Ohio Efficient Electrification Study

Task 3, Transmission Impacts—Executive Summary

Introduction

Over the past several years, EPRI has undertaken an Efficient Electrification research initiative to help the electric power sector and related stakeholders identify cost-effective and resilient strategies to produce and use clean energy. In 2018, the potential for electrification in the entire United States was assessed as part of the U.S. National Electrification Assessment (US NEA) [1], which highlighted the role that increased adoption of electric end-use technologies across the building (residential and commercial), industrial, and transport sectors could play in creating new value for consumers, businesses, and communities throughout the country.

Subsequently, EPRI has partnered with a number of U.S. and international utilities to conduct subnational assessments using the same analytical tools as in the US NEA but more tailored to the states in which these utilities operate. The current study does just this: It evaluates the potential for efficient electrification in Ohio out to the year 2050. In doing so, the analysis assesses key drivers of electrification and identifies important opportunities and challenges. Task 3 of the project, the insights for which are summarized here, focuses on long-term modeling and scenario analysis of end-use electrification and electricity supply under a variety of assumptions for the future. Funding for this Ohio Efficient Electrification Study was provided by Ohio Edison Company, The Cleveland Electric Illuminating Company, and The Toledo Edison Company.

Efficient Electrification

For many applications, from transportation to heating to manufacturing, electricity can provide a ***more efficient and economical alternative, with lower environmental impact, for the same or better-quality service****. Electricity currently represents approximately one fifth of final energy consumption in both Louisiana and Texas. Rapidly changing technologies and other drivers create new opportunities across the energy economy and could be leveraged to accelerate the trend toward even higher electricity shares going forward.*

The analysis employs state-of-the-art modeling using EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN)[1] framework. US-REGEN is an energy-economy model that combines a detailed electric sector capacity planning and dispatch model with a uniquely capable end-use model. The scenarios examined using US-REGEN look deeply into the potential evolution of the Ohio energy system under a range of scenarios. These scenarios explore uncertainties around future technology advances and the prevailing climate policy environment. The insights derived from the scenarios demonstrate how electrification can influence electricity consumption, economy-wide CO_2 emissions, and final energy consumption[2] from now to mid-century.

The next section briefly outlines the scenarios developed for this analysis. This is followed by succinct descriptions of the key insights derived from the assessment.

Qualitative Bookend Analysis

This section describes the bookend analysis in terms of the chosen scenarios and the approaches used to investigate the qualitative impacts. The two main approaches are to study the potential for the changing resource mix to motivate new transmission interconnections and the changing load shape to impact planning and operations.

[1] More information about the structure and assumptions of US-REGEN can be found in the model documentation [2] and in the final section of this executive summary.

[2] "Final energy" is a measure of the energy consumed at the end-user level (for example, in homes, at factories, and onboard vehicles). It does not include the energy consumed in processes upstream from the end user, such as the energy used for electricity generation or crude oil refining (conversion losses).

Table 1. Scenario matrix for Task 1 of the Ohio Efficient Electrification Study

Scenarios	Advanced End-Use Technologies	Carbon Price	Coordinated Vehicle Charging
Reference Scenario	No	No	No
Advanced End-Use Technology	Yes	No	No
Advanced End-Use Technology and Clean Energy	Yes	Yes	No
Coordinated Vehicle Charging (CVC) under Advanced End-Use Technology	Yes	No	Yes
Coordinated Vehicle Charging (CVC) under Advanced End-Use Technology and Clean Energy	Yes	Yes	Yes

Scenarios

This qualitative transmission analysis examines the evolution of the Ohio energy system under three of the five total plausible scenarios for the future (Table 1) using EPRI's US-REGEN model. The scenarios are not constructed to achieve a specific outcome regarding the extent of economy-wide electrification or decarbonization. Rather, scenario analysis explores how the electricity and end-use sectors in Ohio could potentially evolve under different assumptions and storylines. The analysis then compares results across these future "states of the world" without suggesting that one pathway is preferable to or more likely than another.

For detailed information about the scenario selection see *Ohio Efficient Electrification Study: Task 1, Energy System Assessment—Executive Summary* [3]. The criterion for selecting scenarios for the qualitative transmission analysis was to conduct a "bookend" analysis, which explores the range of possible outcomes, rather than any specific one. The bookend scenarios are as follows, with their colloquial and full names:

- Reference: Reference Scenario
- AdvTech: Advanced End-Use Technology.
- AdvTech_Clean: Advanced End-Use Technology and Clean Energy

The scenarios not chosen (indicated by gray text in Table 1) incorporate a coordinated vehicle charging feature, which is seen as a mitigating factor for potential transmission operations and planning issues.

