HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

# Paving the Way For Decarbonization and Electrification:

## *Energy Efficiency's Role in an Integrated and Modernized Energy System*


**Maria Lappas**

Joint Master in Public Policy / MBA Candidate, Class of 2021
Harvard Kennedy School & Harvard Business School


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**Client**
*Midwest Energy Efficiency Alliance*

**Seminar Leader**
John Haigh, Harvard Kennedy School

**Faculty Advisors**
Joseph Aldy, Harvard Kennedy School
Jurgen Weiss, Harvard Business School

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# Introduction

Year after year, increasing numbers of decarbonization commitments made by state governments and other market participants bring the nation closer and closer to a truly clean energy future. These decarbonization commitments—whether executive, statutory, or utility-based—define bold, high-level visions that are either binding or goal-oriented. Utilities, energy companies, implementation contractors, and trade allies then translate these visions into practical action while also advancing their own internal, value-added strategic objectives. To date, these cumulative pledges from state legislatures and utilities in the United States account for 53.2% of total electricity sales and 56.8% of the power sector's total carbon dioxide emissions.[i] As these proportions grow, utilities must continue to thoughtfully manage and balance each and every piece of these widespread decarbonization efforts. Some pieces primarily reduce greenhouse gas emissions while others are desperately needed to maintain system resiliency and reliability. Paired with the simultaneous trend of electrification that is integrating the power and transportation sectors, the transition to a cleaner energy future is even further complicated as additional assets in sectors like transportation will require greater connectivity to the electrical grid, effectively increasing the load imposed on an aging system.

A question that then remains is how can existing and emerging energy technologies help to facilitate and accelerate this transition to a decarbonized energy system where the system load can be managed most effectively and efficiently. Over the past few decades, much thought and research have been devoted to the benefits of each technology on a standalone basis, whether renewable energy, energy efficiency, electric vehicles, demand response, or other distributed energy resources (DERs). Out of all of these technologies, energy efficiency has repeatedly proven itself, on average, as the "nation's least-cost resource."[ii] More attention, however, must be devoted to ***how and in what targeted areas can energy efficiency serve as a complement within the management of a broader energy system that is moving towards greater decarbonization and electrification***.

Put more concretely, these questions arise as the role of energy efficiency in this transition is considered:

1. What are the synergies and competitive interactions between energy efficiency and these other supply-side and demand-side technologies in the American power sector?
2. How can industry stakeholders, specifically utilities, then best respond to the broad decarbonization goals emerging out of state legislatures and executive actions?
3. Are there research insights, best practices, and lessons learned that can be leveraged to push progress forward at utility-level implementation?

Undoubtedly, energy efficiency must play a leading role in the clean transition, but arguments provided about its critical role can be strengthened by greater investigation into its impact on other pieces of the clean energy system, not solely on the end-goal of reduced electricity consumption. The investigative lens used should be one that is cross-cutting rather than siloed. This analysis aims to answer these questions using a more integrated lens.

### *Focus of the Analysis*

The analysis that follows will focus in particular on the relationship between energy efficiency and the following supply-side and demand-side technologies within U.S. electricity markets: (1) renewable energy, (2) demand response; and (3) electric vehicles. This analysis will also specifically emphasize the associated impacts and implications in thirteen states within the American Midwest: Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. While adoption trends and relationships will be described at an overall strategic level, the key impacts will then be contextualized to the markets and stakeholder dynamics within these thirteen midwestern states. In this grouping alone, utilities are operating across three wholesale markets or in the traditionally regulated manner, along with operating either in competitively restructured states or not. The analysis will also narrow its stakeholder scope to the role of the electric utility to showcase how arguably the most important stakeholder in the electricity value chain can appropriately respond to these broad trends and technological relationships in order to seize opportunities for optimization across the energy system.

### *Structure of the Analysis*

Part I of this analysis sets up the market landscape under review—to include trends and foundational relationship principles—by discussing various findings and insights from recent academic literature, scientific research, and market research studies. Synergistic and competitive interactions between energy efficiency and the aforementioned technologies are presented and evaluated. This analysis, however, does not explore the effectiveness of economic incentives and business models used by market stakeholders to drive adoption, such as subsidies and cost recovery mechanisms. This theoretical foundation surrounding the technologies' trajectories and interactions ultimately gives a foundational basis by which to assess practical, real-world outcomes and recommendations for improvement later on in the analysis.

Part II, in turn, quantitatively describes energy efficiency's relationship with renewable energy, demand response, and electric vehicles by way of statistical regression models aimed at highlighting possible underlying correlations that manifested over a period of time as these trends evolved. In comparison to Part I where the scope and nature of the relationship is defined, the findings from this section explore the magnitude and strength of that relationship. While difficult to explicitly derive causation, these statistical findings are additional tools by which to shape and inform public debate and future research. The objective of these regression models is to take the next step in the conversation beyond theory into actual practice and observations from reality.

Finally, Part III concludes this analysis with additional guidance and recommendations on how regulators and utilities can effectively communicate and implement these important takeaways regarding the complementary and competitive interactions of energy efficiency with the other supply-side and demand-side technologies. This discussion also includes perspectives on the main impediments to progress that are largely outside of the utilities' direct control but that can be expressed and deliberated in ongoing public debates.

## Part I: Literature and Research Review

The following section gives a broad overview of the benefits of energy efficiency and its relationship with other supply-side and demand-side technologies, such as renewable energy, demand response, and electric vehicles.

### *Role of Energy Efficiency*

Before diving into the complex relationships between energy efficiency and the other technologies, it is important to describe what energy efficiency measures offer in terms of improving the management of the broader energy system. First and foremost, in this analysis, energy efficiency is defined as "the persistent and maintained reduction in energy and/or demand, as compared to baseline consumption, to provide the same or an improved level of service."[iii] This permanent reduction then leads to the following major energy benefits (see Appendix A for a more comprehensive illustration of benefits):

- **Increased energy savings:** by lowering demand, energy efficiency measures reduce costs for utilities and also their customers in the bills that they end up receiving.
- **Avoided/deferred capital investment and upgrade costs:** whether directly related to generation or transmission/distribution, energy efficiency can help to offset the need to build and acquire new resources—contributions to date since 1990 have been the equivalent of 313 additional large power plants with output of 500 MW.[iv]
- **Increased system reliability:** if placed in the appropriate geographical location, energy efficiency measures can serve as a non-wires alternative to positively contribute to transmission/distribution requirements and "relieve grid congestion."[v]

Beyond the benefits described above, energy efficiency has consistently been designated as the "nation's least-cost resource," costing program administrators at investor-owned utilities roughly 2.5 cents per kWh on a savings-weighted average basis, which accounts for the energy efficiency measure's entire lifetime or lifecycle.[vi] It costs publicly owned utilities 2.4 cents per kWh.[vii] The midwestern states included in the study conducted by the Lawrence Berkeley National Laboratory (LBNL) were all shown to have even lower costs of saved electricity than the national average from the perspective of the program administrator, ranging from 1 cent per kWh to 2.2 cents per kWh (excluded states: KS, NE, ND).[viii] For comparison's sake, Lazard's most recent levelized cost of energy estimates put the new build of the energy system's lowest cost resource—wind energy—at 2.6 cents per kWh.[ix] These quantitative findings, however, do not take into account the customer, or program participant, costs, which can amount to as high as 61% of the total cost of saved electricity, as within the midwestern region of LBNL's study (approximately 2.7 cents out of the 4.5 cent average reported).[x] Given meaningful differences in impact based on demographic characteristics, it is very important to be explicit about which point of view is used in evaluating the costs, especially when assessing the impacts on low-income and disadvantaged communities.

### *Interactions between Energy Efficiency and Renewable Energy*

According to recent reporting from the U.S. Energy Information Administration (EIA), renewable assets, specifically solar and wind, are to account for 70% of the new electricity generating capacity to come online in 2021, totaling 27.6 GW out of the planned 39.7 GW.[xi] With increasing renewable penetration—whether utility-scale or not—thought should be given to how energy efficiency, the lowest-cost resource, plays a role in facilitating this transition whether via system operations, business models, or operating strategies.

A renowned, commonly cited study from the International Renewable Energy Agency finds that combining the implementation of renewable energy and energy efficiency in an accelerated fashion would lead to an approximately 21% reduction in the growth of total primary energy supply by 2030 in comparison to the business-as-usual, or reference, case for the United States.[xii] The combined implementation of both technologies also leads to higher shares of renewable energy in the power sector, reaching 54% of electrical generation in the United States by 2030.[xiii] The positive interaction does not end there as this combined scenario leads to significant reductions in energy intensity—defined as energy use per unit of gross domestic product—where 50-75% of the savings realized are attributable to energy efficiency measures specifically.[xiv] In sum, the integration of renewable energy and energy efficiency leads to a much cleaner electrical grid as well as more productive output per unit of energy employed in economic activity. By lowering the demand that is needed to be met by renewable energy sources, energy efficiency helps to reduce the costs of investment to bring these assets online. If optimized and coordinated correctly, energy efficiency provides a reasonably effective pathway for displacing fossil-fuel based generation assets with renewable energy technologies.

