2024 Regional Resource Assessment

A RELIABILITY IMPERATIVE REPORT

JANUARY 2025

HIGHLIGHTS

- Members and states may need to add capacity at 17GW/year — over three times the recent average of 4.7GW/year — for 20 years to reliably meet future demand and policy goals. Achieving this pace will require overcoming supply chain, permitting, labor and interconnection queue delays.
- Under MISO's new Direct Loss of Load (DLOL) accreditation methodology, thermal resources will continue to provide the bulk of the region's accredited capacity even while RRA modeling indicates that lower-accredited wind and solar will account for 62% of installed capacity and 87% of the region's energy by 2043.
- Greater reliance on solar power is shifting the region's net load ramp from morning to evening, which is increasing the region's 1-hour ramp need by 2-3 times by the early 2030s.

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Preface

The Regional Resource Assessment (RRA) is one of the periodic studies MISO conducts to forecast how the mix of electricity-generating resources in the MISO region could evolve going forward. Two other MISO studies of this general type are the OMS-MISO Survey[1] and the MISO Futures.

While RRA, OMS-MISO Survey and the Futures are similar in some ways, each study was designed for a different purpose, uses different data inputs, covers different time periods, and uses different methodologies and modeling assumptions. Accordingly, the results of the studies may differ.

For example, the RRA assumes members and states will be able to add new generation capacity at an unprecedented rate of 17 GW/year for the next 20 years to reliably achieve their publicly announced resource plans and policy goals. Accordingly, the RRA projects capacity surpluses in 2030 and beyond.

In contrast, the OMS-MISO Survey is based on much lower expectations of new installed capacity, reflecting the pace at which resources have received interconnection agreements and come online in recent history. The 2024 OMS-MISO Survey therefore forecasted a range of possible outcomes, varying from capacity deficits beginning in 2025 to capacity surpluses through 2029.

Again, these divergent results reflect that the RRA and the OMS-MISO Survey were designed for different purposes and use different data inputs, methodologies, assumptions and time horizons.

MISO believes the RRA, OMS-MISO Survey and Futures all provide valuable insights as stand-alone studies. But MISO also recognizes the challenge involved in interpreting studies of the same type that have different outcomes.

To that end, MISO is exploring ways to integrate and align the RRA, the OMS-MISO Survey and the Futures. MISO will keep stakeholders informed of this work.

[1] OMS is the **Organization of MISO States**, which represents the state regulatory agencies in the MISO region. The OMS-MISO Survey is a jointly administered survey and report.

Executive Summary

The key high-level insights of the 2024 Regional Resource Assessment are as follows:

Insight 1

Members and states may need to add capacity at 17 GW/year — over three times the recent average of 4.7 GW/year* — for 20 years to meet future demand and policy goals. Achieving this pace will require several factors, including overcoming supply chain, permitting, labor and interconnection queue delays.

Insight 2

Under MISO's new Direct Loss of Load (DLOL) accreditation methodology, thermal resources will continue to provide the bulk of the region's accredited capacity even while RRA modeling indicates that lower-accredited wind and solar will account for 62% of installed capacity and 87% of the region's energy by 2043.

Insight 3

Greater reliance on solar power is shifting the net load ramp from morning to evening and increasing the system's average 1-hour ramp need by 2-3 times by the early 2030s.

** 4.7 GW/year reflects average from Planning Year 2022-2022 of projects that have communicated commercial operations dates to MISO. Projects include, but are potentially non-exhaustive of surplus, replacement, generator updates, ERIS to NRIS interconnection upgrades, and external capacity returning to MISO. MISO COD Tracker*

Figure 1: Key insights of the 2024 Regional Resource Assessment (RRA)

CONTEXT

Reliably achieving the decarbonization targets set by many MISO members and states requires an accurate and collective view of how resource plans are evolving, and a shared understanding of how operational risks and needs will emerge and shift over time. MISO's **Regional Resource Assessment (RRA)** offers that collective view and provides insights that can inform the work that members, states and MISO are doing individually and collaboratively to plan ahead. The RRA supports the **MISO Reliability Imperative**, which is the shared responsibility that members, states and MISO have to address the imminent and complex challenges to electric system reliability in the region.