The AdvTech_Clean scenario, which includes advanced end-use technologies and carbon pricing, is the most aggressive in terms of affecting the transmission operations and planning status quo. The combination of effects represented in this scenario creates rapid changes and introduces uncertainties at both ends of the supply chain.

Resource Mix Analysis

The resource mix is investigated in absolute and relative terms, by new and existing installations, and, in an effort to identify transmission impacts, the resource mix is consolidated into three locational categories, Existing, New, and Renew. Generation in the New category is natural gas combined-cycle technology and the Renew category it is grid-scale solar and wind. The categories are defined as subsets of the full set of generation technologies. If these technology categories have different locations, then the analysis shows that a good portion of the total is potentially located in new locations around the service territory. For instance, a single coal plant with an 80% capacity factor replaced with renewable resources having 20% capacity factors requires four times as much capacity, and likely requires much more land and may be in diverse locations.

When the changing resource mix is viewed from this perspective, the impact is about where the energy is being produced, whether in existing locations or in new locations yet to be determined for both the New and Renew categories.

From Figure 1, it is apparent that in Ohio the energy locations are changing already. Thus, experience over the past five years should serve as significant preparation for further potential changes having significant magnitudes. When compared with 2015, annual renewable energy reaches up to 24% renewables by 2040 in the AdvTech_Clean scenario and between 42% and 77% of the energy comes from new locations by 2030.

Figure 2 shows capacity locations by year and technology. As seen in the resource mix analysis, the penetration of renewable resources, with low capacity factors compared with traditional resources, is amplified from a capacity viewpoint. This further emphasizes the likelihood of new, diverse locations being needed for grid-scale wind and solar resources.

The capacity location analysis indicates that the resource mix may continue to change significantly from coal to gas, as has been seen. More than 45% of new and renewable capacity is present as of 2030, when compared with 2015. Furthermore, the analysis indicates that the energy source locations may change. Between 12% and 13% of renewable capacity is present by 2030; this does not include rooftop solar, because it is uncertain how the impact to net demand would affect the transmission system.

