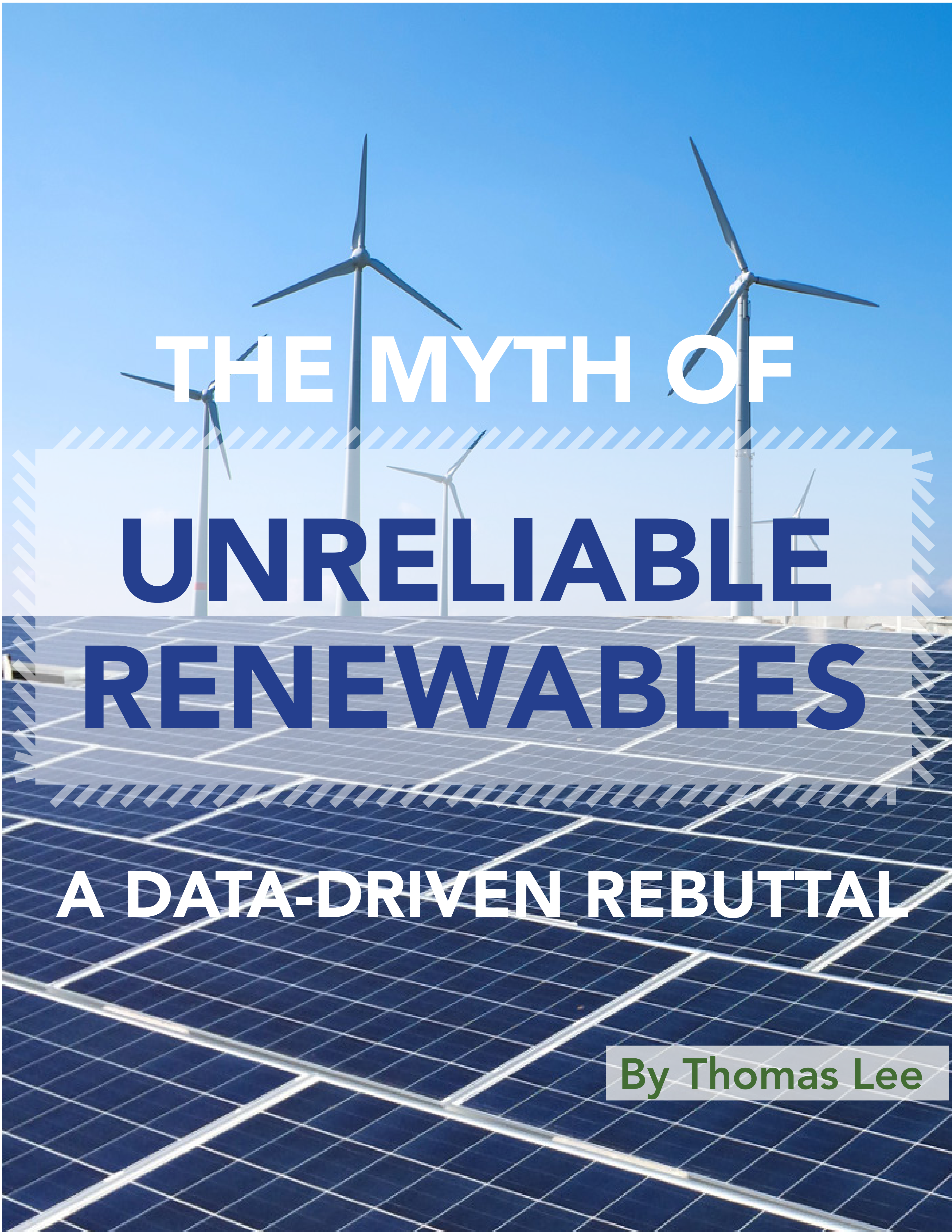


THE MYTH OF UNRELIABLE RENEWABLES

A DATA-DRIVEN REBUTTAL

By Thomas Lee

"The sun doesn't always shine and the wind doesn't always blow." While the intermittency of renewable energy sources like solar and wind represents a genuine engineering, economic, and policy challenge, many politicians wield only this single concern about unreliability to justify their opposition to increased renewable energy utilization. At the extreme, some fear that rapid deployment of renewable energy will cause massive blackouts and push civilization back to the dark ages. This article seeks to quantitatively challenge these assumptions.

