The Electricity Journal 31 (2018) 14–19

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

Electrification: Conversion woes

Hossein Haeri*, Matei Perussi

The Cadmus Group, LLC, United States

ARTICLE INFO

Keywords:
Electrification
Fuel conversion
Econometrics
Price elasticity
Elasticity of substitution
efficiency

ABSTRACT

With market forces bent on electrification, natural gas distribution companies may have to contend with a less friendly residential market. This article examines the effects of technology and price on historical trend in market share for electricity and natural gas in residential heating markets. Inter-fuel elasticity of substitution is estimated via econometric analysis of state-level panel data from 2001 to 2017. The results suggest that market shares are insensitive to relative prices in the short run. In the long run, the response tends to be material and statistically significant.

1. Introduction

Not long ago, pessimists said electric utilities were descending into a death spiral. In 2013, a study commissioned by the Edison Electric Institute (EEI) predicted that the twin forces of distributed generation and energy efficiency would disrupt the electric utility industry. The study, *Disruptive Challenges*, argued that lower sales, coupled with rising infrastructure costs, would trigger a vicious cycle, leading to higher rates that, in turn, would drive down demand.[1] Over time, the report reasoned, this dynamic would undermine electric utilities' finances and credit-worthiness. The prediction's power lied as much in its ostensibly plain math, as the finality of the future it foreshadowed.[2]

Ensuing developments suggest that the story may have been more complicated. Electric utilities' operating environments have indisputably changed, with electricity sales flat in many local markets (despite the GDP growth, signaling a weakening of its linkage with electricity demand), and most forecasts expecting them to stay that way. Distributed generation, especially where coupled with net metering, has made an unmistakable mark on revenues, and operating expenses have risen. Inflation-adjusted rates, however, have mostly remained stable across all sectors, if not declining in some regions.

Nor do indices of financial heath—revenues, earnings, price-to-earnings ratios—bear alarming signs of deterioration. According to the EEI, investor-owned utilities earned a five-year average annual return of almost 13.5%, not far behind the S&P 500's 16% — hardly symptomatic of an industry in decline.[3]

As concerns about the utility industry's collapse have passed, the ideas about it have evolved. In 2015, the EEI report's author outlined a set of solutions (pathways) that, if implemented, could presumably derail a spiral, calling for a transition to a "21st Century Utility" where utilities can prosper by transforming their businesses with the aid of regulatory reforms that reward better service and lower costs. The report's prescriptions—innovation, improving operating efficiencies, engaging customers, offering block rates, seeking new revenue sources, and, paradoxically, redoubling energy efficiency programs—remained mostly unobjectionable, but they were hardly revolutionary.[4] Beyond that, the report's recommendations were thin and, surprisingly, made no mention of widely expected growth opportunities, especially electrification, a real reason for optimism.

* Corresponding author.
E-mail address: hossein.haeri@cadmusgroup.com (H. Haeri).

[1] Kind, Peter. "Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business." Prepared for the Edison Electric Institute. January 2013.

[2] The downward spiral's logic was set forth more plainly in a November 2012 report by the Deloitte Center for Energy Solutions: "The Math Does Not Lie: Factoring the Future of the U.S. Electric Power Industry." Two supplemental papers followed this report: "Beyond the Math" (March 2013) and "The New Math" (undated) presenting recommendations for the electric sector regarding ways to transform its business model to cope with the "coming evolution."

[3] Edison Electric Institute. *Stock Performance. Financial Update Quarterly Report of the U.S. Investor-Owned Electric Utility Industry.* Quarter 4, 2017.

[4] In 2015, the report's author outlined a set of solutions ("pathways") that, if implemented, could presumably derail the spiral, calling for a transition to a "21st Century Utility," where utilities could prosper by transforming their businesses with help through regulatory reforms that reward better service and lower costs. See Kind, Peter. *Pathway to a 21st Century Electric Utility.* Ceres, Inc. November 2015.

https://doi.org/10.1016/j.tej.2018.10.011

2. The electrifying vision

Since the passage of the Rural Electrification Act in 1936, few ideas have been more closely tied to social and economic progress than electrification. Once again, electrification is being recognized as something of an indispensable instrument for solving a different and, arguably, larger problem—climate change.