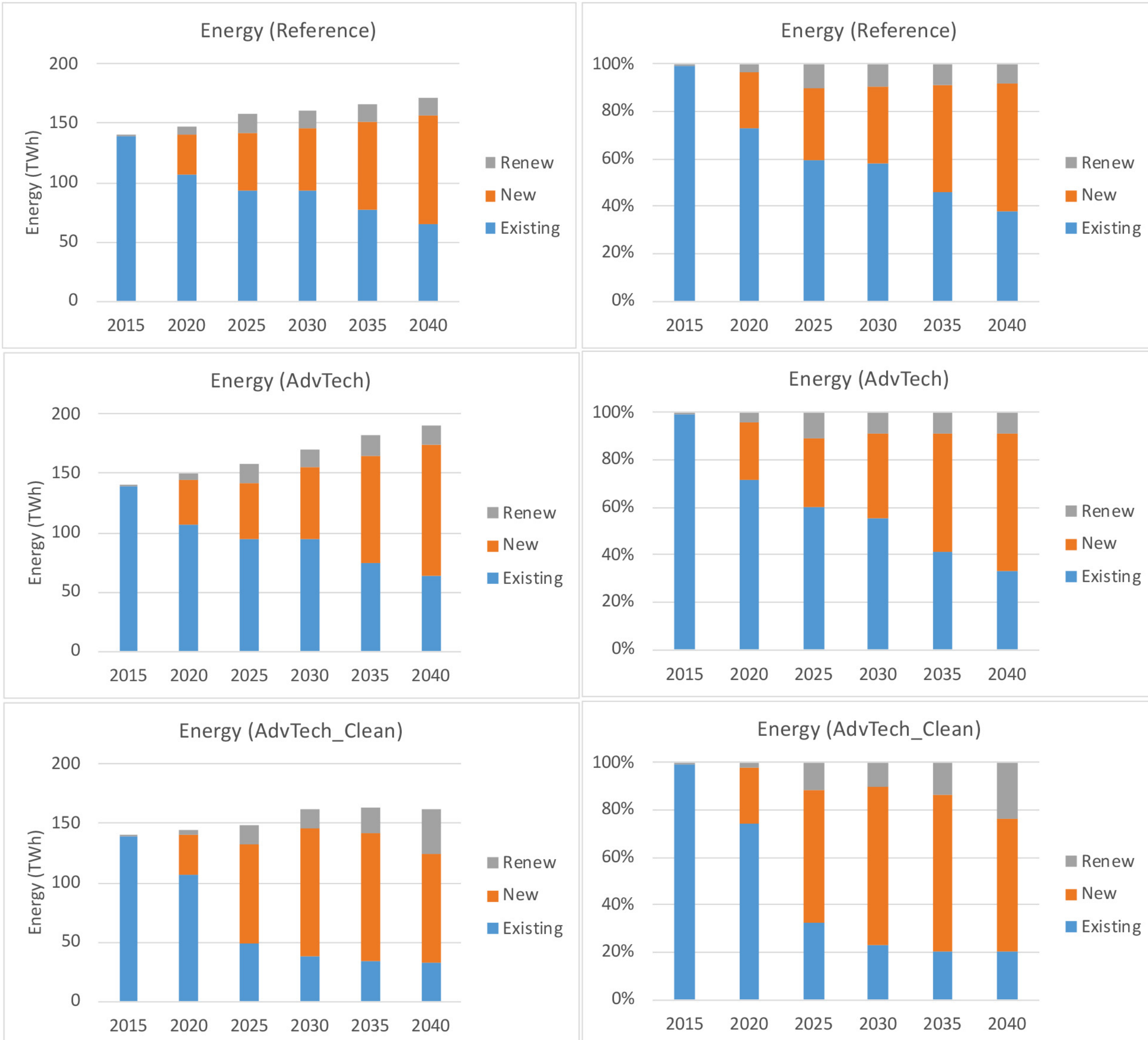

Figure 1. Energy production locations by year and bookend scenario

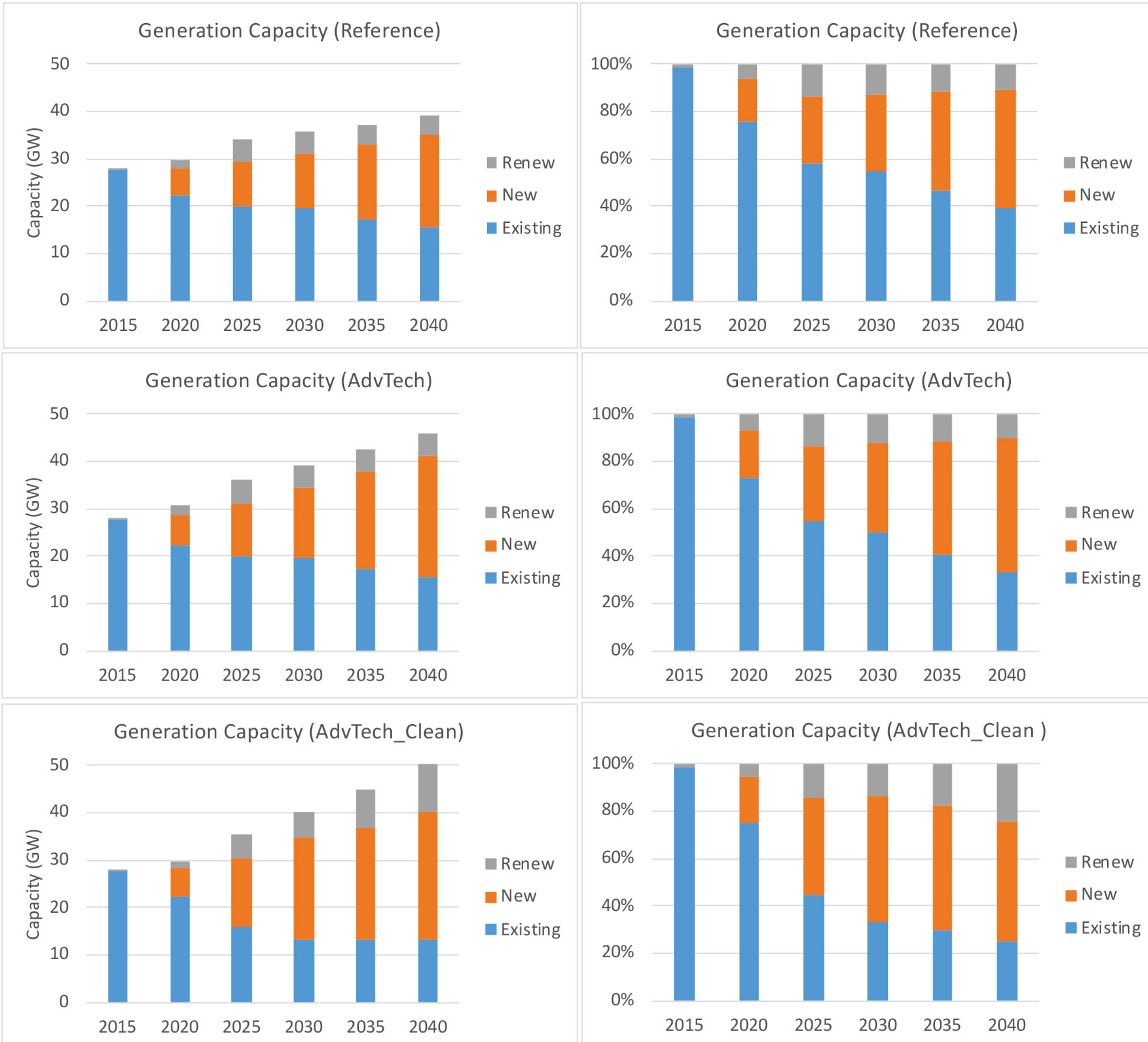

Figure 2. Capacity locations by year and scenario

Table 2. Potential impacts of changing load shape metrics

Metric	Transmission Planning	Transmission Operations
Energy	Congestion	Congestion
Load (Base/Peak)	Flow patterns, congestion	Flexibility, congestion
Ramp	Congestion	Deliverability, reserve, flexibility
Load Factor	Utilization, marginal cost	N/A

Load Shape Analysis

The load shape analysis begins with results of Task 1 for years from 2015 to 2040, which are those most relevant to transmission planning. The results include time series data for end-use categories and energy production and generation capacity in the study years.

According to the Department of Energy, the advanced metering infrastructure (AMI) is "an integrated system of smart meters, communications networks and data management systems that enables automated, two-way communication between a smart meter and a utility." The AMI data available through FirstEnergy's initiative and other utilities in Ohio could help provide more insights into hourly load shapes for new and existing loads across the state.

The time series data are used to calculate several transmission operations and planning impact metrics as follows.

Interval Metrics

Statistical metrics are used to understand the significance of the magnitude for change; each metric may have an impact on transmission planning or operations or both. The metrics are as follows:

- Energy (TWh): total energy
- Load (GW): base (min) or peak (max) load
- Ramp (GW/h): maximum hourly change in energy, up or down
- Load factor (%): ratio of average to peak load

The data dimensions are over the scenarios, REGEN years, and the end uses.

Potential Impacts

To help understand the impact of each metric on transmission planning and/or operations, Table 2 contains entries by metric and transmission category that list the area of that category that may potentially be affected.