INTERMITTENCY AND BLACKOUTS

Intermittency consists of two factors in the primary energy supply: variability and uncertainty. Variability refers to how much the available amount of solar and wind energy changes across different timescales, and uncertainty refers to how much our human forecasts differ from the actual amounts. Due to the need for constant balance between generation and consumption on the grid, these two factors are incredibly important for grid operators.

The Economist argues in its 2015 special report on climate change that "[m]ore renewable power is not always better" because wind and sunshine are "erratic. " Utility companies who have "over invested in generating capacity from fossil fuels" in Europe now "worry that the growth of solar and wind power is destabilising the grid, and may lead to blackouts or brownouts."

Oklahoma Senator James Inhofe, who famously threw a snowball to deny climate change , stated "the leas[t] reliable [source of energy in the US] would be some of the renewables, like wind for example. He claimed that replacing baseload fossil fuels with other energy sources like renewables would "result in substantial power blackouts within the next few years," described a frightening future where "Americans may not be able to rely on the cool breeze of an air conditioner or a ceiling fan on a hot summer day."

Along similar lines, the Southwest Power Pool consists of utility companies from states like Texas, Oklahoma, and Kansas, which have generation mixes dominated by fossil fuels. In its public comment opposing the EPA Clean Power Plan, the SPP argues that shutting down baseload coal plants (and implicitly substituting with renewables and other sources) would "introduc[e] the very real possibility of rolling blackouts or cascading outages that will have significant impacts on human health, public safety, and economic activity."

...some fear that rapid deployment of renewable energy will cause massive blackouts and push civilization back to the dark ages. This article seeks to quantitatively challenge these assumptions.

Does using more renewable energy cause more blackouts? The data from actual power grids reveal a reality different from this seemingly logical assumption. It appears that a much higher amount of renewables may be integrated into the energy system while still maintaining system reliability. While there are cost tradeoffs society must consider, renewables will not destroy modern civilization. Fundamentally, they will allow us to keep the lights on without turning off the future of the planet.

MEASURING GRID RELIABILITY

In order to evaluate the theory that renewable energy causes power outages, it is important to consider SAIDI, or the System Average Interruption Duration Index, a standard industry benchmarking metric defined as the sum of customer-weighted interruption durations in minutes divided by the total number of customers served. By quantifying both number of people affected and outage durations, SAIDI is a comprehensive metric.

National Renewable Energy Laboratory, "Variability of Renewable Energy Sources," Transmission Grid Integration, accessed March 13, 2016. http://www.nrel.gov/electricity/transmission/variability.html

Joel Budd, "Special Report: Climate Change - When the Wind Blows," The Economist, November 28, 2015, accessed March 11, 2016. http://www.economist.com/news/special-report/21678955-renewable-power-good-more-renewable-power-not-always-better-when-wind-blows

"How to lose half a trillion euros," The Economist, October 12, 2013, accessed March 11, 2016.

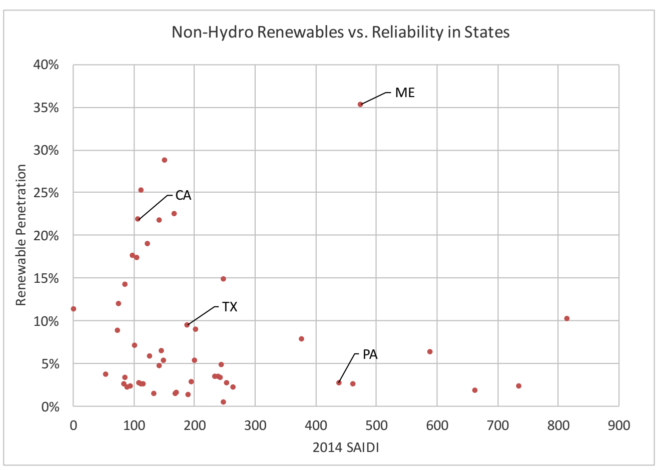
Arlette Saenz, "Sen. Jim Inhofe Throws Snowball on Senate Floor in Attempt to Debunk Climate Change," ABC News, February 26, 2015, accessed March 11, 2016. http://abcnews.go.com/Politics/sen-jim-inhofe-throws-snowball-senate-floor-attempt/story?id=29255635