Moving forward, scenario planning and further studies will be key to determining the best possible deployment of energy efficiency measures given the degree of renewable penetration and the associated time value of these demand-side resources. Recent research from LBNL draws a meaningful distinction between environments of low penetration versus high penetration of variable renewable energy (VRE) in the case of deploying energy efficiency measures.[xv] In higher VRE scenarios that alter the timing of peak loads, residential energy efficiency upgrades reducing consumption in the evening actually "deliver higher value savings" than other energy efficiency upgrades in larger office buildings with daytime savings.[xvi]

It is also important to note that wind energy and solar energy each have their own unique impacts on the timing of peak loads as well as the resulting load shapes and pricing. Under a scenario of high wind energy, LBNL finds that there may be increased "irregular hourly price volatility" alongside "moderated average diurnal price profiles over longer," in comparison to a scenario of high solar energy with "strong effects on diurnal price profiles."[xvii] The following figure shows an example of the impact of VRE penetration on mean diurnal energy prices, or the infamous "duck curve," within the Southwest Power Pool market (SPP).

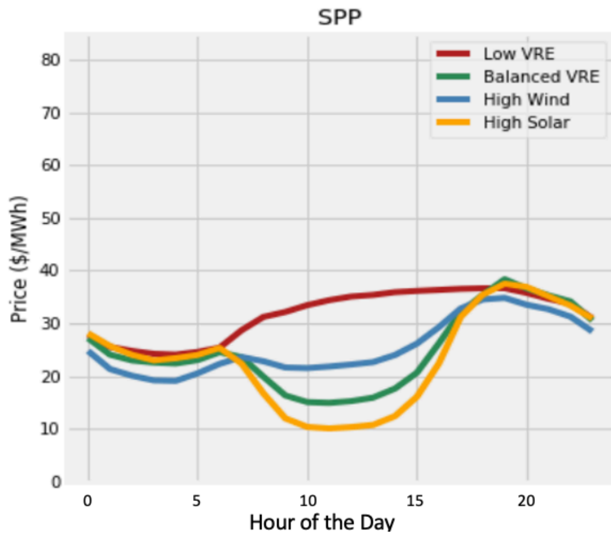



**Figure 1: VRE's Impacts on Mean Diurnal Energy Prices for Weekdays in Southwest Power Pool**
Source: Seel et al. (2018)—Lawrence Berkeley National Laboratory

Taken together, VRE's impacts on load and energy pricing fundamentally alter the value attributed to investments in energy efficiency measures. A study regarding the time value of energy efficiency and the resulting dynamics in capacity values within the California Independent System Operator (CAISO) gave a brief preview of the future consequences in being a market leader in renewable energy.[xviii] With a 40% renewable penetration, Boomhower and Davis (2020) show that the timing premium increases by 13 percentage points due to shifting peak prices towards the evening where air conditioners can capitalize on the energy savings.[xix] More empirical and research studies should be exclusively devoted to analyzing the effects of VRE on the suite of energy efficiency measures available on the market for implementation.

Given these multidimensional factors—specific technology deployed, load, and timing—and their implications, further studies should be conducted at the level of the distribution system and then at level of the electricity market, especially as each utility continues to plan and invest in renewable generation and government officials define ambitious decarbonization goals. With declining renewable prices, these efforts are rapidly accelerating, and with the eagerness to deploy clean assets onto the electrical grid, the relationship between existing, planned, and future energy efficiency measures and renewable energy penetration should be fully assessed and optimized appropriately.

### *Interactions between Energy Efficiency and Demand Response*

By far, out of all the other energy system technologies, the relationship between energy efficiency and demand response has been studied the most, although there is still more work to be done to assess the relationship holistically at all steps in the value chain instead of solely during changes in load. Nevertheless, the relationship between energy efficiency and demand response with respect to load is critical to properly managing these resources within the electrical grid. Two important nuances distinguish demand response from energy efficiency measures, namely its active rather than passive nature and its impermanence. A study by the Lawrence Berkeley National Laboratory defines demand response as an:

> "active reduction, increase, shift, or modulation of energy and/or demand on a limited time basis, as compared to baseline consumption in response to a price/incentive payment or command signal, which may result in a lower level of service"[xx]

Utilities typically engage in demand response programs due to concerns over costs and reliability—including high wholesale electricity prices, high peak demand, and capacity shortages.[xxi] The objective is to properly balance supply and demand whether in a manual or automated fashion for a specified period of time or event, as opposed to a continuous reduction. Unlike energy efficiency measures, demand response is often considered by utilities to be a "dispatchable resource" that can be called upon when needed.[xxii]

The Lawrence Berkeley National Laboratory described that demand response and energy efficiency predominately interact with one another when "changes in one resource affect the size, grid need, or availability of the other resource."[xxiii] That interaction is strengthened by the presence of demand flexibility, where there is an ability via technological means to "actively lower, increase, shift, or modulate energy usage, compared to a baseline scenario reflecting the passive state of operation, and in response to utility grid needs."[xxiv] Demand flexibility, through installed energy efficiency measures, unlocks additional load that is potentially available for demand response events. Increased demand flexibility, if present, fundamentally creates a "win-win" situation from the perspective of both energy efficiency and demand response. On its own as a piece of equipment, energy efficient technology is able to perform the same service for the end-consumer at the same quality or even better. With the inclusion of other technological components such as "controls technology, thermal improvements, or different operational strategies," the complete energy efficiency measure may further alter the system's load shape as a result of modified average consumption patterns.[xxv] It is this inclusion of these additional technological components that unlocks load potential for demand response events.

Table 1 below briefly summarizes the various kinds of interactions that may exist between the two demand-side resources—sometimes alongside demand flexibility depending on the circumstance.

**Table 1: Summary of Interactions—Energy Efficiency (EE) & Demand Response (DR)**

| ***Relationship*** | **Size of Resource** | **Grid Need for Resource** *System Operator Perspective* | **Availability of Resource** |
|---|---|---|---|
| Complementary | EE measures may unlock additional, enhanced load available for DR due to demand flexibility | EE measures may lower loads at the system level to a point where there is a decreased probability of a DR event occurring | The additional technological means embedded in EE measures, whether programmable or communication, may increase the degree of load available for events |
| Competitive | DR, through load shifting, may incentivize increased total energy consumption and the adoption of comparatively less efficient | EE measures may lower loads at the system level during times where increased load is more advantageous (i.e., renewable energy curtailment) | EE measures may decrease the load available that can then be dispatched for events |

| | | | |
|---|---|---|---|
| | technologies to increase load flexibility<br>EE measures may decrease the load available for DR events to shed or shift load | leading to increased need for DR to shift load | |

Source: Satchwell et. al. (2020)—Lawrence Berkeley National Laboratory (2020), *A Conceptual Framework to Describe Energy Efficiency and Demand Response Interactions*

When considering the above interactions between energy efficiency and demand response, however, it is important to keep in mind a critical distinction between the perspective of the building where the asset is installed versus the entire system.[xxvi]

From a building's view, the installation of energy efficiency measures may possibly affect and alter the degree of technical potential (volume), technical capability, or the fraction of demand flexibility participating in demand response events in light of subsequent customer behavior and usage (See Figure 2 below).[xxvii] Two dimensions are primarily about the technical element, with the third concerned about the human element in permitting utilization of the potential and capability available.

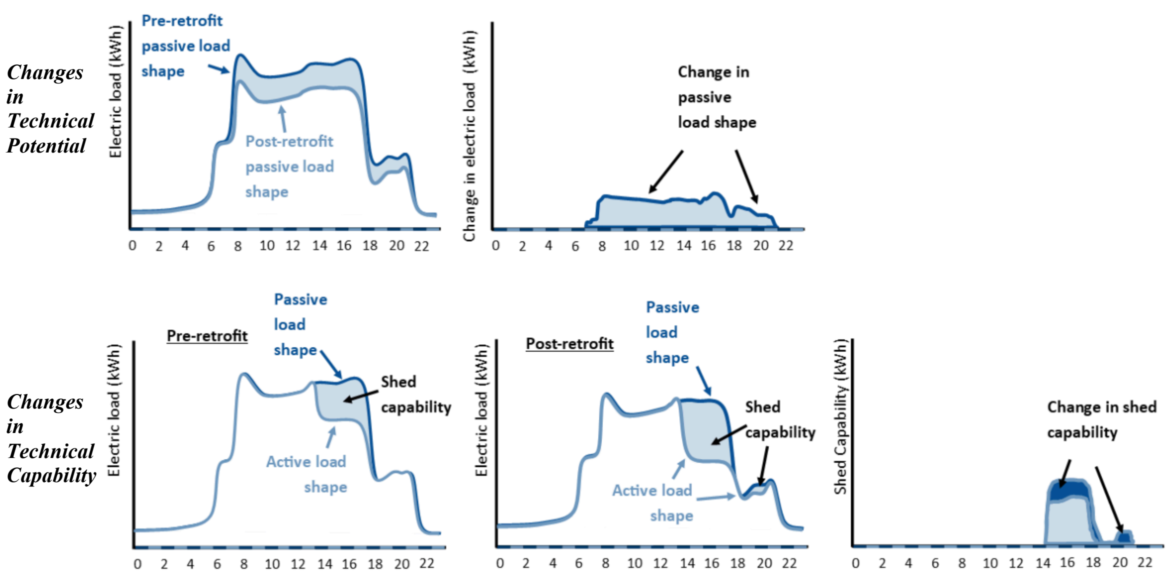



**Figure 2: Illustrating Changes in Technical Potential & Capability Available for Demand Response**

Source: Satchwell et. al. (2020)—Lawrence Berkeley National Laboratory, *A Conceptual Framework to Describe Energy Efficiency and Demand Response Interactions*