Large changes in any metric over the planning horizon or a large range of changes between the two scenarios, indicating uncertainty over the planning horizon, may have significant impacts on transmission planning and operations. Significant changes and uncertainty in both the total value and the end-use level can indicate an impact. In total, they may make overall planning and operations tasks require new processes and technologies. In the end uses, they may indicate large shifts in the timing and location of the load.

Energy change and uncertainty may forewarn intrastate congestion, which is not modeled in US-REGEN and thus motivate additional analysis to validate the warning.

Peak and base load change and uncertainty may forewarn changing flow patterns and congestion in planning, and they may forewarn shortages of flexibility and additional congestion in operations. Examples are that base load reductions over time may decommit units more often and spawn deliverability issues in a local area.

Up and down ramp changes and uncertainty may indicate additional congestion in planning studies, resulting in the inability to deliver reserve under some contingencies and supply/demand scenarios. In operations, likewise, large energy ramps up and down are common in regions with high renewable penetration, and although wide-area energy balances may seem within standards, local deliverability, unit commitments, and reserve deployments require additional careful attention.

Finally, changes in the load factor indicate changes in utilization of the transmission system and the marginal cost of transmission to the ratepayers. There is no expected impact on operations.

Analytical Framework

The load shape analysis relies on two types of graphs of the annual statistics for each metric.

- **Annual value for each scenario, by end use and year.** There are two such graphs, one for each scenario. Within each, it is apparent how the metric trends over time for that scenario. Each graph gives a sense of the change in the metric over time.
- **Range of values across scenarios, by end use and year.** This graph shows the range of metric values across the scenarios over time. A growing range over time may indicate increasing uncertainty over the planning horizon.