James Inhofe, "ICYMI: EPW Hearing Highlights how EPA Regulations are 'Shutting down the backbone of our electricity system,'" James Inhofe Senate Website, May 14, 2014, accessed March 11, 2016. http://www.inhofe.senate.gov/newsroom/inhofe-informant/icymi-epw-hearing-highlights-how-epa-regulations-are_shutting-down-the-backbone-of-our-electricity-system

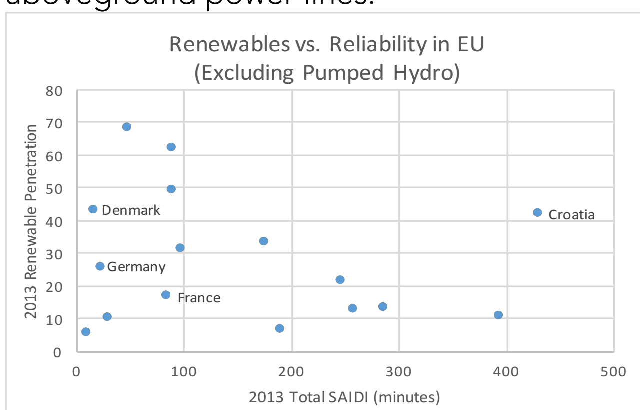
We will examine both utility-level SAIDI Values for the US from the EIA in 2013-14, which has only two years, but fifty states worth of discrete data, as well using values from the European Union's CEER Benchmarking Report, which has fewer locations, but data from 1999 to 2013. In both cases, we are looking at correlations between the renewable penetration, average retail price with reliability metrics. Studies both examining a wide cross section of the regions, as well as examining trends over time show the surprising effects of renewable utilization.

CROSS-SECTION STUDY

To obtain a snapshot of the relationship between renewable energy and grid reliability, consider a cross-section in time using the most recent data available. As it turns out, the Unreliable Renewables Hypothesis is unsupported by data in either the US or EU: higher renewable penetration does not necessitate lower grid reliability.



For the US, the figure "Non-Hydro Renewables vs. Reliability in States" fails to show any strong correlation between higher renewable penetration and increased SAIDI. In fact, there is a very weak negative correlation - implying states which enjoy more renewables today also happen to enjoy more reliable electricity. For example, comparing California to Texas illustrates that a region can achieve both higher renewable penetration and higher reliability (i.e. lower SAIDI). One possible explanation for the Maine outlier in the top middle was its unexpected snowstorm in November 2014, which caused fallen trees that damaged aboveground power lines.



Similarly for the EU, the figure "Renewables vs. Reliability in EU" fails to show any positive correlation between renewables and SAIDI that political opponents would expect to see. Again, there is in fact a weak negative correlation between SAIDI and renewables share (R-squared 0.09). For example, both Denmark and Germany have more reliability as well as more renewable penetration compared to France.

Poor grid reliability is perhaps ironic for the birthplace of Nikola Tesla - father of modern

James Inhofe, "Washington Times: The Dim Future Of Affordable, Reliable Energy," James Inhofe Senate Website, May 5, 2015, accessed March 11, 2016.