From a system's view, the interaction is based on aggregate effects and is closely tied to the "coincidence of the energy/demand savings at the building level and the net load driving system conditions."[xxviii] A substantial emphasis is placed on the effects on demand response as a resource, or tool, at the disposal of the utility operator in order to balance system needs and requirements.[xxix] The installation of energy efficiency measures may either alter the need for or availability of demand response, incorporating each of the elements from the building outlook into the overall aggregate to deliver a net result that defines the nature of the relationship.[xxx]

As highlighted by the LBNL study, the timing of these interactions at a system level cannot be emphasized enough as the nation transitions toward a cleaner energy system with increasing penetration of intermittent renewable energy sources. Energy efficiency measures may unintentionally exacerbate the need to build load when excessive renewable generation is not met with customers at the other end of the value chain eager to use the electricity produced by these assets. Therefore, the pairing of demand response and energy efficiency will be pivotal for grid balancing so as to avoid a sharp seesaw of curtailment and ramp-up.

### *Interactions between Energy Efficiency and Electric Vehicles*

Analyses covering the relationship between energy efficiency and electric vehicles are still nascent and developing. According to Bloomberg New Energy Finance, by 2040, 58% of passenger vehicles sold globally will be electric, up from 2.7% in 2020.[xxxi] To support this transition, extensive infrastructure must be constructed throughout the nation with need for connectivity to the electrical grid.

The Rocky Mountain Institute describes that the replacement of light-duty vehicles with electric vehicles would necessitate 1,000 TWh of additional electricity per year, which is roughly a 25% increase of the nation's electricity demand today.[xxxii] As electric vehicles are primarily charged at building sites, whether at home or at work, the increases in electricity demand would result in corresponding "incremental growth in building electricity use."[xxxiii] Utilities must not only prepare to support the infrastructure's and vehicles' connections to and demands on the grid, but also work to anticipate and accommodate the altered timing and shapes of the imposed load. The figure below provides an illustrative example of possible scenarios regarding the impacts of electric vehicle charging on the electrical grid in New England.[xxxiv] Without appropriately reducing or shifting the increase in demand, the peak impact could change by nearly 20% with just 25% fleet penetration.

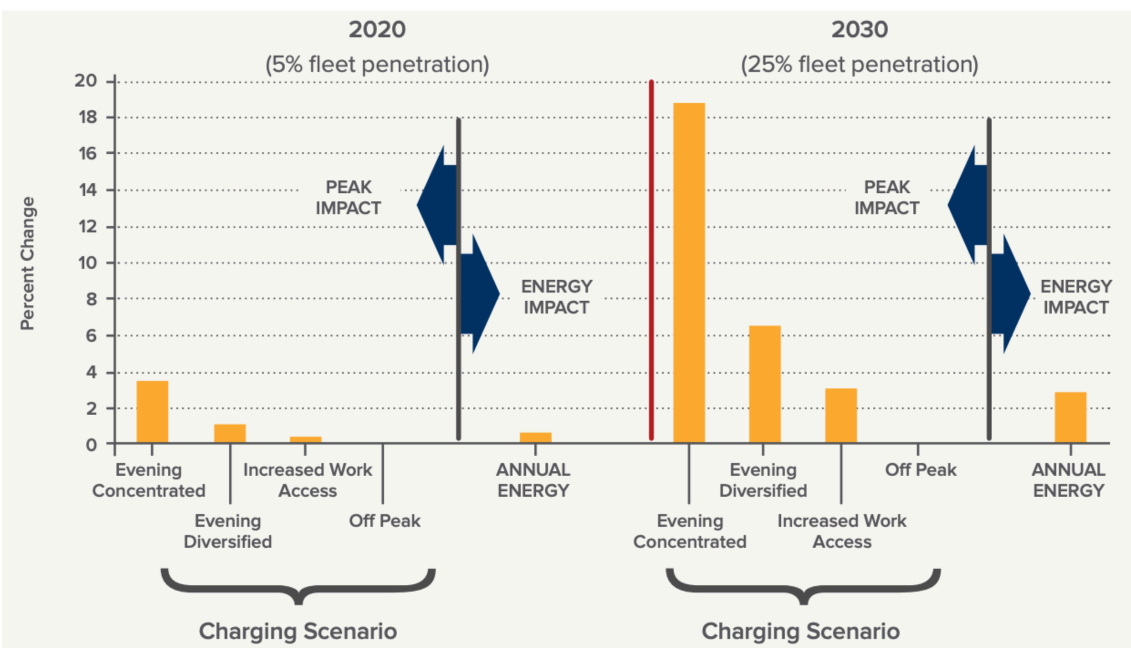



**Figure 3: Hypothetical Impacts of Plug-In Hybrids on System Demand in New England**

Source: Fitzgerald et. al. (2016)—Rocky Mountain Institute, *Electric Vehicles as Distributed Energy Resources*; Vermont Energy Investment Corporation and the National Association of State Energy Officials, September 2013.

Energy efficiency measures are in a position to act as a positive enabler of this market transformation in transportation. In conjunction with smart charging technology (e.g., timing and "two-way" capabilities), energy efficiency measures—especially those that incorporate demand flexibility—have the potential to better ensure stability and reliability.[xxxv] The increased load imposed by vehicle electrification will be stabilized by enabling interactive communications between the technologies and the grid through increased demand flexibility in order to reduce and adequately manage peak loads. The Rocky Mountain Institute provides an illustrative example of this potential reality in California (see below). In this scenario, the implementation of broad, aggressive, and cost-effective energy efficiency measures—such as "LED retrofits, appliance replacements, and retrocommissioning" 50% of the building stock—that together achieve an average hourly savings of 7% are bundled with smart electric vehicle charging to offset the increase in peak load imposed by the electric vehicle's electricity usage.[xxxvi]

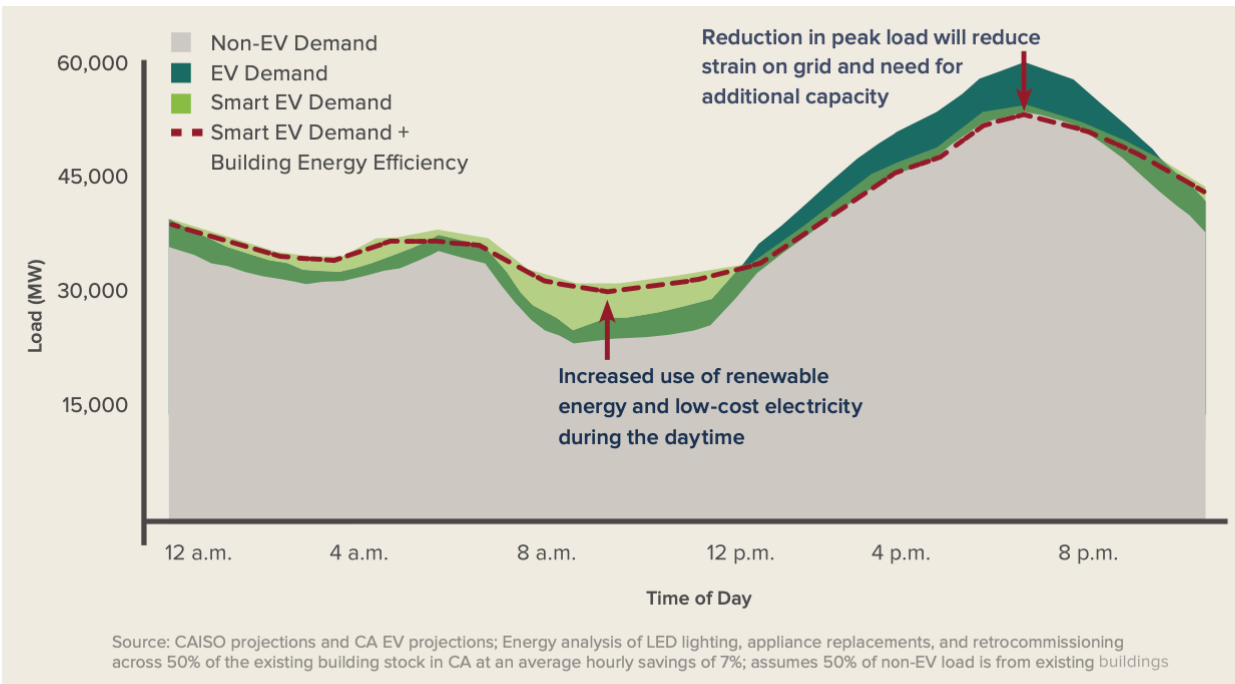



**Figure 4: Hypothetical Impacts of Smart EV Charging & Building Energy Efficiency on Peak Load**
Source: Egerter et. al. (2018)—Rocky Mountain Institute, *Energy Efficiency and Electric Vehicles: How Buildings Can Pave the Way for the Global EV Revolution*