The RRA has a 20-year study period, which for this year's iteration runs from 2024 through 2043. Because the RRA was designed to focus on the long-term time horizon as opposed to the near-term, this year's RRA results are generally reported beginning in 2029. The region's primary nearer-term resource assessment is the OMS-MISO Survey, which MISO administers in partnership with the Organization of MISO States (OMS).

The RRA uses a **voluntary survey tool** to compile information about members' and states' publicly announced resource plans and clean-energy goals. While members and states conduct long-term resource planning, it is not always industry practice to develop detailed resource plans a full 20 years in advance. Thus, to complete the RRA's 20-year outlook, MISO uses computer models to identify additional resources its members might choose to build to achieve their policy objectives and meet their anticipated demand and reserve requirements. This step, called the **Resource Expansion**, produces a forecasted portfolio of existing, planned and computer model-selected resources. For the purposes of this report, model-selected resources are referred to as "policy-driven resources" because they are selected primarily to meet member and state policy objectives rather than reliability requirements.

The Resource Expansion supports two other parts of the RRA. The first, the **Resource Adequacy Analysis**, assesses whether the portfolio of resources that members and states may choose to build to achieve their policy goals will be sufficient to meet a loss of load expectation (LOLE) target of 1 day in 10 years, which is a commonly used criterion in the electricity industry. The analysis also evaluates how the region's seasonal and diurnal risk profiles may change as members increasingly replace conventional resources with intermittent renewables and storage to achieve their policy objectives. The second component, the **Flexibility Assessment**, evaluates how sources of uncertainty and expected variability are increasing the operational complexity of the grid, expanding periods of system stress and driving a need for greater system flexibility such as dispatchable fast-ramping resources.

This year's RRA utilizes the **Direct Loss of Load (DLOL)**-based methodology for accrediting resources that MISO intends to implement beginning in the 2028-2029 Planning Year. DLOL-based accreditation methodology differs significantly from MISO's current accreditation practices, and the forecasted accreditation values in this RRA are intended to help inform resource-planning decisions that members and states make going forward. Details about how DLOL methodology was used in this year's RRA are included in this report, and a more thorough explanation is provided in the RRA Technical Appendix.

The results of this year's RRA are generally described at the region-wide level. Supplemental charts and data are provided on MISO's website, along with the Technical Appendix noted above. The website also hosts an interactive emissions dashboard and the online portal for the RRA's survey tool that MISO members use to submit information about their existing and planned generation resources.

THREE KEY INSIGHTS EMERGE FROM THIS YEAR'S RRA

INSIGHT 1:

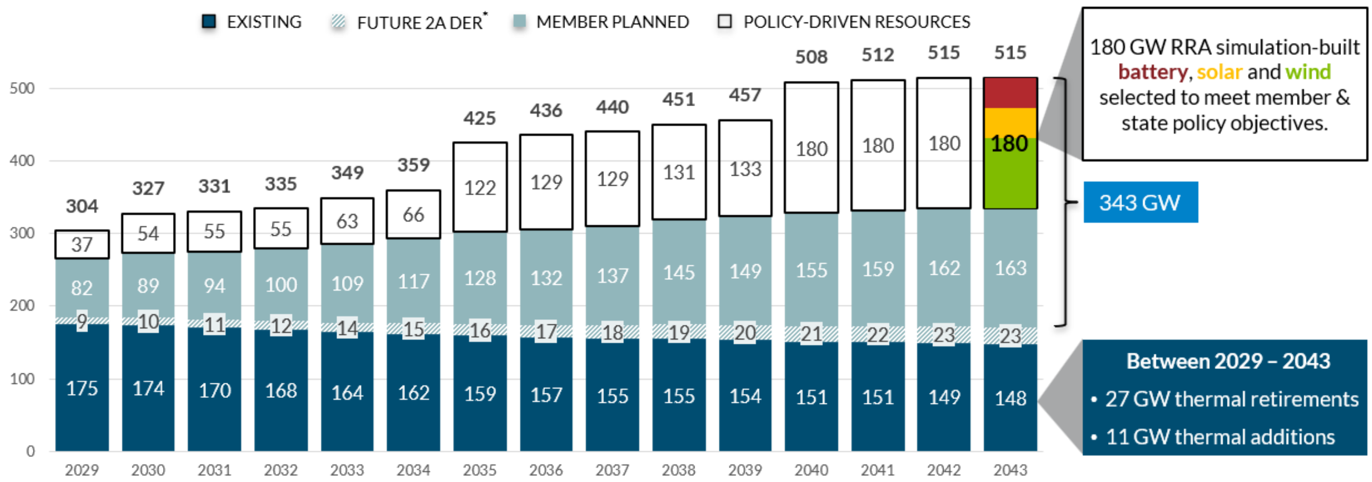
Members and states may need to add capacity at 17 GW/year — over three times the recent average of 4.7 GW/year[2] — for 20 years to meet future demand and policy goals. Achieving this pace will require several factors, including overcoming supply chain, permitting, labor and interconnection queue delays.