"Southwest Power Pool," ISO/RTO Council, accessed March 11, 2016. http://www.isorto.org/About/Members/SPP

Southwest Power Pool, "RELIABILITY IMPACT OF EPA'S PROPOSED CLEAN POWER PLAN," October 2014, accessed March 11, 2016. http://www.spp.org/documents/23421/cpp%20reliability%20impact%20oct%2014.pdf

IEEE-P1366

John Kueck and Brendan Kirby, "MEASUREMENT PRACTICES FOR RELIABILITY AND POWER QUALITY: A TOOLKIT OF RELIABILITY MEASUREMENT PRACTICES" (Oak Ridge National Laboratory: ORNL/TM-2004/91, June 2004), accessed March 11, 2016.

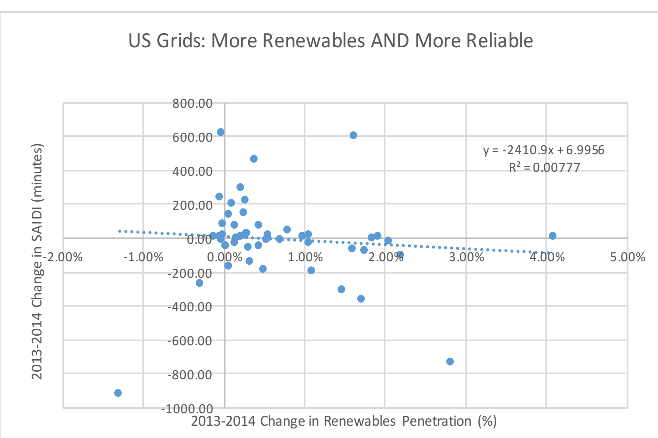
AC power (his hometown Smiljan was part of Austrian Empire and is now in Croatia). One possible explanation for the Croatia outlier is the lingering effect of its War of Independence (part of the Yugoslav Wars of 1991 to 2001) which damaged 37 billion USD worth of infrastructure. In addition to destroying power transmission and distribution systems, the war carved out a grid system that had not been "topologically defined on the principle of self-sufficiency" while it was part of Yugoslavia. Despite this setback, Croatia's grid has been steadily improving: SAIDI decreased 60% and renewables share increased 20% over 2006-2013.

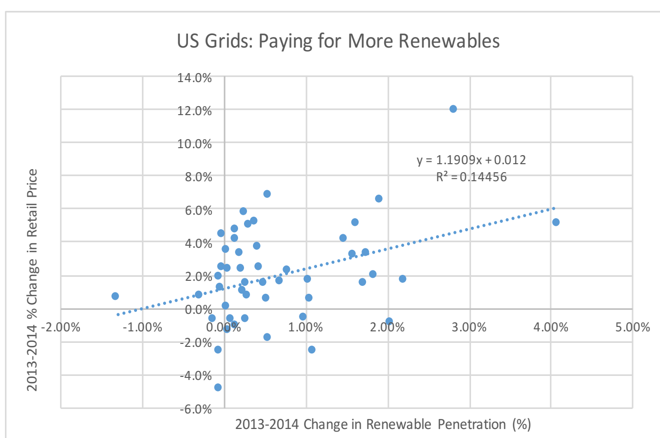
LONGITUDINAL STUDY

More robust longitudinal analysis (multiple time periods for each region) further casts doubt on the Unreliable Renewables Hypothesis. Since the variables are calculated for each individual jurisdiction, longitudinal studies control for any originally-omitted factors. Political opponents of renewables would expect that an increase in renewables penetration would lead to 1) decreased reliability or 2) increased costs. The data presents a more nuanced picture.