### *Concluding Summary*

From each of these highlighted relationships, a common thread emerges with regards to the deployment of energy efficiency. The question is not whether it should happen, but in fact, how it should happen so that it is both cost-effective and balanced across the system. The aperture by which we solve these challenges simply needs to widen to be systemwide rather than ad-hoc or purely local. The relationship between energy efficiency and renewable energy emphasizes the time-value aspect, while energy efficiency's relationship with demand response and electric vehicles emphasizes the mutually beneficial use of demand flexibility. Thus, the next task at hand for society and the stakeholders within the electric power industry is to properly manage and weigh these relationships in a comprehensive manner.

# Part II: Quantitative Assessment

The following section dives into a quantitative analysis of the relationships described previously in order to see if practical realities do indeed match the theoretical arguments presented as well as to determine areas of further investigation needed.

### *Overview of Methodology, Limitations, and Unit of Analysis*

To statistically investigate the complementary and competitive relationships between energy efficiency and these other energy technologies described in Part I, this quantitative analysis outlines a series of multiple linear regressions that were conducted:

- Regression describing the relationship between Energy Efficiency and Renewable Energy
- Regression describing the relationship between Energy Efficiency and Demand Response

A regression describing the relationship between energy efficiency and electric vehicles could not be conducted properly due to the inability to quantify the number of electric chargers at residences, which are critical to assessing the true load impacts (>80% of drivers charge at home).[xxxvii] This gap in data availability should be addressed as soon as possible by government officials and/or industry partners in order to be able to conduct more robust systemwide analyses.

In examining energy efficiency's relationship with renewable generation and demand response, the efforts of thirteen states within the American Midwest were assessed after aggregating the data across the various electric utilities and energy providers that service customers within their respective borders.

> States Assessed: Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin

Fixed effects were employed in the regression models for both year and state. These fixed effects helped in controlling for any unobserved bias or omitted variables across states (e.g., unique and consistent legislative/other regulatory mandates) or across years (e.g., the enactment of solar tariffs). Fixed effects aim to control for "across group" variation rather than "within group" variation seen among different observations falling within that particular grouping. The objective is to ensure that any sort of unintentional omitted variable bias does not unduly influence the results of the regression models.

The time period of these regressions was from 2013 to 2019 due to the availability of data in the U.S. EIA's database for the Annual Electric Power Industry Report regarding energy savings due to energy efficiency as well as demand response. Each of the continuous variables are expressed in terms of natural log, allowing for the changes in the quantitative coefficients and the outcome variables to be expressed in terms of elasticities. With the outcome variable expressed in terms of natural log, the impacts of the policy-related dummy variables are expressed in terms of 100 times the value of the coefficient. Thus, this multiple linear regression is a blend of both a log-log and a log-level statistical relationship.

Given limitations on the data available, individual states rather than electric utilities were used as the unit of analysis and reference point for this quantitative analysis. Ideally, electric utilities would have been the focus of choice, but there were some limitations in the data available for analysis.

For example, to properly analyze the role of electric utilities in the relationship between renewable generation and investments in energy efficiency measures, there would have to be more granular, publicly available data on the percentage of electricity sales attributable to renewable energy for each and every utility, whether vertically integrated or not. The best national data available via the U.S. Energy Information Administration that could attempt to describe this particular relationship is the annual net generation of renewable power plants associated with the specific utility that owns that very facility within a specific state. However, utilities who do not own renewable generation assets—or any generation assets at all whether by choice or by state law—can purchase this cleaner form of electricity from other utilities who do own these sorts of assets in order to ultimately provide this cleaner service to their customers. Therefore, utilities who do offer renewable-based electricity to customers but do not own renewable generation plants would be left out of the regression analysis, biasing the end results.

In addition, there is no comprehensive, publicly available database regarding the number of electric vehicle chargers deployed via utility program offerings in the private and public domains. Thus, any conclusions about the relationship between energy efficiency and electric vehicles could not be rightfully attributed to the work of the electric utility.

### *Variable Selection*

Annual incremental energy savings measured in megawatt-hours (MWh) were chosen as the quantitative, technological measure to represent energy efficiency in the statistical regressions. This particular variable takes into account incremental savings within the reporting year (i.e., savings from <u>newly</u> installed energy efficiency measures). Given it represents new additions and not the total amount of resources operating in the environment, this measure is not ideal when attempting comparisons to either annual net renewable generation or yearly demand response savings that represent the entirety of those resources deployed within a given year.

Unfortunately, a true and accurate estimate of the total annual savings from energy efficiency is not available to the public given the breadth of energy-efficient technologies available in the marketplace, wide disparities in these measures' useful lives, and the need for measurement and verification practices to ensure that the engineer's estimates prepared initially still hold true in the future. For example, a study by the American Council for an Energy-Efficient Economy reports that the average measure life for the top 41 electric utilities highlighted in their annual scorecard ranged from 3.7 years to 20.4 years (with an average of 11.1 years across the grouping).[xxxviii] It would be difficult to point to a standard assumption that could truly and quickly capture the breadth and depth of the technologies out there that satisfy a variety of application and consumer needs. Thus, the incremental proxy provided by the U.S. Energy Information Administration is the best available variable for this analysis.

The two other technology-related variables used to explore their respective relationship with energy efficiency were annual net renewable generation and yearly energy savings from demand response. Annual net renewable generation only includes megawatt-hours from solar and wind generation assets within the state that were not combined heat and power plants, as the relationship described before between energy efficiency and renewable energy is defined by challenges with intermittency in the electric power sector. Yearly energy savings from demand response is also expressed in megawatt-hours, allowing for a consistent comparison with regard to units of measure. Like the measure for net renewable generation, the variable for demand response captures the total yearly impact of this resource in the energy system.

Both regressions included variables associated with state policies regarding renewable energy and/or energy efficiency to see (1) if the technological interactions and synergies dominate the nature of the relationships described; or (2) if statewide policies and human attitudes also drive the direction of the relationship. The specific policies incorporated into the regressions include mandatory energy efficiency resource standards (EERS) as well as mandatory renewable portfolio standards (RPS). Given concerns over possible multicollinearity, the voluntary standards were excluded from the analysis. The value of the particular policy-related dummy variable was assigned based on whether or not the state in question had the specific policy enacted within that specific year (i.e., 1 for "yes" and 0 for "no").

Within each of these regression models, there was also one consistent control variable—state gross domestic product (GDP) per capita—used for reasons similar to those given by Theel and Westgaard (2017) in their own analysis of utility-based energy efficiency policies.[xxxix] Even though the relationship has been altering in recent years with the transition to a predominantly service economy, energy investments and use are likely to be paired with economic growth and activity.[xl] As result, this should be properly controlled for in the regression using state GDP per capita. Similar to the Theel and Westgaard (2017) model, population and GDP figures for each state were obtained from the U.S. Census Bureau and the U.S. Bureau of Economic Analysis, respectively, to calculate the states' GDP per capita in millions of current dollars.[xli]

Some of the observations for the technological variables were omitted as the values were not associated with a specific energy provider as designated by information collected by the U.S. Energy Information Administration. Only measures associated with a specific energy provider within the states under investigation—as opposed to broader programs—were aggregated into the state-by-state analysis to avoid possible overcounting or overstatement.

### *Summary of Regression Design and Variable Selection*

The tables and associated equations listed below summarize each of the variables used in these simple, high-level statistical regression models and their role as either an outcome, explanatory, or control variable (see Appendix D for each variable's summary statistics).