Careful thought should be placed on how to interpret the total load and its ramp values for individual end uses relative to those for the net value, because the hours for the largest and smallest values are not likely coincident across the end uses, making the total not equal to the total value of the corresponding end use values.

Summary

Finally, each metric is summarized in tabular form for the analyses at three points in the supply chain:

- **End-use load**: Aggregate Ohio state-level load at the end-use customers. It includes all end-use categories, including those affected by technology and policy changes and those not affected. Changes in metrics at this level indicate fundamental load shifts.
- **Net end-use load**: Aggregate Ohio state-level load at the end-use customer distribution meters. It is the end-use load minus rooftop solar energy production. Changes in metrics at this level indicate changes to the load being supported by the transmission system.
- **Renewable-adjusted load**: Aggregate Ohio state-level load to be followed by nonrenewable generation and other controls. It is the net end-use load minus transmission-connected renewable energy production. Changes in metrics at this level indicate changes to the transmission flow patterns because of the variability and uncertainty in renewable energy production.

Table 3 provides a summary of the supply chain impacts seen in the bookend analysis. The green values indicate that there is no significant change in the metrics or their range over the study years. Orange text indicates that there are notable changes.

No significant issues are observed in the *end-use level* on the supply chain.

At the *net end-use level*, there is a drop in the load factor over time, which may impact transmission utilization.

At the *renewable-adjusted level*, there is a wide range of the baseload metric across the bookend scenarios and there is a drop in the load factor. The changing base load metric, net of renewables, may affect flow patterns and operational flexibility.

Table 3. Qualitative impact summary

End-Use Load	Net End-Use Load	Renewable-Adjusted Load
No significant transmission operations and planning impacts	No significant transmission operations and planning impacts	Significant base load impacts may affect flow patterns and operational flexibility
Decreasing load factor may affect transmission utilization	Decreasing load factor may affect transmission utilization	Decreasing load factor may affect transmission utilization

Metric	Transmission Plannig	Transmission Operations
Energy	Congestion	Congestion
Base Load	Flow Patterns	Flexibility
Peak Load	Flow Patterns, Congestion	Congestion
Down Ramp	Congestion	Deliverability, Reserve, Flexibility
Up Ramp	Congestion	Deliverability, Reserve, Flexibility
Load Factor	Utilization, Marginal Cost	N/A

Metric	Transmission Plannig	Transmission Operations
Energy	Congestion	Congestion
Base Load	Flow Patterns	Flexibility
Peak Load	Flow Patterns, Congestion	Congestion
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Up Ramp	Congestion	Deliverability, Reserve, Flexibility
Load Factor	Utilization, Marginal Cost	N/A

Metric	Transmission Plannig	Transmission Operations
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Base Load	Flow Patterns	Flexibility
Peak Load	Flow Patterns, Congestion	Congestion
Down Ramp	Congestion	Deliverability, Reserve, Flexibility
Up Ramp	Congestion	Deliverability, Reserve, Flexibility
Load Factor	Utilization, Marginal Cost	N/A

Key Insights

The qualitative analysis of transmission operations and planning impacts has identified five key insights. The first two validate the current state of the art in transmission planning, whereas the final three suggest the potential need for detailed system studies and enhanced coordination between the electric utilities in Ohio and PJM Interconnection (PJM) in operations.

Insight 1: REGEN transmission expansion is based on economic transfers.

Observed transmission upgrades in the MISO-NE region are based on economic transfers. These upgrades may connect with PJM or into MISO, and through-flows may affect planning and operations.

The AdvTech_Clean scenario expands transmission between Ohio and the northeastern Midcontinent Independent System Operator (MISO) region by 1.25 GW by 2025. Should this scenario become likely, this expansion may occur on an important interface between PJM and MISO or within PJM.

Insight 2: Electric utilities and PJM are careful about accounting for energy efficiency and distributed energy resources.

Electric utilities in the state of OH and PJM are careful about accounting for energy efficiency (EE) and distributed energy resources (DER) in their planning exercises.

Communication between the electric utilities in Ohio and PJM carefully accounts for EE and DER. Demand-side management programs (DSMs), a form of distributed resource, clear in the PJM market auction as a resource or an aggregated resource, whereas price-responsive demand, like energy efficiency, is integrated within the PJM load forecasting process. Electrification technologies show potential inroads for electric vehicles, but air conditioning and space heating have little change across scenarios.