MISO members plan to build a total of 163 GW of new resources on an Installed Capacity (ICAP) basis by 2043, as indicated by this year's RRA Survey, signed Generator Interconnection Agreements, and publicly announced plans. Those planned resources are shown in the teal-colored segments of the bars in Figure 2 below.[3] Existing resources that members and states plan to keep online through the RRA's study period

[2] 4.7 GW/year reflects average from Planning Year 2020-2022 of projects that have communicated commercial operation dates to MISO. Projects include, but are potentially non-exhaustive of surplus, replacement, generator uprates, ERIS to NRIS interconnection upgrades, and external capacity returning to MISO. MISO COD Tracker.

[3] The cumulative capacity values that Figure 2 indicates for existing, planned, and policy-driven resources include the years 2024-2028, even though those years are not shown on the chart.

are shown in dark blue. All resources are shown in terms of ICAP, which is the maximum amount of generation that a resource can theoretically produce under ideal conditions.



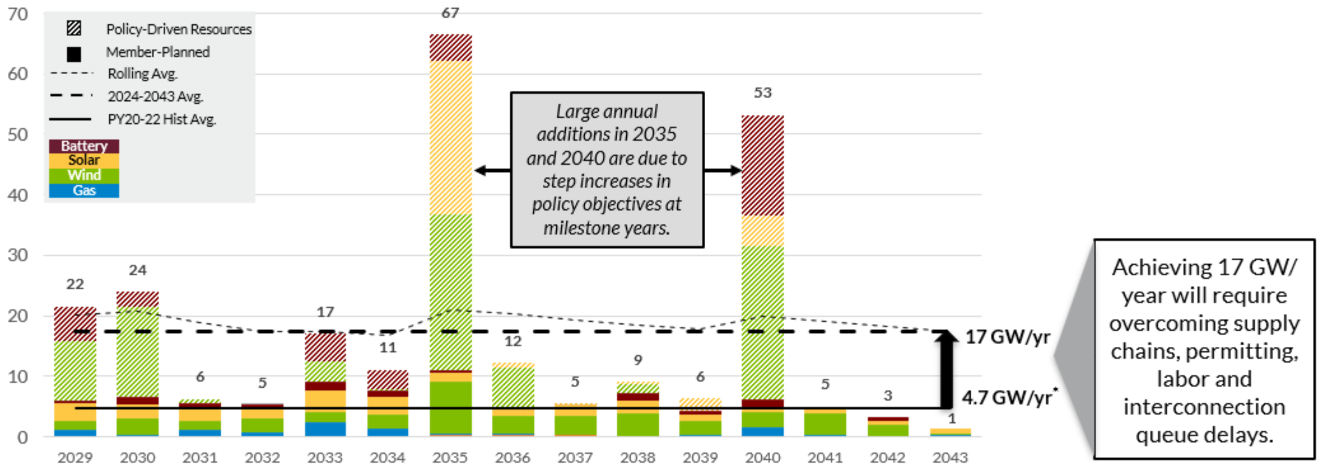
** Future 2A DER: The 2024 RRA utilizes Future 2A load assumptions. Future 2A assumptions for distributed energy resources (DER), developed by Applied Energy Group based on DER technical potential during Series 1, include Demand Response (DR), Energy Efficiency (EE), and Distributed Generation (DG). For the 2024 RRA, Energy Efficiency and Utility Distributed Generation (UDG) was netted from load; DR and DGPV are reflected as resource additions.*