**Table 2: Overview of Variables and Data Sources for the Energy Efficiency and Renewable Energy Regression Model**

| Variable Name | Type of Variable | Nature of Variable & Units | Data Sources |
|---|---|---|---|
| Annual Incremental Energy Efficiency Savings | *Outcome Variable* | Continuous Units: MWh | U.S. Energy Information Administration (EIA) Annual Electric Power Industry Report [Form-861][xlii] |
| Annual Net Renewable Generation *(solar and wind only)* | *Explanatory Variable* | Continuous Units: MWh | U.S. Energy Information Administration (EIA) Power Plant Operations Report [Form-923][xliii] |

| | | | |
|---|---|---|---|
| Mandatory Renewable Portfolio Standard | *Explanatory Variable* | Dummy | Database of State Incentives for Renewables & Efficiency[xliv]; National Conference of State Legislatures List of State Renewable Portfolio Standards and Goals[xlv]; Center for Climate and Energy Solutions Map of U.S. State Electricity Portfolio Standards[xlvi] |
| Mandatory Energy Efficiency Resource Standard | *Explanatory Variable* | Dummy | American Council for Energy-Efficient Economy (ACEEE) State & Local Policy Database[xlvii]; National Conference of State Legislatures Table of Energy Efficiency Resource Standards or Voluntary Targets[xlviii]; Center for Climate and Energy Solutions Map of Energy Efficiency Standards and Targets[xlix] |
| State GDP per capita | *Control Variable* | Continuous Units: Millions of Current USD per person | U.S. Bureau of Economic Analysis (State GDP data)[l]; U.S. Census Bureau (State Population Data)[li] |

**Associated Regression Equation:** $\ln(\widehat{EE\_incremental})_{sy} = \hat{\beta}_0 + \hat{\beta}_1 \ln(Net\_Renewable\_Gen) + \hat{\beta}_2 Mand\_RPS + \hat{\beta}_3 Mand\_EERS + \hat{\beta}_4 \ln(State\_GDPpercap) + \lambda_{state} + \lambda_{year} + \hat{\epsilon}$

**Table 3: Overview of Variables and Data Sources for the Energy Efficiency and Demand Response Regression Model**

| Variable Name | Type of Variable | Nature of Variable & Units | Data Sources |
|---|---|---|---|
| Yearly Demand Response Energy Savings | *Outcome Variable* | Continuous Units: MWh | U.S. Energy Information Administration (EIA) Annual Electric Power Industry Report [Form-861][lii] |
| Annual Incremental Energy Efficiency Savings | *Explanatory Variable* | Continuous Units: MWh | U.S. Energy Information Administration (EIA) Annual Electric Power Industry Report [Form-861][liii] |
| Mandatory Energy Efficiency Resource Standard | *Explanatory Variable* | Dummy | American Council for Energy-Efficient Economy (ACEEE) State & Local Policy Database[liv]; National Conference of State Legislatures Table of Energy Efficiency Resource Standards or Voluntary Targets[lv]; Center for Climate and Energy Solutions Map of Energy Efficiency Standards and Targets[lvi] |
| State GDP per capita | *Control Variable* | Continuous Units: Millions of Current USD per person | U.S. Bureau of Economic Analysis (State GDP data)[lvii]; U.S. Census Bureau (State Population Data)[lviii] |

**Associated Regression Equation:** $\ln(\widehat{Incr\_DR})_{sy} = \hat{\beta}_0 + \hat{\beta}_1 \ln(EE\_incremental) + \hat{\beta}_2 Mand\_EERS + \hat{\beta}_3 \ln(State\_GDPpercap) + \lambda_{state} + \lambda_{year} + \hat{\epsilon}$

### *Findings from Regression Models*

Utilizing the multiple linear regression models that leverage panel data across the years 2013 to 2019 while alongside both state and year fixed effects, the following key takeaways were gathered from the statistical regressions' output (refer to Appendices B and C for more comprehensive statistical findings). The results describe industry impacts within thirteen states in the American Midwest.

<u>Regression Describing the Relationship between Energy Efficiency and Renewable Energy</u>

Although the effect of net renewable generation was found to be insignificant both statistically and practically, mandatory renewable portfolio standards were found to have positive, statistically significant impacts (i.e., $p < .05$) on the degree of incremental energy efficiency savings (see Model 6 in Appendix B):

- *States with a mandatory renewable portfolio standard experienced an increase in energy efficiency savings that was, on average, 96.8% higher than the total amount of savings in states without a mandatory renewable portfolio standard.*

This is one of the most robust models from the output, predicting roughly 98.8% of the variation in incremental energy savings from energy efficiency while incorporating state and year fixed effects.

<u>Regression Describing the Relationship between Energy Efficiency and Demand Response</u>

In this regression, incremental energy efficiency savings were found to have a marginally significant impact (p-value of .083) on the yearly demand response energy savings (see Model 5 in Appendix C):

- *In the most robust model (Model 5), a 1% increase in the incremental energy efficiency savings within a state resulted in a .865% increase in yearly demand response savings—possibly hinting at a blending of multilevel interactions.*

Furthermore, like in the previous regression, policies were again found to have a statistically significant, large impact:

- *States with a mandatory energy efficiency resource standard experienced an increase in demand response energy savings that was, on average, 389% higher than the total amount of savings in states without a mandatory energy efficiency resource standard.*

The intended control variable was also found to be statistically significant in this particular model, where a 1% increase in the state GDP per capital resulted in an approximate 9.73% increase in yearly demand response energy savings.

### *Discussion of Findings*

<u>Regression Describing the Relationship between Energy Efficiency and Renewable Energy</u>

Although the primary objective was to better understand the realization of technological synergies between these clean technologies in the American Midwest, this quantitative analysis shed light on the strong effects of state policy decisions on the broader energy ecosystem. The presence of mandatory renewable portfolio standards nearly doubled the amount of energy efficiency savings realized within the associated states. This massive, sweeping impact cannot be understated. It is also important to note, however, that energy efficiency standards were at the cusp of reaching marginal significance with an approximate p-value of .15 and would be responsible for an average 20% increase in energy efficiency savings. The lack of a statistically significant relationship with net renewable generation (approximate p-value of .23) could be attributable to variable choice as net generation within a state does not fully account for the imports and exports conducted across state lines via electricity sales. Therefore, net generation could either underestimate or overestimate the true volume of renewable electricity sales to customers serviced by the state's utilities.

This quantitative analysis also runs into a "chicken-and-egg" problem, especially in examining the relationship between energy efficiency and renewable energy. Energy efficiency has long been thought of as a least-cost *pathway* to achieve higher renewable penetration by lowering system demand and deferring needed investment in transmission, distribution, and possibly storage to accommodate increasing volumes of wind and solar energy on the grid.[lix] So, undoubtedly, a question then remains about whether or not investments in energy efficiency "cause" investments in renewable energy, or vice versa. The expressed theory would support the former and not necessarily the latter if the interactions of these technologies were thought to be sequential in nature. While the theoretical arguments are strong and should be given consideration in present and future efforts, the timing of these state policies in the Midwest show perhaps an act of putting the "cart before the horse." The two figures below highlight the timing in which the mandatory standards for both energy efficiency and renewable energy were enacted. For this reason, to study the relationship, energy efficiency energy savings was chosen as the outcome variable while net renewable generation served as the explanatory variable.

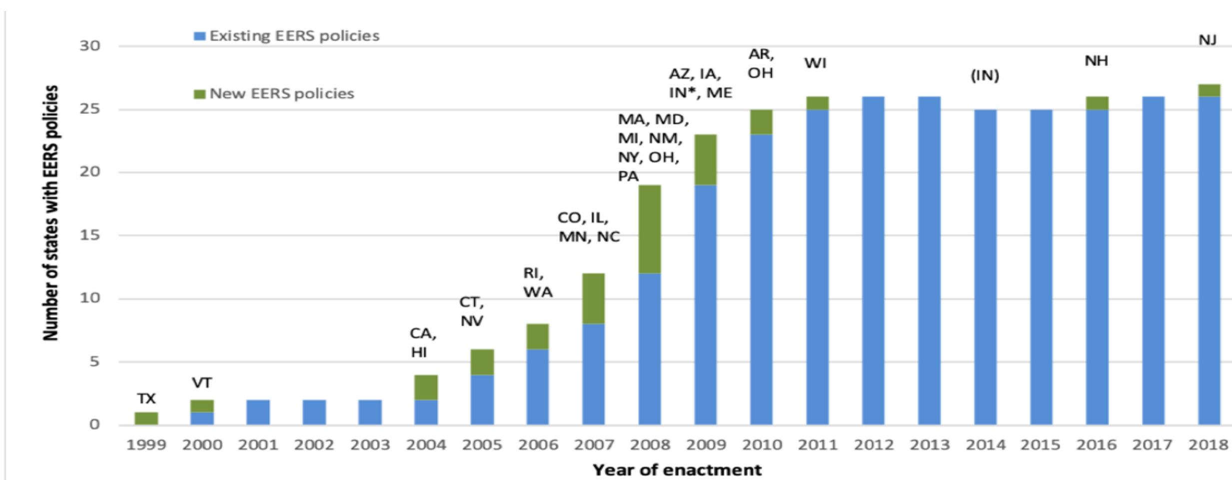


**Figure 1. States with an EERS by year of adoption. *Indiana's EERS was rolled back in 2014.**

**Figure 5: Enactment Year & Total Number of States with Energy Efficiency Resource Standards**[lx]

Source: American Council for an Energy-Efficient Economy (2019), *Policy Brief: State Energy Efficiency Resource Standards (EERS)*