However it has been defined or modified—beneficial electrification,[5] strategic electrification,[6] smart electrification, efficient electrification,[7] environmental electrification, or "emissiency" (a portmanteau of emission and efficiency)[8] – electrification has come to mean shifting away from direct combustion of fossil fuels to electricity. While using fossil fuels directly remains—for some end uses—the more-efficient or less-expensive option, electricity serves as the best option for a broad range of end uses. Recent studies find that nearly one-quarter of the Paris agreement's goal can be achieved through electrification and decarbonization of end uses, primarily transportation and heating.[9]

The transportation sector offers the largest opportunity for electrification. Well-to-wheel—the number of miles per gallon that a gasoline-powered vehicle would need to achieve to match a typical electric vehicle's CO_2 emissions—provides one way of comparing the global warming effects from gasoline and electricity-fueled vehicles. Using this metric, electric vehicles charged on the grid system produce less global warming emissions than the average gasoline-fueled vehicles sold anywhere in the United States—possibly even where power generation is primarily coal-based.[10] As several recent studies have found, moderately widespread electrification of light-duty vehicles, medium-duty vehicles, and certain off-road equipment could displace 430–550 million metric tons of CO_2 emissions—the equivalent of removing 80–100 million passenger cars from the road.[11] Transitioning the transportation sector from its nearly total dependence on oil to electricity will at once produce large reductions in CO_2 and improve air quality by lowering other polluting emissions.[12]

Advances in heat transfer technology have also created new opportunities for electricity to substitute for direct, on-site use of fossil fuels (e.g., natural gas, propane, fuel oil) in end uses such as space and water heating in homes and small commercial buildings. Instead of transforming chemical energy to heat through combustion, heat pumps transfer heat with astonishingly high efficiency: a heat pump operates at more than 100% efficiency, meaning it transfers more energy than it consumes. Under certain operating conditions, a 300% nominal design efficiency is not unusual for a heat pump. Combustion-based systems, on the other hand, never deliver more energy than they consume.

The efficiency threshold for earning an ENERGY STAR label offers a good way for comparing efficiencies. As of Sept. 1, 2010, a 55-gallon (or smaller) gas water heater—typical in most homes—requires an energy factor (EF) of 0.67 or higher to qualify for the ENERGY STAR label. A heat pump water heater currently needs an energy factor of 2.0—almost three times higher—to qualify. Space heating tells a similar story. To earn the ENERGY STAR label, a gas furnace must achieve an efficiency rating of 90%–95%, as measured by the unit's coefficient of performance (COP).[13] A typical air-source heat pump has a COP of nearly 2.5.[14]

Efficiency, especially at the levels possible with heat pumps, gives electricity a decisive advantage over other fuels, including natural gas, when it comes to CO_2 emissions. A heat pump operates at a sufficiently high efficiency to nearly offset losses in power generation (as much as 67.5% for coal and 56% for natural gas, on average) and transmission and distribution (averaging at 5%).[15] Electricity's advantage further extends to economic factors that drive consumers' heating system choices. A heat pump operates at a high-enough efficiency to offset natural gas's per-BTU price advantage—currently higher than three to one in most regional markets.[16]

In addition to lowering source CO_2 emissions, electrification offers electric utilities significant potential for new revenue streams. Recent studies show that widespread electrification could lead to substantial shifts in fuel shares, with electricity's share of total final energy demand rising to 32% in the medium and 41% in the high scenario—more than double the 19% in 2016.[17]

3. Reversal of fortunes

The average American household annually uses about 36,500 BTUs of electricity and 33,500 BTUs of natural gas. Space and water heating account for about one-third of the electricity use, but amount to over 95% of natural gas consumption, on average, across the country—although usage varies considerably by climate. The choice of main heating fuels also plays an influential role in determining the fuel a household uses for other end uses, such as water heating, cooking, and clothes drying. Natural gas, long the predominant fuel in the residential sector, has been losing market share to electricity. The same, though to a lesser extent, is true for distillate fuel oil, kerosene, and liquefied petroleum gas.

About every five years, the Energy Information Administration (EIA) conducts a Residential Energy Consumption Survey (RECS) to collect data on how households use energy.[18] Results from the last four surveys, conducted between 2001 and 2015, show a steady drops in natural gas' share of domestic space heating. In 2001, natural gas was

[5] Dennis, K. 2015. "Environmentally Beneficial Electrification: Electricity as the End-Use Option." Electricity Journal Volume 28, Issue 9. Pages 100–112. November 2015.