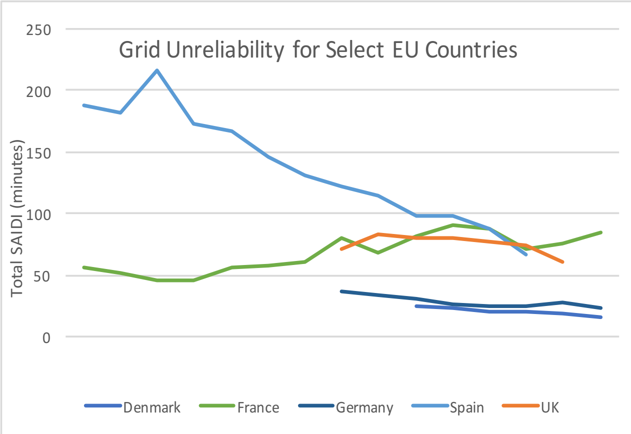
The figure "US Grids: More Renewables AND More Reliable" shows no evidence for assumption 1). States that increased their renewables shares by larger amounts were not guaranteed to have larger positive SAIDI changes - in fact, there is again a very weak correlation in the opposite direction. This suggests that for the period under study, it was not uncommon for an American state to have increased its renewable generation share while improving its grid reliability. A notable outlier in the bottom left is South Dakota, which already enjoyed a relatively high renewable share at 26.6% in 2013 and was actually ranked the third highest renewable penetration in 2014 according to the EIA dataset.

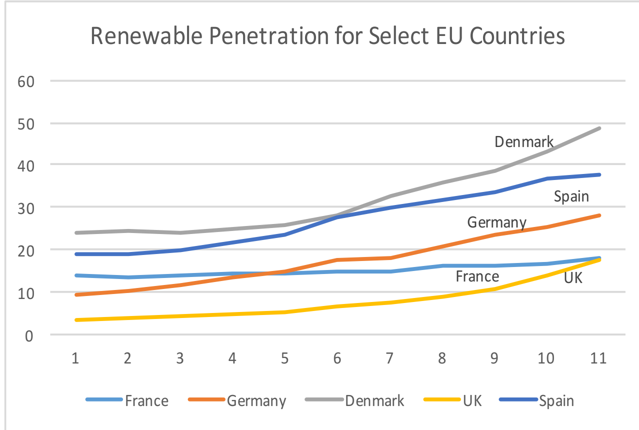
The figure "US Grids: Paying for More Renewables" does indeed show a positive correlation between increased renewables buildout and increased retail prices. However, it is unclear what portion of the generally increased prices are due to the capital costs to install new capacity versus raised levels of operations and maintenance costs that are predicted by the Unreliable Renewables Hypothesis. While the linear regression coefficients are subject to large errors, the slope coefficient of 1.2 implies that a 1% increase in renewable share is expected to lead to a 1.2% increase in retail price. The absence of a similarly large positive correlation in the following cross-sectional analysis, figure "Non-Hydro Renewables vs. Price in States," implies that there is no strong evidence that higher renewable penetration requires higher levels of sustained variable cost to maintain reliability. This suggests that the majority of the 2013-2014 expected price



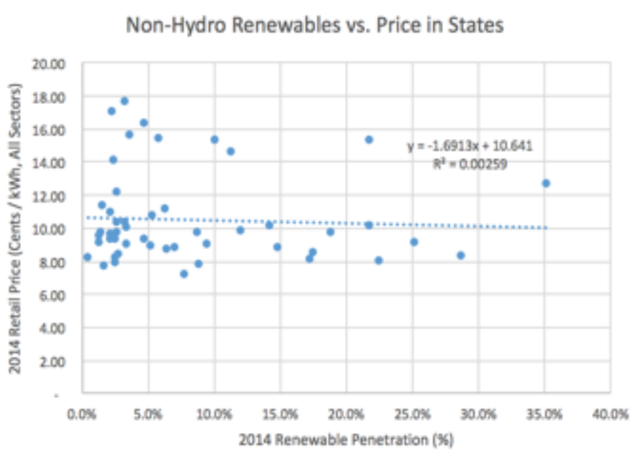


For the United States, utility-level SAIDI values from Form EIA-861 datasets (Energy Information Administration, "Reliability 2014," Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files (Annual data for 2014 re-released January 13, 2016), accessed February 8, 2016. http://www.eia.gov/electricity/data/eia861/) were aggregated to find state-level values weighted by their customer bases. While it is the most authoritative, the EIA dataset unfortunately includes only the years 2013-2014. In addition, the following were compiled for each state over 2013-2014: 1) annual renewable penetration, defined as the percentage of net electricity generation from non-hydropower renewable sources, and 2) retail electricity prices weighted across all sectors (Energy Information Administration, "Electric Power Monthly with Data for December 2014," February 2015, accessed February 8, 2016. http://www.eia.gov/electricity/monthly/,