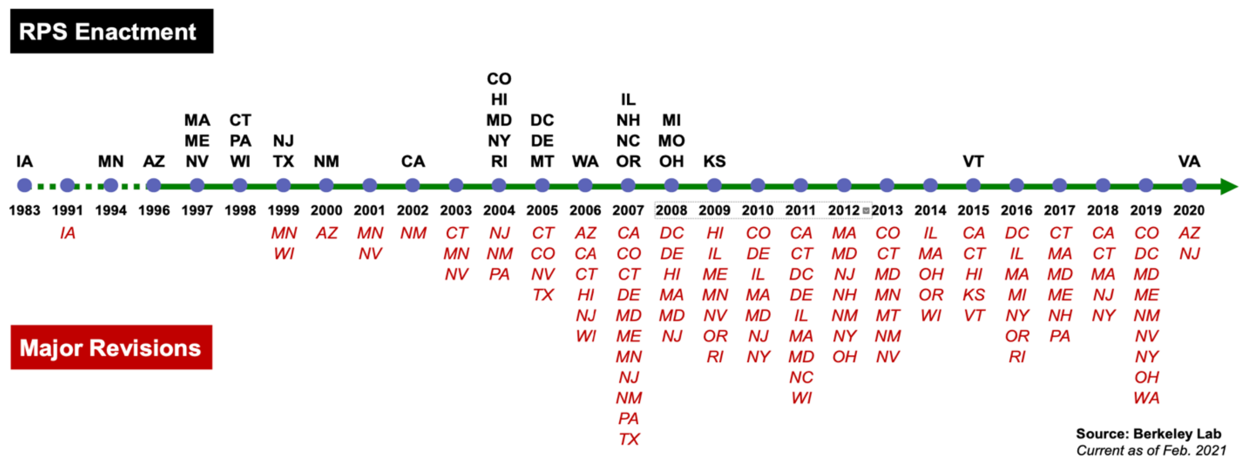



**Figure 6: Enactment Year & Major Revisions of State Renewable Portfolio Standards**[lxi]
Source: Lawrence Berkeley National Laboratory (2021), *"Presentation—U.S. Renewables Portfolio Standards 2021 Status Update (Early Release)"*

As seen from the above figures, seven out of the thirteen midwestern states analyzed had mandatory renewable portfolio standards throughout the analysis' entire time period (note: Kansas repealed its standard in 2015). Three states out of those seven enacted RPS long before implementing EERS (i.e., Iowa, Minnesota, and Wisconsin), and three others enacted both standards within the same year (i.e., Illinois, Ohio, and Michigan). A possible rationale for finding such a strong positive interaction between the presence of a mandatory RPS and savings in energy efficiency could be that these states' relatively early efforts to define and meet the RPS thresholds led them to recognize the value of and invest in energy efficiency in order to resolve some of the challenges with renewable adoption prior to codifying any sort of EERS. This timing element and learning curve could have led to an unobservable influence in the regression that was not fully addressed through the fixed effects since policy enactment occurred several years before the analyzed time period. Although most of the states with a mandatory RPS continued on that path throughout the analyzed period, their respective program implementation and stakeholder actions could have evolved over time as the state progressed through its learning curve. This trend in timing is not limited to the Midwest. Nationwide, a considerable proportion of renewable portfolio standards were developed and enacted earlier than energy efficiency resource standards.

<u>Regression Describing the Relationship between Energy Efficiency and Demand Response</u>
Theoretically, as described in previous sections, the interactions between demand response and energy efficiency are multifaceted with the potential for synergistic or competitive interactions. For the thirteen states examined, the regression model finds the technological relationship to be one that is marginally significant, described in terms of elasticity, where a 1% increase in energy efficiency energy savings led to a 0.865% increase in yearly demand response energy savings. Since the increase is less than one percentage point, yearly demand response energy savings are not as sensitive to savings realized from energy efficiency, but the value is quite close to a proportional, one-for-one relationship. The diminished sensitivity could be due to a significant blending of the complementary and competitive interactions, but overall, the two technologies, directionally, do in fact have a positive impact on one another. The outcome variable of this regression was yearly demand response energy savings because of the technologies' natures and characteristics: energy efficiency is a proactive but passive resource while demand response is an

active—or reactive—resource that is leveraged in response to load levels. Therefore, in effect, the regression examined the effects of energy efficiency investments on the resulting required level of activity for demand response.

Demand response energy savings were much more sensitive to the economic well-being of a state, where a 1% increase in state GDP per capita led to a 9.73% increase in yearly demand response energy savings. It could be that higher GDP per capita leads to utilities and state programs having a greater volume of funds at their disposal to spend on these demand response programs. It could also be that greater economic activity within a state requires more peak shaving or shifting to occur to accommodate the added load imposed on the system due to greater electricity needs.

Energy efficiency policies also had a considerable effect on the prevalence of yearly demand response energy savings, where states with mandatory EERS experienced an approximate 389% increase in savings than in states without an EERS. The policy measures could be signaling to industry stakeholders the importance of investing in the portfolio of demand-side management offerings as well as identifying ways in which these technologies could complement one another. Though not directly related, this state policy measure could be serving as a nudge or forcing mechanism.

### *Areas for Further Research*

To respond to the "chicken-and-egg" dilemma, a randomized control trial (RCT) could be used to test the causality involved with these technological relationships, rather than simply explore directional correlations through regressions. The RCT could properly apply interventions in a more controlled environment that is reflective of electricity market conditions, whether under the jurisdiction of the Southwest Power Pool, the Midcontinent Independent System Operator (MISO), or the PJM Interconnection. It would be also more reflective of the iterative relationship between these resources as they function on today's electrical grid in response to repeated changes in load depending on the time of day and resource needs. The RCT could also take a multi-level approach in its assessment: (1) building level; and (2) system level— similar to the distinction raised in the LBNL's framework for demand response and energy efficiency interactions.[lxii] Thus, the assessment could be broader and more comprehensive rather than narrowly focused like many other studies have been in the past.

To address the issues raised with respect to the timing of related policies, a difference-in-difference statistical approach could be used to assess two states within the same electricity markets that were on parallel trajectories prior to the introduction of various policy interventions. It is strongly suggested that the two states that are analyzed should be from the same electricity market to better ensure the presence of similar rules/constraints, attitudes, and economic opportunities from the perspective of the utilities, who are ultimate stakeholders that implement the technologies and connect them to the electrical grid.

## Part III: Recommendations & Strategies for Stakeholders with a Focus on Impacts to Utilities

After investigating academic theory and quantitative implications, this analysis moves to a brief discussion of some important steps that energy efficiency stakeholders can take to effectively respond to opportunities and challenges associated with defining and managing energy efficiency's relationships with other supply-side and demand-side resources. The promise of these evolving clean energy technologies and coordinated policymaking can help to bridge the gap between the status quo and the energy transition's end goals of decarbonization and electrification.

### *(1) Integrate Policies for Clean & Alternative Technologies in State Policymaking*

A variety of clean energy technologies beyond renewable energy is needed to reach full decarbonization and electrification. State policymakers should explore consolidating and instituting broader alternative energy standards to signal and incentivize more comprehensive rather than siloed investments in the system. For example, although not entirely carbon neutral, Pennsylvania's alternative energy portfolio standard brings together this breadth of resources under one piece of legislation and then couples this consolidation with distinct tiers to highlight the differences in approach needed (e.g., different thresholds for renewable energy sources versus demand-side management).[lxiii] Nevertheless, the entire vision is combined under one umbrella rather than separate, potentially conflicting, silos. This cohesive vision can then be translated by utilities and public utility commissions into integrated planning and implementation.

### *(2) Incorporate Distribution System Planning into Integrated Resource Planning*

Like what was done in this brief, high-level analysis, utilities have the chance to broaden and improve the purpose and objectives of integrated resource planning (IRP) by adding more concentrated and deliberate planning regarding the distribution system. With the passage of the Federal Energy Regulatory Commission's (FERC) Order No. 2222, distributed energy resources (e.g., energy efficiency, demand response, distributed generation, EV chargers) have been formally defined and recognized by the top federal market regulator as major keys to success for the electrical grid's future. As described by FERC, Order No. 2222 is a "bold action [that] empowers new technologies to come online and participate on a level playing field" in the spirit of competition and continuous innovation.[lxiv] DERs are definitely here to stay, and given FERC's order, resistance by industry players will be futile. Moreover, those who resist will lose market opportunities if immediate action is not taken to plan ahead for widespread and rapid adoption of DERs.[lxv] If caught lagging behind on the adoption curve, utilities may not be able to pursue investments in the distribution system in an expeditious manner later on, as robust, time-intensive planning data and analyses will most likely be requested by regulators for ultimate support and approval.[lxvi]

Similar to the model used in Hawaii, the inclusion of distribution system planning (DSP) into the overarching integrated resource planning process would better prioritize and improve the evaluation of DERs and could possibly "lead to non-wires solutions that are cost-competitive with traditional distribution investments."[lxvii] The primary objective is to transition away from emphasizing answers for load growth and new infrastructure to crafting solutions within more localized and dynamic distribution environments that have follow-on, upstream impacts on the entire system.[lxviii] To fully embrace where the electrical grid's future is headed and maintain market leadership, utilities should incorporate the DSP process into their strategic planning and operations. Critical components of the DSP process will include incentive alignment, purposeful integration across stakeholder groups, and increased information and data sharing with industry partners, which has already created some tension over privacy concerns and the need to protect critical infrastructure.[lxix] The most challenging out of the three components will likely be the alignment of incentives in order to reach meaningful collaboration. Grid modernization and changes in stakeholder business models will undoubtedly need to move hand in hand. The state of Minnesota is a leading pioneer of advanced distribution system planning along with a handful of other states across the country, but time will tell if other states in the Midwest will follow suit and adequately prepare.