[6] *Northeastern Regional Assessment of Strategic Electrification*. Northeast Energy Efficiency Partnership. July 2017.

[7] Electric Power Research Institute. *A Preview of the U.S. National Electrification Assessment*. April 2018.

[8] Dennis, Keith, Ken Colburn, and Jim Lazar. "Environmentally Beneficial Electrification: The Dawn of 'Emissions Efficiency.'" The Electricity Journal. Vol. 29, No. 6. July 2016.

[9] Williams, J.H., et al. *Pathways to Deep Decarbonization in the United States*. The U.S. report from the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. 2014. See also Gowrishankar, Vignesh and Amanda Levin. *America's Clean Energy Frontier: Pathways to a Safer Climate Future*. Natural Resources Defense Council. NRDC 2017.

[10] Electrification's comparative impacts in transportation have been studied extensively. For example, see A. Elgowainy, et al. *Well to Wheel Analysis of Energy Use and Green House Gas Emissions of Plug-In Hybrid Electric Vehicles.* Argonne National Laboratory. ANL/ESD/10-1. June 2010. See also Anair, Don and Amine Mahmassani. *State of Charge: Electric Vehicles' Global Warming Emissions and Fuel-Cost Savings across the United States.* Union of Concerned Scientists. June 2012.

[11] Electric Power Research Institute and Natural Resourced Defense Council. *Environmental Assessment of a Full Electric Transportation Portfolio*. September 2015.

[12] Ibid.

[13] In June 2011, the U.S. Department of Energy raised efficiency requirements to 90% for many furnace styles, but the stricter requirements were suspended following a Jan. 11, 2013, court ruling, pending the outcome of a lawsuit by the American Public Gas Association.

[14] The air-source heat-pump COP is calculated based on a heating seasonal performance factor of 8.5.

[15] Generation losses are based on thermal conversion factors of 10,493 for coal and 7,870 for natural gas power plants in 2018, reported by the Energy Information Administration. Delivery losses are based on the national average reported by the Energy Information Administration.

[16] The latest Energy Information Administration figures.

[17] Mai, Trieu, et al. Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. National Renewable Energy Laboratory. NREL/TP-6A20-71500. 2018.

[18] U.S. Energy Information Administration. *Residential Energy Consumption Survey*. 2001–2018.

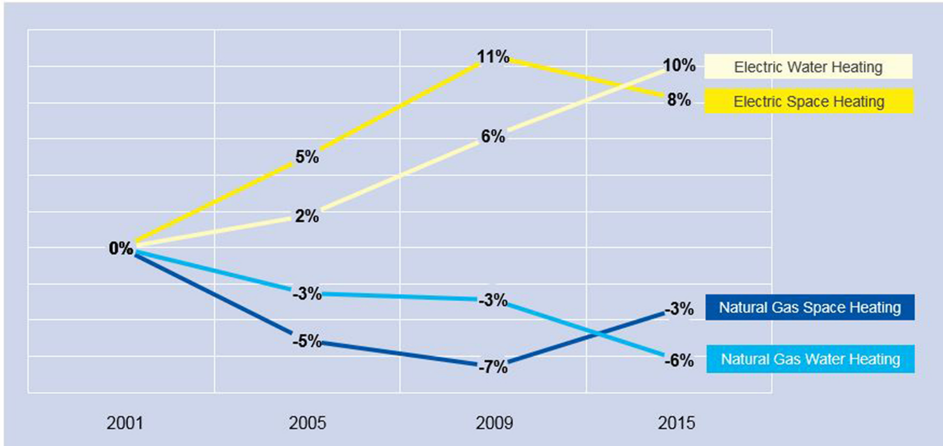

Fig. 1. Change in Space and Water Heating Market Shares by Fuel Type.

the fuel of choice for nearly 65% of households using either electricity or natural gas for space heating. About 56% of households reported to be using natural gas for heating have in 2015. Survey results showed a nearly proportional increase in electricity's share of this market, from 29% to 38%.

Water heating results tell a similar story: in 2001, nearly 59% of households with electric or natural gas water heaters used natural gas as their primary water-heating fuel; today, less than 52% do. Meanwhile, electricity's share of this market rose from 41% in 2001 to over 48% today, as shown in Fig. 1. Propane, oil, and wood claim the remaining share of the market, typically in places that are cold, too remote from natural gas pipeline, and where electricity is expensive.