Should electric vehicle charging and/or discharging become dispatchable or used for grid services like voltage controls, additional attention may be needed to account for the impact of such controls on transmission operations and planning.

Insight 3: The resource mix is changing significantly toward natural gas.

Expected changes to energy production locations may motivate additional transmission resources. New transmission interconnections may be made to synchronous condenser units and to inverter-based resources.

Power system technologies in Ohio are currently changing, with a strong coal-to-gas shift and moderate integration of solar and wind. Resource locations are changing already, and in the AdvTech_Clean scenario, there are up to 24% renewables as of 2040. It is likely that new utility-scale renewable generation is built on greenfield sites, requiring new transmission interconnections. Across the bookend scenarios, between 42% and 77% of generation capacity is replaced by 2030.

Increasing renewable energy resources may indicate the need for additional resource locations and additional transmission. Such increases also multiply the number of interconnection studies and induce efficiencies in the associated queuing process.

It is known that inverter-based resources have significantly different behavior under short-circuit conditions. This changing behavior may require additional system protection studies, resource changes, and operational changes. Special considerations for voltage control from synchronous condensers and inverter-based devices require detailed engineering studies in transmission planning and voltage scheduling in transmission operations.

Insight 4: Increasing renewable generation may reduce base load significantly.

Increasing renewable generation may significantly reduce the base load metric for the renewable-adjusted load over time. The potential operations impacts may be mitigated by mid-term forecasting, and the potential planning impacts may be mitigated by interconnection studies and appropriate transmission upgrades.

In the net end-use load, which is supported by transmission at the substation level, the base load metric is largely unaffected, but at the renewable-adjusted level, it decreases significantly and may affect operational flexibility. For instance, when there are no spinning resources economically needed on the system and renewables are the only resources providing energy, there could be difficulty ramping up as the sun sets and the load returns.

The Ohio renewable-adjusted base load in 2020 is between 9.0 GW and 9.5 GW for the bookend scenarios, and it reduces to between 6.1 GW and 6.8 GW by 2025, about 3 GW in 5 years. Further, the base load reduces to between 3.7 GW and 6.7 GW by 2035, down as much as 5 GW in 15 years, with a 3.0 GW range, whereas in the In Advanced End-Use Tech and Clean Energy scenarios, the minimum system load plus renewable generation is zero. This pace of baseload reduction may alter transmission flow patterns, making them less predictable. This potential uncertainty may also motivate revisions to maintenance scheduling practices and switching protocols in transmission operations.

Insight 5: The load factor decreases because of renewables, potentially affecting transmission utilization.

The net load factor decreases owing to peak load increasing faster than annual energy, potentially affecting transmission utilization. This may be mitigated by the existing use of transmission rates based on peak transmission demand and controlled vehicle charging.

In 2015, the load factor metric is 61%, and in 2020, it ranges from 57% to 58% at the net end-use load level. By 2040, this metric ranges between 52% and 53%. The range of values across scenarios is tight; this steady decrease is due to the introduction of rooftop solar and may decrease transmission utilization.

The peak load hours are occurring at hour ending 08:00 (between 7 AM and 8 AM) in February, and electrification of space heating is increasing over the horizon the bookend scenarios. In addition, some portion of uncontrolled vehicle charging is occurring on-peak. Between 2015 and 2040, the peak load increases between 24% and 45%, whereas the annual energy increases only from 4% to 17%. This has the effect of reducing the load factor on the transmission system.

The effects of controlled electric vehicle charging may be expected to mitigate this impact to the extent that the charging avoids peak load periods and occurs during periods when the net end-use load is low—base load periods.

References

1. *U.S. National Electrification Assessment*. EPRI, Palo Alto, CA: 2018. 3002013582.
2. *US-REGEN Model Documentation*. EPRI, Palo Alto, CA: 2018. 3002010956.
3. *Ohio Efficient Electrification Study: Task 1, Energy System Assessment—Executive Summary*. EPRI, Palo Alto, CA: 2022. 3002023157.

Additional Information

For additional information about this analysis, contact Robert Entriken (rentriken@epri.com) or Baskar Vairamohan (bvairamohan@epri.com). In addition to the high-level transmission assessment (Task 3) described in this executive summary, the project also includes energy system assessment (Task 1), an environmental assessment of greenhouse gas emissions and air pollution from the energy system (Task 2), and electrification potential and implementation plan (Task 4).

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

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