### *(3) Support & Institute Forward Capacity Markets*

As mentioned earlier, in the fall of 2020, the Federal Energy Regulatory Commission passed Order No. 2222 which directed the removal of barriers to market participation of distributed energy resources, like energy efficiency, within wholesale markets. Thus, supported by technological synergies and regulatory policies, the Midcontinent Independent System Operator and Southwest Power Pool—in conjunction with their utilities—should design and institute mandatory forward capacity markets, similar to the capacity markets in PJM. Today, MISO only has a voluntary capacity market with limited participation.[lxx]

Mandatory capacity markets would not only allow for competitive, market-based values for DERs, but also recognize what these technologies bring to the table. DERs can help to effectively manage the system's peak demand. Also, it does not hurt that, for these DER investments, utilities can receive capacity payments rather than simply recoup program costs through utility tariffs. These payments can serve as an incentive to help shift human behavior and drive more widespread adoption of DERs. In essence, these capacity markets would be another pathway by which to translate all of the robust planning done via IRP and DSP into incentivized, motivated, and positive market actions for the benefit of the transition, the grid, and customers.

### *(4) Foster Greater Alignment between Regulators & Utilities*

In the spirit of comprehensive coordination and integration, regulators should partner with investor-owned utilities in exploring possibilities to reform current rules and restrictions around utility budgets and funding streams in order to better align incentives and motivations. In particular, regulators should explore opportunities to allow certain pools of money for investment in clean energy technologies to be fluid across technology type. This flexibility could possibly be organized and demarcated by the technology's nature and broad attributes, such as distributed energy resources or demand-side management resources, in order to set defined parameters and avoid misuse and abuse of funds. Regulators can seek to find a middle ground with the utilities while also balancing the public interest and need for just and reasonable rates. If utilities find that implementing flexible energy efficiency measures would make more sense to balance grid needs, then they should be allowed to divert funds devoted to technologies of similar nature and objectives—like demand response programs—in order to ensure reliable and high-quality service for their customers.

By doing so, utilities can remain nimble in responding to emerging trends, technological relationships, and grid needs without undue administrative or regulatory burden. Oversight is still necessary to ensure accountability and transparency, but more thought must be put into balancing the intent and realities of these bureaucratic and administrative processes. The extensive, iterative, and time-intensive planning processes described previously could be balanced with greater flexibility in financial execution, as a wide variety of industry and public stakeholders transparently participate in the planning process. The impact of these reforms would be significant as investor-owned utilities—despite their relatively small volume in comparison to publicly owned utilities and cooperatives—were found to "serve three out of every four utility customers nationwide."[lxxi] An improvement in alignment can lead to more cost-effective service, increased reliability, and better penetration of a deliberately complementary suite of energy technologies like energy efficiency, demand response, electric vehicle charging equipment, and solar and wind generation assets. These described benefits directly mirror those of improved planning processes.

### *(5) Bundle the Various Distributed Energy Resource Offerings into Consolidated Customer Packages*

With the rise of several enabling technologies and trends such as mobile capabilities, the Internet-of-Things, and "as-a-service" pricing models, utilities across the country have recognized the need to bundle their offerings—*electricity plus DERs like energy efficiency.*[lxxii] Bundling requires utilities to design enhanced, custom-centric business models that then require a reconfiguration of their internal operations that ultimately breaks down organizational silos.[lxxiii] Utilities should rise to meet these customer expectations. In the process of doing so, utilities have an opportunity to reimagine their structures so as to better streamline and strengthen their outreach in order to increase customer satisfaction and identify beneficial cost-cutting measures and synergies.[lxxiv] Instead of connecting customers to several different divisions and programs within the utility, customer experience representatives could serve as the utility customer's personal guide and gateway to the entire suite of offerings available to their specific sector, whether residential or commercial and industrial.

In breaking down silos across utility departments, there can be more deliberate collaboration between the workforce that then allows for the presentation of a more cohesive service offering that both builds upon the transition's momentum and increases profitability. The customer outreach and engagement would be holistic rather than ad-hoc in nature. With looming competitive pressures from non-traditional market entrants, utilities must respond to these market disruptions in order to maintain and deliver high-quality service from the start, whether through offerings developed solely in-house, through meaningful partnerships with industry stakeholders, or even through strategic acquisitions.[lxxv] The push to bundling is about raising the bar in delivering optimal solutions quickly and with maximized value.

### *(6) Collect Better Data & Conduct Additional Research Studies Specific to the Region*

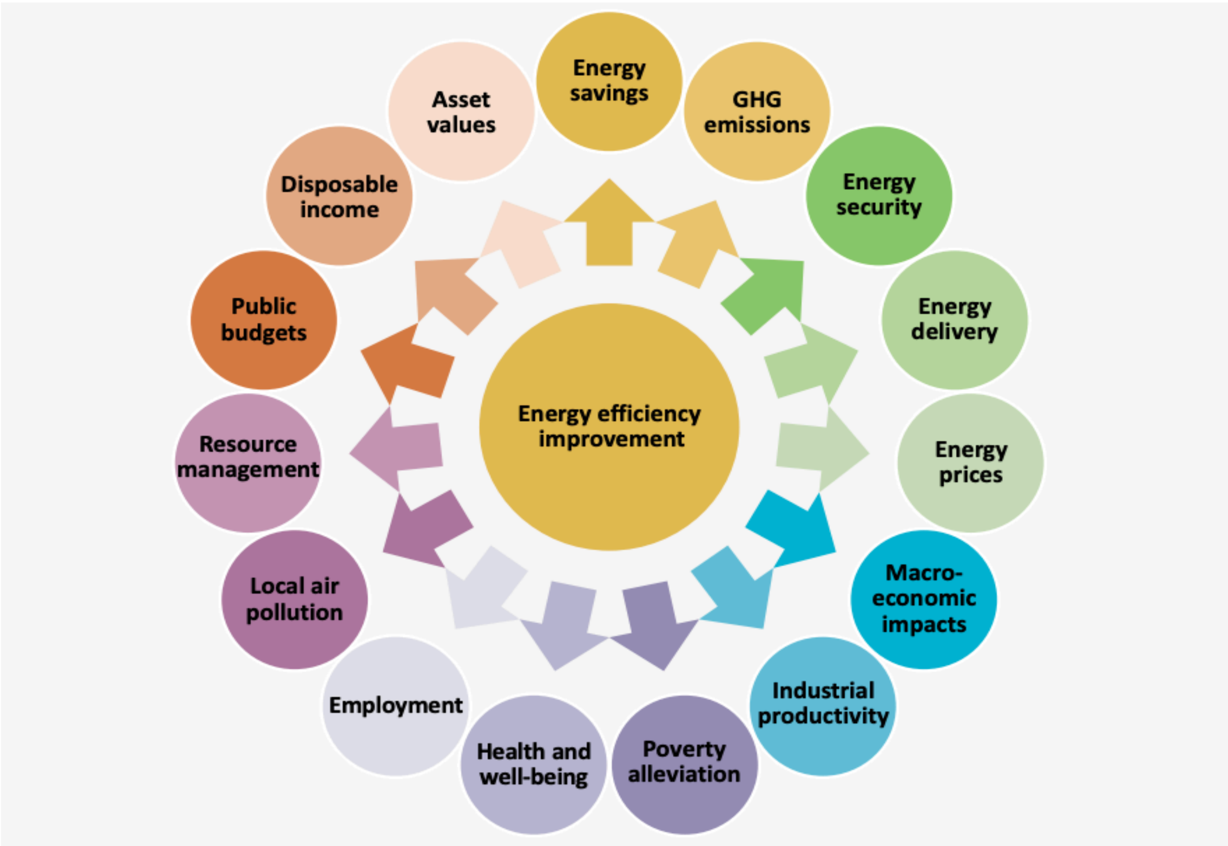
All of the suggestions highlighted above require credible and detailed data to conduct the extensive analyses and assessments needed to evaluate and determine the path forward. The data limitations discussed in prior sections should be addressed immediately to ensure that the proper local, regional, and national strategic and scenario planning can take place in a better informed rather than an imprecise, or slightly ambiguous, manner. The scaling deployment of advanced metering technology will aid in this endeavor, but industry stakeholders cannot afford to wait in the meantime.