The rise in electricity's share of domestic space and water heating may not be the sole problem for natural gas: the steady year-on-year decline in the fuel's market share suggests that these reductions may indicate a trend, rather than temporary setbacks. Perhaps equally important, the combined share of electricity and natural gas has hardly changed, signaling a zero-sum pattern, wherein electricity's gains in these markets may have come almost entirely at the expense of natural gas.

4. Consumers' choices

Though no one knows exactly how consumers and home-builders make fuel choices, a few obvious clues exist. For example, access to a gas line is a clear reason, as is a climate that dictates the need for heating, since natural gas generally works better in colder climates, where electric furnaces can be too expensive to run and heat pumps lose their efficiency. Existence of built-in infrastructures like a heating and cooling distribution systems is another reason – though ductless a heat pump gets around this problem, giving electricity a distinct advantage over natural gas. Heat pumps, on the other hand, deliver cooling as well as space heating, a feature that adds to their appeal in more moderate climates where both heating and cooling are needed. For many, natural gas might be preferable for cooking because a gas range offers better temperature control, though modern convection ovens and induction stoves are beginning to challenge this notion. Convenience, comfort, and taste are the less tangible factors.

Cost—mainly of fuels, but also of initial capital expenses and operation—is another factor. In the short term, consumers react to fuel price changes by using less, as economic theory suggests. Over the longer term, however, consumers may buy a house that uses their fuel choice, or they may switch from the fuel that their home currently uses. Historical data show a strong negative correlation between natural gas' share of the residential heating market and its price relative to electricity

Generally, the responsiveness of demand for a product to its price is expressed by elasticity—the percentage change in demand likely to result from a 1% change in price.[19] In the case of reasonably similar products, the change in relative demand for one product depends on its substitute's price, and the magnitude of this effect depends on the responsiveness of relative demand for the two products. Elasticity of substitution serves to measure this responsiveness, as the proportionate change in relative demand for two products resulting from a change in their relative prices. Elasticity of substitution also shows the degree to which two goods can substitute for each other.

Grounded in production theory, elasticity of substitution typically arises in the context of production functions, which describe the relationships between inputs and outputs in a production process. The theory holds that, as factor prices change, a firm substitutes a cheaper input for a more expensive one. In other words, it measures the ease with which one input in the production process can be replaced by another, holding total output constant.

The concept is also useful for describing consumer utility functions, that express the consumer's preferences for the combination (bundle) of goods and services that offers the highest utility. Consider a household that uses natural gas and electricity to generate comfort—in this case, space and water heating. The household's total utility can be expressed as the sum of the marginal utility from using gas and electricity to produce comfort. Utility maximization dictates that the ratio of the household's marginal utility from gas to its price equals the ratio of electricity's marginal utility to its price. Put another way, and with some manipulation of the principle's underlying algebra, it can be shown that the relative amounts of gas and electricity a household uses depend, among other things, on relative gas and electricity prices.[20]

Elasticity of substitution, therefore, may be directly estimated from a regression equation that relates relative demand for energy, in BTUs, for gas and electricity, to their relative per-unit prices, and other predictors, as in the following equation: $= \alpha + \beta_1 (P_g/P_e) + \beta_2 (G_{BTU}/E_{BTU})_{-1} + \beta_3 HDD + \beta_4 CDD + \beta_5 T + \varepsilon$

This relationship simply states that the relative share of gas and

[19] Measuring demand's responsiveness to price in percentage terms (rather than their respective units) offers an attractive alternative as it is unit-free.

[20] The household's total utility (u) can be expressed as $u = \delta_1 g + \delta_2 e$, where δ_1 and δ_2 are partial derivatives of the utility function and represent the marginal utilities from gas and electricity. The condition for utility maximization is that the ratio of (mu_g) to (p_g) equals the ratio of (mu_e) to (p_e), that is: $mu_g/p_g = mu_e/p_e$, or, rearranging the terms, $mu_g/mu_e = p_g/p_e$. The proof can be found in standard micro-economic textbooks. For example, see Henderson, James M. and Richard E. Quant. Microeconomic Theory, Third Edition. McGraw-Hill. pp 73–75. 1980.

Table 1
Statistical results.