Figure 2: Total Installed Capacity (ICAP) in Gigawatts (GW)

One of the key takeaways of Figure 2 is that the combined level of existing and planned resources is not sufficient to achieve the decarbonization and renewable energy goals that members and states have publicly announced, under Future 2A load assumptions. To fill that gap, the RRA modeled additional resources members and states might choose to build to meet their policy goals. As the chart shows, a total of 180 GW of these policy-driven resources were added throughout the RRA's 20-year study period.

If members and states added those 180 GW of policy-driven resources to the 163 GW they already plan to build, they would have to add a total of 343 GW of new resources by 2043 — an average of 17 GW/year for 20 consecutive years. As Figure 3 below illustrates, that rate of new resource additions would be unprecedented and extraordinary for the MISO region, since the region's actual pace of new additions has only averaged 4.7 GW ICAP per year in recent years.[4]

[4] See footnote 2 for more details.



** See Footnote 2 for more details*

Figure 3: Annual Additions (ICAP, GW)

This year's RRA did not include any constraints to limit how much new capacity could be added every year to meet policy objectives. As Figure 3 illustrates, the model added large amounts of capacity in 2035 and 2040 due to increases in member and state policy objectives at these milestone years, with some years far exceeding the 17 GW annual average.

Efforts to add new resources could be further complicated by supply chain delays, permitting issues and other factors beyond the control of members, states and MISO. The situation could be further exacerbated by the large load additions that are expected in the MISO region due to the growth of data centers, electric vehicles and other factors. The load assumptions used for this year's RRA do not account for those types of large load additions.

It is important to recognize that the incremental needs the RRA identifies in member and state plans are not actual resource shortfalls at present. Instead, the RRA identifies informational findings that members and states may choose to address as they continually refine their resource plans, policy goals and investment decisions.

INSIGHT 2:
Under MISO's new Direct Loss of Load (DLOL) accreditation methodology, thermal resources will continue to provide the bulk of the region's accredited capacity even while RRA modeling indicates that lower-accredited wind and solar will account for 62% of installed capacity and 87% of the region's energy by 2043.

The term accreditation refers to how MISO calculates and assigns capacity values to resources reflecting their contributions to grid reliability when the system is most at risk, considering limiting factors such as their forced outage rates, maintenance, and resource availability. In March 2024, MISO proposed a new Direct Loss of Load (DLOL)-based accreditation methodology that more accurately reflects resource availability and performance in reflection of the risks the region now faces due to widespread retirements of dispatchable resources, increasing reliance on weather-dependent resources, and more frequent and severe weather events, among other factors.

The DLOL-based methodology uses a two-step process. The first step calculates probabilistic, resource-class average accreditation values using LOLE modeling. The second step tailors unit-level accreditations to individual generators based on their real-time offers during low margin hours. The DLOL forecast in this RRA focuses on the class-average accreditation values (step 1).

The Federal Energy Regulatory Commission (FERC) approved the DLOL-based methodology in October 2024, and MISO intends to implement it in the 2028-2029 Planning Year, giving stakeholders three years to prepare. To help inform stakeholders' future investment decisions, this RRA provides forecasted DLOL-based seasonal accreditation values for wind, solar and other technologies at the resource class-level, as well as estimated seasonal Planning Reserve Margin Requirements (PRMRs).

Figure 4 below shows projected DLOL-based accredited capacity for different resource classes in each season of the years 2030, 2033 and 2043. The projections stem from the RRA's Resource Expansion portfolio, driven by member-planned resources and member and state policy objectives. Figure 4 also includes forecasted seasonal PRMR values based on the DLOL accreditation methodology.