In addition, much of the work conducted by leading researchers and industry experts focuses on the impacts of energy efficiency's relationships with other supply-side and demand-side technologies within states such as California and New York (as well as the broader East Coast). This discrepancy could be a result of their market characteristics, such as a high volume of customers served, the degree of clean technologies deployed, and their relatively higher wholesale and retail electricity prices.[lxxvi] More research, however, should be focused on the unique market and stakeholder dynamics with the American Midwest (e.g., lower electricity prices)—especially the dynamics within the entire region, within specific states, or even within MISO and SPP. For example, the Midwest has relatively high wind potential, and three Midwest states included in this analysis rank within the top-five for current net wind generation in 2020 (i.e., Illinois, Iowa, and Kansas).[lxxvii] Without system-level research dedicated to assessing how to manage high wind penetration, utilities, legislators, and regulators may be placed at a disadvantage when striving to make decisions on how to achieve greater optimization and reliability.

## Conclusion

The road ahead to a more modern, cleaner, and truly integrated energy system will not be easy. The journey to achieving decarbonization and electrification will require disciplined, holistic planning coupled with meaningful and swift action. Time is no longer a luxury for industry stakeholders, whether utilities or regulators. Significant changes to the electrical grid are already underway today with increasing renewable penetration and increasing electric vehicle sales, with even more promising forecasts in the next decade. The energy technologies and policy tools at the disposal of utilities and public officials—such as energy efficiency and its resource standards—must be used in a deliberately integrated fashion in order to capture the most benefits from these interactive relationships. Even within just the American Midwest, this analysis showed that energy efficiency, in particular, has a unique opportunity to serve as a synergistic bridge between all of these clean supply-side and demand-side resources. Whether by leveraging demand flexibility or by properly deploying these measures at the right places and at the right times to fully capture its time value, energy efficiency has a meaningful role to play alongside other resources on the modernized grid. Now, the task at hand is to begin integrating these relationship principles at each and every layer—starting from the building level, to the market level, and then to the broader system level—while always remaining flexible in responding to the new realities and trends of tomorrow.

## Appendix A: Illustrating the Wide Range of Benefits from Energy Efficiency




**Range of Benefits from Implementing Energy Efficiency Measures**

Source: International Energy Agency (2014), *Capturing the Multiple Benefits of Energy Efficiency*

## Appendix B: Multiple Linear Regression Model Describing the Relationship Between Energy Efficiency & Renewable Energy

<u>*Regression Equation*</u>**:**

$$\ln(\widehat{EE\_Incremental})_{sy} = \hat{\beta}_0 + \hat{\beta}_1 Net\_Renewable\_Gen + \hat{\beta}_2 Mand\_RPS + \hat{\beta}_3 Mand\_EERS + \hat{\beta}_4 \ln(State\_GDPpercap) + \lambda_{state} + \lambda_{year} + \hat{\epsilon}$$

| | OUTCOME VARIABLE | | | | | |
|---|---|---|---|---|---|---|
| | ***ln(Annual Incremental Energy Savings), MWh*** | | | | | |
| VARIABLES | *Model 1* | *Model 2* | *Model 3* | *Model 4* | *Model 5* | *Model 6* |
| *ln(Annual Net Renewable Generation of Solar & Wind), MWh* | -0.230 | 0.0850 | -0.326 | -0.270 | -0.118 | **-0.281** |
| | (0.150) | (0.206) | (0.207) | (0.231) | (0.170) | **(0.233)** |
| *ln(State GDP per Capita) (Millions of Current Dollars / Person)* | | -6.186** | -2.823 | -4.096* | 0.772 | **0.0366** |
| | | (2.358) | (2.039) | (2.227) | (0.642) | **(0.951)** |
| *Mandatory Renewable Portfolio Standard* | | | 0.560 | 0.488 | 0.949** | **0.968**** |
| | | | (0.753) | (0.762) | (0.447) | **(0.459)** |
| *Mandatory Energy Efficiency Resource Standard* | | | 2.700*** | 2.769*** | 0.183 | **0.204** |
| | | | (0.728) | (0.716) | (0.113) | **(0.140)** |
| *Constant* | 15.39*** | 78.28*** | 46.04** | 58.52*** | 5.609 | **16.23** |
| | (2.116) | (23.77) | (20.07) | (21.55) | (5.844) | **(12.29)** |
| Observations | 88 | 88 | 88 | 88 | 88 | **88** |
| Adjusted R-squared | 0.005 | 0.067 | 0.401 | 0.374 | 0.988 | **0.988** |
| State Fixed Effects | | No | No | No | Yes | **Yes** |
| Year Fixed Effects | | No | No | Yes | No | **Yes** |

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

## Appendix C: Multiple Linear Regression Model Describing the Relationship Between Energy Efficiency & Demand Response

Regression Equation:

$$\ln(\widehat{Incr\_DR})_{sy} = \hat{\beta}_0 + \hat{\beta}_1 EE\_Incremental + \hat{\beta}_2 Mand\_EERS + \hat{\beta}_3 \ln(State\_GDPpercap) + \lambda_{state} + \lambda_{year} + \hat{\epsilon}$$

| | OUTCOME VARIABLE | | | | |
|---|---|---|---|---|---|
| | *ln(Yearly Demand Response Energy Savings), MWh* | | | | |
| VARIABLES | *Model 1* | *Model 2* | *Model 3* | *Model 4* | *Model 5* |
| *ln(Annual Incremental Energy Efficiency Savings), MWh* | -0.0836 | 0.0756 | 0.120 | 0.831 | **0.865*** |
| | (0.116) | (0.128) | (0.132) | (0.590) | **(0.491)** |
| *ln(State GDP per Capita), Millions of Current Dollars / Person* | | 5.204*** | 6.695*** | 2.250 | **9.732**** |
| | | (1.974) | (2.032) | (2.311) | **(3.892)** |
| *Mandatory Energy Efficiency Resource Standard* | | -0.663 | -0.853 | 4.000*** | **3.890***** |
| | | (0.539) | (0.565) | (1.170) | **(0.930)** |
| *Constant* | 8.886*** | -49.58** | -64.87*** | -32.60 | **-113.5**** |
| | (1.418) | (22.34) | (22.90) | (25.95) | **(43.19)** |
| Observations | 91 | 91 | 91 | 91 | **91** |
| Adjusted R-squared | -0.002 | 0.076 | 0.085 | 0.721 | **0.748** |
| State Fixed Effects | | | No | Yes | **Yes** |
| Year Fixed Effects | | | Yes | No | **Yes** |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

## Appendix D: Summary Statistics for Regression Models

| ***Regression on Relationship between Energy Efficiency and Renewable Energy (n=88)*** | **MEAN** | **STANDARD DEVIATION** | **MINIMUM** | **MAXIMUM** |
|---|---|---|---|---|
| *ln(Annual Incremental Energy Efficiency Savings), MWh* | 11.92 | 2.52 | 5.68 | 14.99 |
| *ln(Annual Net Renewable Generation of Solar & Wind), MWh* | 15.19 | 1.42 | 9.37 | 17.09 |
| *ln(State GDP per Capita), Millions of Current Dollars per Person* | 10.93 | 0.14 | 10.63 | 11.28 |
| *Mandatory Renewable Portfolio Standard* | 0.57 | 0.50 | 0.00 | 1.00 |
| *Mandatory Energy Efficiency Resource Standard* | 0.48 | 0.50 | 0.00 | 1.00 |

| ***Regression on Relationship between Energy Efficiency and Demand Response (n=91)*** | **MEAN** | **STANDARD DEVIATION** | **MINIMUM** | **MAXIMUM** |
|---|---|---|---|---|
| *ln(Yearly Demand Response Energy Savings), MWh* | 7.89 | 2.20 | 0.00 | 12.22 |
| *ln(Annual Incremental Energy Efficiency Savings), MWh* | 11.92 | 2.52 | 5.68 | 14.99 |
| *ln(State GDP per Capita), Millions of Current Dollars per Person* | 10.93 | 0.14 | 10.63 | 11.28 |
| *Mandatory Energy Efficiency Resource Standard* | 0.48 | 0.50 | 0.00 | 1.00 |

# Endnotes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[xv] Joachim Seel et al., "Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making" (Lawrence Berkeley National Laboratory Electricity Markets and Policy Group, May 2018), https://eta-publications.lbl.gov/sites/default/files/report_pdf_0.pdf, p. 6, 8-9.; Joachim Seel et al., "Presentation: Impacts of High Variable Renewable Energy Futures on Electric-Sector Decision Making: Demand-Side Effects — Implications for Energy Efficiency Valuation, Retail Rate Design, and Opportunities for Large Energy Customers" (Lawrence Berkeley National Laboratory Electricity Markets and Policy Group, July 2020 Webinar).
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[xxi] Ibid, 5.
[xxii] Ibid, 11.
[xxiii] Ibid, 6.
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