Dependent Variable: Sales Ratio Natural Gas/Electricity (MMBTU)			
	Estimated Coefficient	t Value	Approximate p Value
Intercept	−0.1813	−1.78	0.0762
Predictor Variables			
Price Ratio Natural Gas to Electricity ($/MMBTU)	−0.0384	−2.70	0.0071
Sales Ratio MMBTU Natural Gas/MMBTU Electricity (Legged)	0.976	248.26	< .0001
Annual Heating Degree Days (HDD)	0.0288	3.25	0.0012
Annual Cooling Degree Days (CDD)	−0.0052	−1.10	0.2726
Time Trend (2000 = 1, 2016 = 17)	−0.0076	−5.64	< .0001
Autoregressive Error Term (AR1)	−0.5229	−17.35	< .0001
Durbin Watson Statistic			2.36
R2			0.99

electricity (G_{BTU}/E_{BTU}) for household heating energy use is a function of relative gas and electricity prices (P_g/P_e). When P_g/P_e goes up, gas becomes relatively more expensive than electricity, inducing consumers to substitute electricity for gas; so, the G_{BTU}/E_{BTU} ratio drops. Conversely, when P_g/P_e declines, G_{BTU}/E_{BTU} rises.

The equation includes five additional predictor variables that help explain household heating energy use: heating and cooling degree days (HDD and CDD); a one-year lagged value of relative gas and electricity demand to account for the dynamic delay in a consumer's response, especially when this involves switching space- and water-heating systems; and a trend variable (t) to capture omitted time-varying determinants of fuel choice, such as technological improvements and new appliance features that affect consumers' purchasing decisions.

β_1 and β_2 serve as this equation's two critical parameters, providing estimates of elasticity of substitution for the short run (β_1) and for the long run ($\beta_1 / (1 - \beta_2)$). The values for elasticity of substitution range from zero to infinity, with a value of zero meaning one fuel cannot be substituted for another—for example where natural gas is not available.

The equation's parameters were estimated for the residential sector, using panel data for 50 states and the District of Columbia from 2001 to 2017, with 867 observations. State-by-state data were compiled from three publicly accessible sources: EIA (residential energy sales and prices); the National Oceanic and Atmospheric Administration (average annual temperatures); and the U.S. Bureau of Economic Analysis (implicit price deflator). Space and water heating's shares of total consumption were calculated by applying RECS' estimates and interpolating the values for the intervening years.

All variables, except the trend (t) were transformed into logarithms—a means of handling potentially non-linear relationships and of transforming a variable's skewed distribution into an approximately normal pattern. The logarithmic transformation also converted β coefficients into elasticities—an appreciable convenience when estimating elasticity serves as the main point of the analysis. In estimating the relationship's coefficients, the authors used an error-correction procedure to address a potentially autoregressive (serially correlated) error term, a common problem with time-series data.

Overall, the results indicate satisfactory outcomes. As shown in Table 1, the estimated coefficient of determination (R^2) suggests that the model fits the data well, though the statistic's rather large value results from including the lagged independent variable. The causal directions, indicated by the estimated coefficients' signs, are consistent with theory, and are statistically significant for the variables that underpin substitution elasticities.

The results also show statistically significant, negative relationships between relative prices (β_1), the previous year's sales (β_2), and natural gas' and electricity's relative shares of residential sector energy sales. With a value estimated at 0.038, measured by β_1, relative heating fuel shares were expected to be insensitive to relative prices. As shown in previous studies, demand for energy, in general, tends to be relatively inelastic; this response can be even weaker and slower when involving conversions to another fuel.

Conversion can be expensive: electric space and heating systems involve specialized peripheral equipment and preparations—duct work, pipes, flues, and wiring. Therefore, replacing a system with one using the same fuel would (almost) always be cheaper, faster, and more convenient than replacing it with one that involves fuel switching. As a recent study by researchers at the Rocky Mountain Institute found, conversion to electricity will unlikely be cost-effective for existing homes heating with natural gas, unless the furnace and air conditioner are replaced at the same time.[21]

The results point to a different picture emerging in the long run. Over time, households have more flexibility to respond to prices and switch fuels when renovating their homes or buying a new one. Based on the estimated coefficients, a 1% change in relative prices will likely depress the market share of natural gas by about 1.6%.[22] Considering that in 2017, natural gas accounted for about 74.3% of the residential sector's heating energy demand, 1.6% elasticity means, at the current average prices of $10 per MMBTU for gas and $35 per MMBTU for electricity, a 1% (approximately 10 cent per MMBTU) increase in natural gas prices would likely cause its market share to contract by 1.2% from 74.3% to 73.1%. Modest as it is, the effect translates into a 1 million MMBTU loss in annual natural gas sales, with a value of about $10 million at today's average prices and theloss accumulates year-on-year over the life of the equipment.