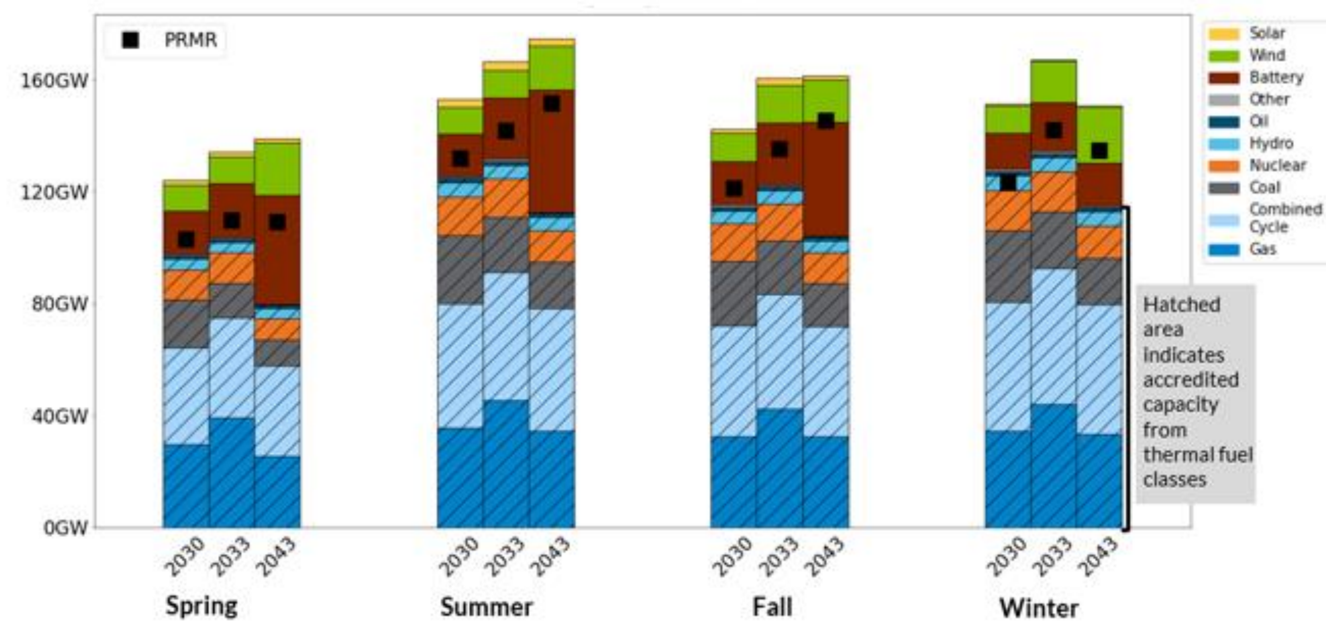


Figure 4: DLOL accredited capacity in 2030, 2033 and 2043

As Figure 4 indicates, dispatchable thermal resources with high DLOL-based accreditation values, such as natural gas and coal, are forecast to provide a much larger proportion of the region's total needed accredited capacity compared to wind and solar, which have significantly lower accreditation values due to their weather-dependent nature and other factors. Battery storage is also projected to provide a significant portion of total DLOL accredited capacity.

But notably, RRA modeling also indicates that wind and solar resources that have relatively lower accreditation values will account for a full 62% of the region's installed capacity and 87% of the region's energy by 2043 (not shown in Figure 3; see Figure 22 on page 25 for more details). This demonstrates how the many new wind and solar resources that members and states plan to build may yield large numbers in terms of installed capacity and energy, while making more limited contributions to DLOL accredited capacity.