increase is caused by the capital cost factor, i.e. the initial investments required to install new solar and wind generation capacity. Price increases for new capacity are not unique to renewables, but are associated with any energy source. Therefore, the data does not support the assumption that the intermittency from increased renewables necessarily leads to higher grid maintenance costs in order to maintain reliability.



Comparing differences within the EU, we see a similar pattern with the extra benefit of a longer-trend study. A simple comparison of SAIDI trends for select EU countries dispels the unreliable renewables myth. France is mostly powered by nuclear, the quintessential baseload that runs every minute of the day and every day of the year (except for maintenance or other outages). Theoretically, one would expect lower outages of the French grid due to the reliability of nuclear. On the other hand, Denmark and Germany, posterchildren for rapid renewable deployment, actually enjoy a significantly more reliable grid to start with, as well as consistent improvement in reliability as measured by SAIDI.

A more systematic study is taken as follows. To minimize the effect of short-term fluctuations, data is included for countries with the first and last years where there is both planned and unplanned SAIDI data available, as well as available Eurostat data (for renewables and prices). To provide a country-to-country comparison, the CAGR growth rates were found for changes in SAIDI, renewables share, and retail prices.

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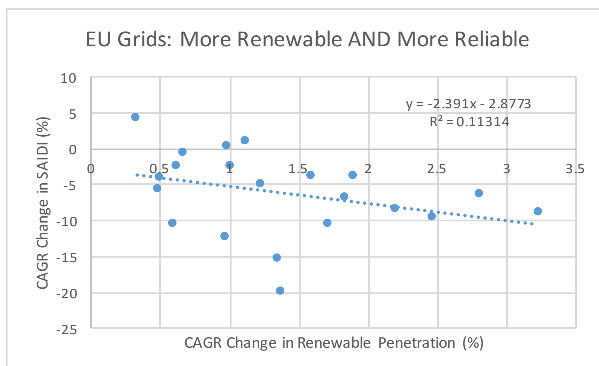

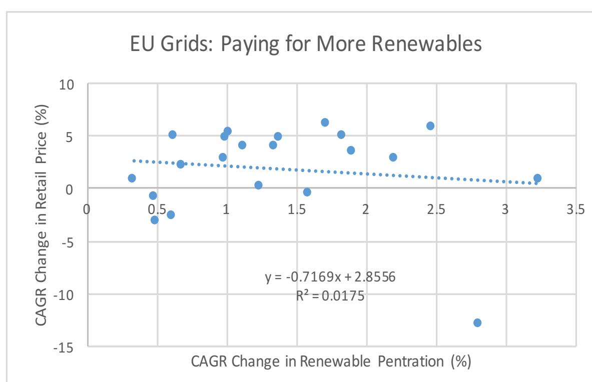

EIA's "Electric Power Monthly with Data for December 2014" includes state-level data for both 2014 and 2013.). Retail prices were adjusted for inflation according to annual average CPI. Federal Reserve Bank of Minneapolis, "Consumer Price Index, 1913-," accessed April 9, 2016. https://www.minneapolisfed.org/community/teaching-aids/cpi-calculator-information/consumer-price-index-and-inflation-rates-1913 For the European Union, SAIDI data was compiled from the CEER's Benchmarking Report 5.2 which provides SAIDI data for EU countries over several years (Council of European Energy Regulators' Benchmarking Report 5.2 on the Continuity of Electricity Supply - Data Update. Ref: C14-EQS-62-03 12 February 2015). For each country, the following was obtained from the European Commission's Eurostat database: 1) renewable penetration, defined as the ratio between renewable electricity production (excluding hydropower pumping) and the gross national electricity consumption, (European Commission Eurostat, "Electricity generated from renewable sources," Europa, accessed March 11, 2016), and 2) average retail prices charged to final household consumers (including any taxes, European Commission Eurostat, "Electricity prices by type of user - Medium size households," Europa, accessed March 11, 2016.