As defined here, market share is a function of the gas-to-electricity price ratio. What drives future market shares is not merely the separate fluctuations in gas and electricity prices, but the gap between these. Market share losses come not only from rising future natural gas prices, but also from falling electricity prices—though at a slightly different rate.[23] Natural gas' market share will likely continue to contract as the two prices diverge.

The latest EIA long-term, energy-price forecasts (2018–2050) help illustrate the point. The authors used the EIA forecast to calculate cumulative annual percent price changes through 2050, as shown in Fig. 2. The forecasts show gas and electricity prices rising in tandem until 2022, when they begin to diverge gradually through the end of the decade.

By 2030, electricity prices are projected to rise by 10.5% and natural gas prices will rise by 17% over their current rates. This will give electricity an additional 6.5% price advantage. If these predictions

[21] Billimoria, Sherri, et al. *The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings.* Rocky Mountain Institute. 2018. Available online: http://www.rmi.org/ insights/reports/economics-electrifying-buildings

[22] The long-run elasticity value is calculated as −0.0384 / (1–0.976) from Table 1.

[23] Note that changes in electricity's price (the ratio's denominator) would not generate the same proportionate change in the ratio as would changes in gas prices (the ratio's numerator).

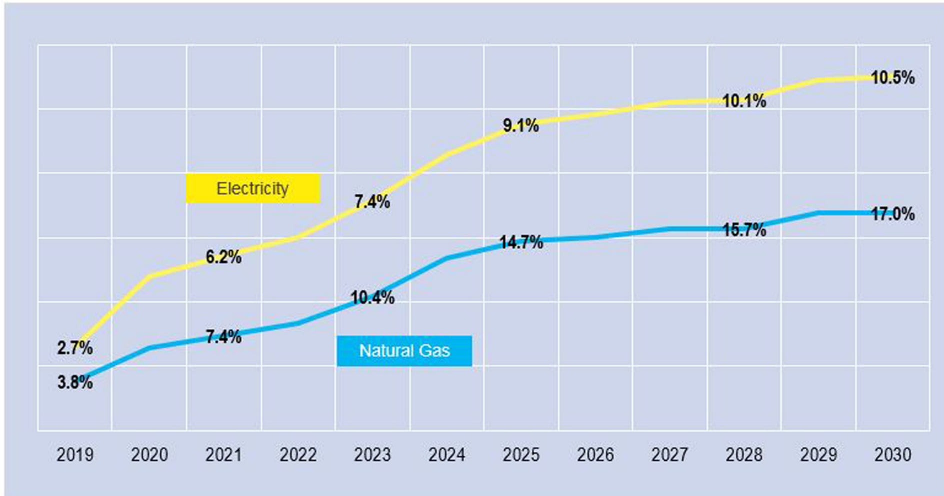

Fig. 2. Cumulative Annual Change in Natural Gas and Electricity Prices 2018–2027.

hold, by 2030, natural gas will likely to cede 7.7% of its market share to electricity. After 2030, the gap stabilizes as electricity and natural gas price curves flatten and stay that way to 2050, the end of the forecast horizon.

5. Looking ahead

At first blush, electrification appears as a marked shift in the conventional view that has guided energy policy in America for the last several decades: generating and transmitting electricity involves substantial environmental externalities and loss; therefore, less of it should be used. However, as proponents of electrification note, end-use efficiency may no longer provide an adequate metric for energy policies designed to control greenhouse gas emissions.[24] Rather, metrics should focus on lowering total CO_2 emissions; therefore, electrification (including the conversion of residential heating loads to electricity) must play a role in any climate change policy with a chance of bringing emissions down to levels considered necessary to keep global warming below the 2 degrees Celsius (2 °C) safe limit, as agreed to in the Paris climate agreement.[25]