Figure 5 below illustrates projected changes to class-level DLOL accreditation values going forward as the region's resource mix continues to evolve to achieve member and state policy goals. Solar and wind accreditation values are significantly and consistently lower than thermal resources. Wind has a higher accredited value than solar due to its availability during more hours of the day, while other resource classes have difficulty showing up throughout longer duration expected unserved energy (EUE) events simulated in RRA modeling. Battery accreditation is particularly impacted by the Winter seasonal trend of longer EUE events. Thermal accreditation in shoulder seasons (Spring and Fall) decreases due to the concentration of maintenance during these seasons.

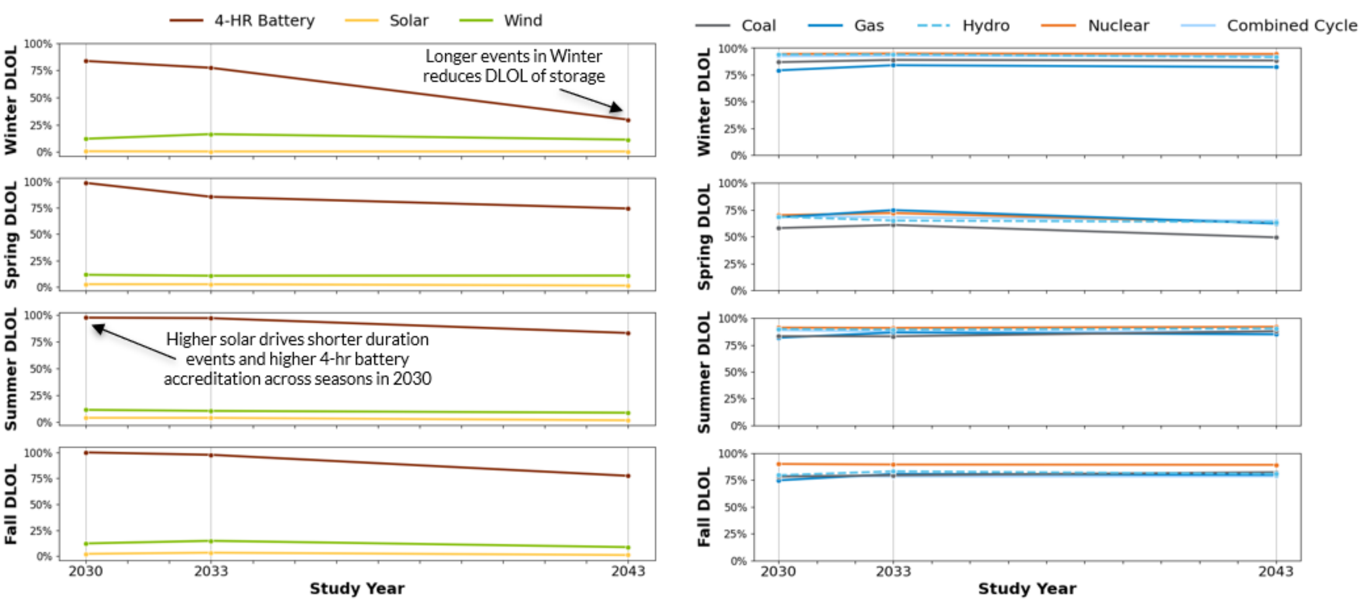


Figure 5: Change in resource class DLOL accredited value by study year

The changing resource mix is shifting the risk of loss-of load events to new hours of the day and seasons of the year. Traditionally, the greatest risk of loss-of-load has been concentrated in summer afternoon hours, as the 2030 portion of Figure 6 below shows. But due to members and states increasingly replacing conventional resources with weather-dependent renewables to achieve their policy goals, along with other factors such as the electrification of the economy and more frequent and severe weather events, the risk of loss-of-load events is shifting outside of the traditional summer peak-load period.