COMPARING THE US VS. THE EU

Through these analyses of SAIDI and other grid metrics, it is evident that reliability is not binary: the power grid can experience a wide range of outage severities. Citizens, utilities, and regulators do not simply choose whether to have a "reliable" or "unreliable" grid. Rather, society as a whole must decide where on this spectrum lies acceptable power system quality. Therefore, when political opponents appeal to the intermittency of renewables to argue against higher renewables adoption, they implicitly posit the existence of some acceptable threshold of reliability risk. The political argument takes the form that it is unacceptable for a new policy or technology to significantly degrade reliability. The crucial question becomes: what is "significant"?

In an efficient market equilibrium (which is only approximately true due to market frictions like Senators' incorrect information), the quantity of "reliability" demanded by different populations is socially efficient for each region. If a politician says today that a new policy will lead to an unacceptably unreliable grid tomorrow, that implies that today's level of grid reliability is acceptable. How much do different countries actually value reliability?
It is very clear at first glance that American-based critics of Germany's Energiewende really represents a case of "American exceptionalism" or "the pot calling the kettle black". For all the complaint about Germany's teetering grid, its expected standard is a SAIDI of 23 versus the whopping 240 minutes of the US. In other words, Germany enjoys a grid that is more than 900% more reliable than the US, with double its renewable penetration. Similarly, Germany's SAIFI is only a third of that in the US - countering the notion that the German grid suffers from a high number of short outages.

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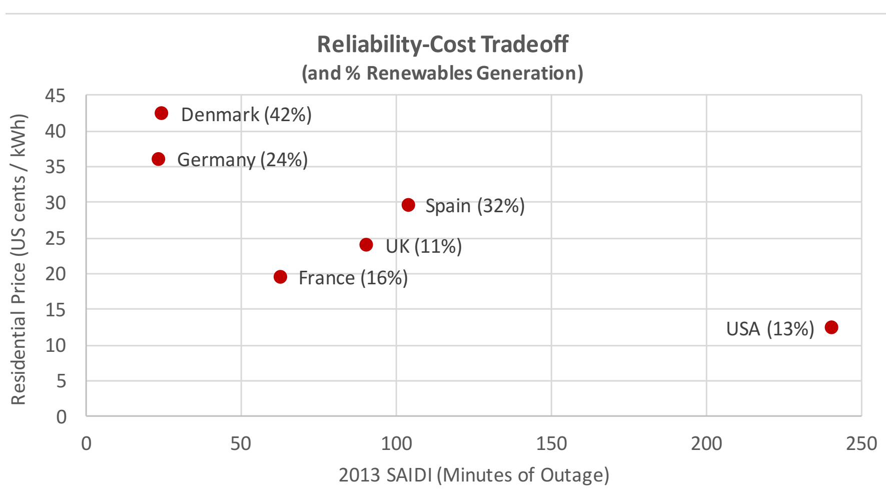
But what about prices in Europe? Germany's retail electricity prices are about double those of the United States (despite the average customer's electric bill being the same amount due to superior energy efficiency). Generally, EU countries have significantly higher retail prices of electricity than in the US, but these prices reflect two fundamental components. First, the difference between EU and US prices are partially due to taxes, since these retail prices include any tax effects from all government levels, i.e. including the EU and other emissions pricing policies. So the American average price is lower partially because American ratepayers enjoy dumping pollution externalities into the atmosphere without any significant carbon price.

Second, perhaps more importantly, this tradeoff chart fundamentally reflects that the German nation (as well as the EU generally) values reliability more than Americans, despite rhetorical complaints to the contrary.