This idea has spurred interest among policymakers in several state and local jurisdictions in America and Canada who are seeking to find ways to accelerate electrification in the residential sector to achieve what some call "deep decarbonization." Understandably, the idea has drawn criticism from gas utilities, for what promises relief to electric utilities can be disruptive to gas distribution companies.[26]

In July 2018, a report from the American Gas Association[27] illustrated the seriousness of this issue to gas utilities. The report serves as a reproof of what it calls "policy-driven electrification" of the residential sector, and it questions the economic and environmental rationales for policy initiatives seeking to convert fossil-fueled housing stocks to electric appliances. Perhaps understandably, the threat can be exaggerated. Several jurisdictions have discussed decarbonizing the residential sector and, in one case, proposed an approach, but no jurisdiction has taken the idea further yet.

Competition between natural gas and electric utilities for the domestic heating market has unfolded for several decades. Through financial incentives, available as part of energy efficiency programs sanctioned by regulators, and in more subtle ways (such as promotional campaigns), the two sides have attempted to woo residential customers. An unmediated process also is at work, whereby consumers switch fuels for reasons of comfort, convenience, and cost, among other things.

A U-shaped relationship exists between temperature and energy demand: energy demand drops as the rise in temperatures lessen the need for heating and, after a certain point, climbs again to satisfy demand for cooling. Electricity's gains in market share can be explained partly by recent trends in population migration to the warmer regions of the west and south. It also reflects changes in consumers' tastes, favoring heat pumps for their cooling features, helping account for electricity gaining market shares, even within the same climate regions.

This trend will likely accelerate as weather warms, prompting more consumers to buy heat pumps and to run them more often.[28] By one estimate, electricity use in places such as Southern California between 2020 and 2060 is projected to rise by 34%, even under "the most optimistic climate and aggressive policy scenario," increasing by as much as 87% without policy interventions.[29]

How much of these gains in electrical load will come at the expense of natural gas is open to debate. Though natural gas will likely serve as the economic choice for heating in many of North America's colder regions, normal market forces will continue to influence what role natural gas plays in the residential sector. Gas utilities that fail to address these issues will be vulnerable.

Hossein Haeri is a Senior Vice President for the Energy Services Sector at Cadmus. He has nearly 30 years of experience in research, teaching, consulting, and utility management in the energy industry. Mr. Haeri specializes in utility resource planning and forecasting, energy efficiency and distributed energy resource planning and performance measurement and verification. He works with utilities, supporting their integrated resource planning (IRP) processes by forecasting resource potential and helping utilities translate the potential into effective program portfolios. He holds a doctorate degree in Regional Science, and the results of his work have been published in numerous conference proceedings and refereed journals. He regularly testifies before regulatory commissions as an

[24] Dennis, Keith, et al. op. cit. p. 54.

[25] Williams, J.H., et al. op. cit.

[26] For a critique of the concept, see Kenneth W. Costello: "Electrification: The Nexus Between Consumer Behavior and Public Policy." The Electricity Journal. 31, 1–7. 2018.

[27] American Gas Association. *Implications of Policy-Driven Residential Electrification*. Prepared by ICF. July 2018.

[28] For a review of research on the relationship between weather and energy use, see Matthew Ranson, et al. *Climate Change and Space Heating Energy Demand: A Review of the Literature*. National Center for Environmental Economics. Working Paper No. 14-07. December 2014. See also Sailor, D. J., & Pavlova, A. A. *Air Conditioning Market Saturation and Long-term Response of Residential Cooling Energy Demand to Climate Change*. Energy. 28(9), 941-951. July 2003.

[29] Reyna, Janet L. and Mikhail V. Chester. Energy Efficiency to Reduce Residential Electricity and Natural Gas Use Under Climate Change. Nature Communications. Vol. 8, No. 14916. May 2017.

expert witness on resource planning and assessment in various jurisdictions.

Matei Perussi is a Senior Associate at Cadmus, with 24 years of experience in statistical techniques for energy and financial analysis. Mr. Perussi provides expertise in advanced statistical methods, forecasting, billing analysis, conditional demand analysis, payment analysis, advanced multivariate analyses, regression analysis, and load analysis. He holds a master's degree in Mathematics, specializing in statistics, from Portland State University. Before joining Cadmus in 2003, Mr. Perussi provided data analysis services for KEMA/XENERGY (now DNV-GL), Chevron Energy Solutions (formerly PG&E Energy Services), and Barakat & Chamberlin.