"85,000 Still Without Power After Early Maine Snowstorm," NBC News, November 3, 2014, accessed March 11, 2016. http://www.nbcnews.com/news/weather/85-000-still-without-power-after-early-maine-snowstorm-n240496

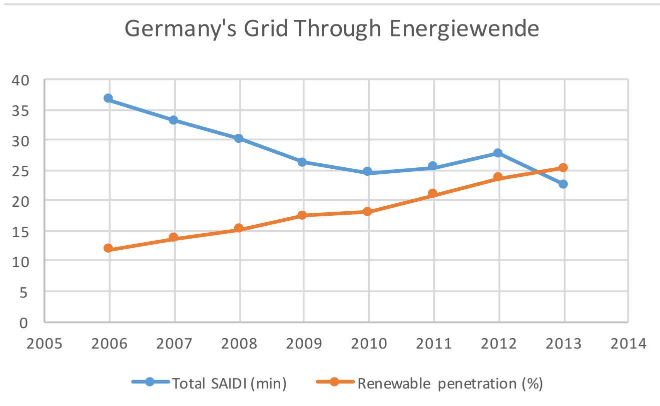
"Croatia - Economy." World of Information (2003). Europe Review 2003/04: The Economic and Business Report. Kogan Page. p.75

Croatia Ministry of the Economy, Labour and Entrepreneurship. "SECURITY OF SUPPLY STATEMENT OF THE REPUBLIC OF CROATIA". Energy Community. July 2009. https://www.energy-community.org/portal/page/portal/ENC_HOME/

SAIFI is the system average interruption frequency index, which measures the number of service interruptions to the average customer

Galvin Electricity Initiative. "Electricity Reliability: Problems, Progress and Policy Solution." The Galvin Project February 2011. http://www.galvinpower.org/sites/default/files/Electricity_Reli-

Another common critique is not that America's grid is better than Germany's but that Germany's grid got worse over time. In fact, the power system became more reliable during Energiewende. As seen in the figure "Germany's Grid Through Energiewende," Germany's grid improved its reliability (measured as the sum of planned and unplanned SAIDI) by 38.4% across all years for which data is available (2006 to 2013). Over the same period, Germany's renewable penetration (excluding pumped-hydropower) more than doubled. It is true that retail prices in Germany increased 39.1%, adjusted for inflation, which is higher than the 16.6% increase for the US over the same period. However, this direct cost comparison is incomplete because Germany's wholesale electricity price also decreased significantly over this period.



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CONCLUSIONS FOR POLICY

The issue of renewables grid integration and reliability has utmost importance for political debate on the future of energy systems. First, politicians have made commitments to dramatically increase renewables adoption, like the state of Hawaii's goal of going 100% renewable by 2050. While there are significant technical obstacles, overstating the unreliability of renewable energy can be (and have been) used to politically stifle these goals. Second, determining the true cost of maintaining grid reliability in a high-penetration world is crucial to resolving the net metering debate.

The higher the perception of renewables' unreliability, the more justification for imposing implicit or explicit solar or wind fees on distributed generation, such as the recent net metering reversal in Nevada. Third, the fear of blackouts drives the fervor to expand the usage of natural gas as a flexible, peaking bridge fuel. To the extent that renewable energy is unreliable, more investments will flow into non-reversible infrastructure that continues fossil fuel dominance.

Using Germany as a scare tactic to obstruct renewables adoption in America is not only ironic, it is politically dishonest by cherry-picking information.

Concrete evidence disproves the politically convenient myth that renewables will necessarily destroy grid stability. A more complete evaluation demonstrates that using Germany as a scare tactic to obstruct renewables adoption in America is not only ironic, it is politically dishonest by cherry-picking information.

Thomas Lee is a junior in the M&T program studying computer science and economics, and is pursuing an MSE in systems engineering as a submatriculant. He is interested in network and economic implications of the societal transition towards cleaner energy sources.