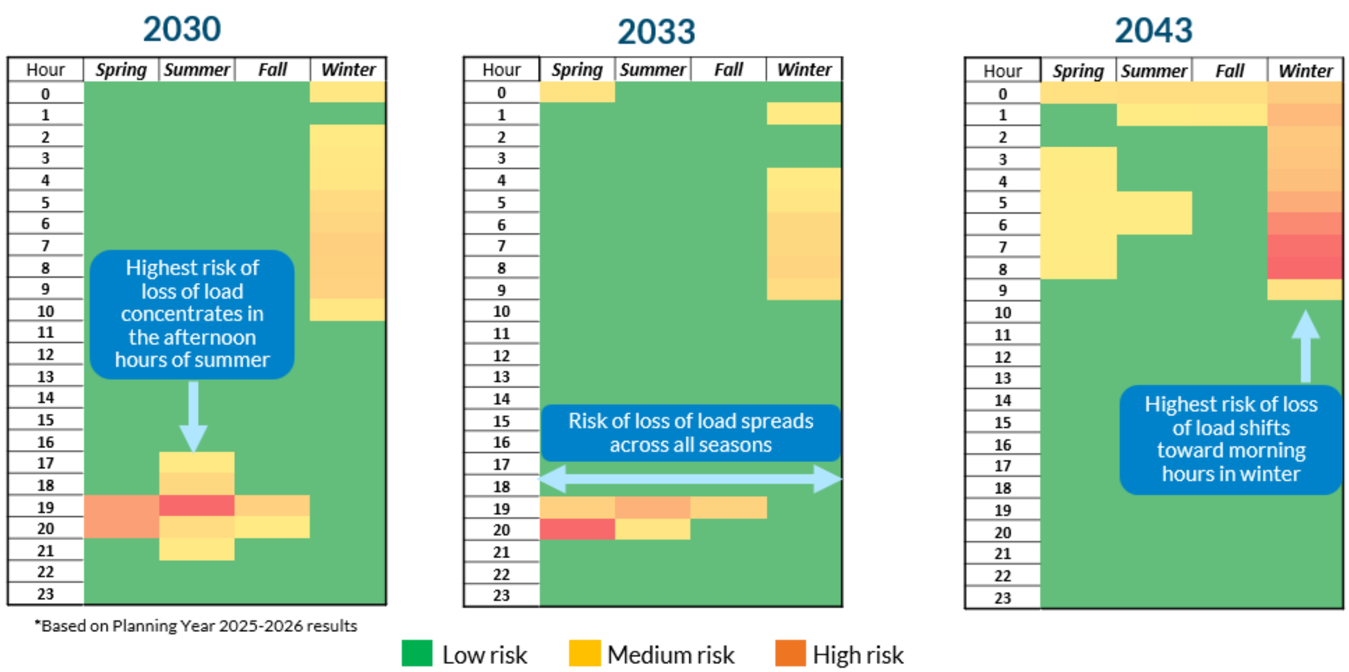


Figure 6: Projected shift in risk of loss of load between 2030 to 2043

By 2033, as Figure 6 shows, RRA modeling indicates that loss-of-load risks will spread across all four seasons of the year. By 2043, the greatest risk will be concentrated in the morning hours of the winter, when the availability of solar energy is particularly low in the MISO region. MISO's DLOL-based accreditation framework is designed to accurately reflect how different types of resources contribute to reliability during the highest periods of risk as the region's risk profile evolves.

INSIGHT 3:

Greater reliance on solar power is shifting the net load ramp from morning to evening and increasing the system's average 1-hour ramp need by 2-3 times by the early 2030s.

If members and states successfully achieve their publicly announced clean-energy policies, about 22% of the region's total annual energy could come from solar resources by 2033, increasing to about 32% by 2043. When wind is added in, the region could see 58% of its annual energy generated by these two types of weather-dependent renewables by 2033, increasing to 87% by 2043.

This growing reliance on variable wind and solar is increasing the need for dispatchable (controllable) fast-ramping resources that can rapidly inject energy into the system when wind and solar become unavailable. The need for fast-ramping resources is largely driven by increasing reliance on solar, which goes offline every evening just as demand is ramping up, as well as other times when the sun is not shining. But wind can also be highly variable and can confound MISO's best forecasting efforts, as evidenced by the multi-day wind droughts that have posed reliability challenges in the region in recent years.

Figure 7 below illustrates how increasing reliance on wind and solar is expected to change the region's net load profile, which refers to total system load minus generation provided by wind and solar.

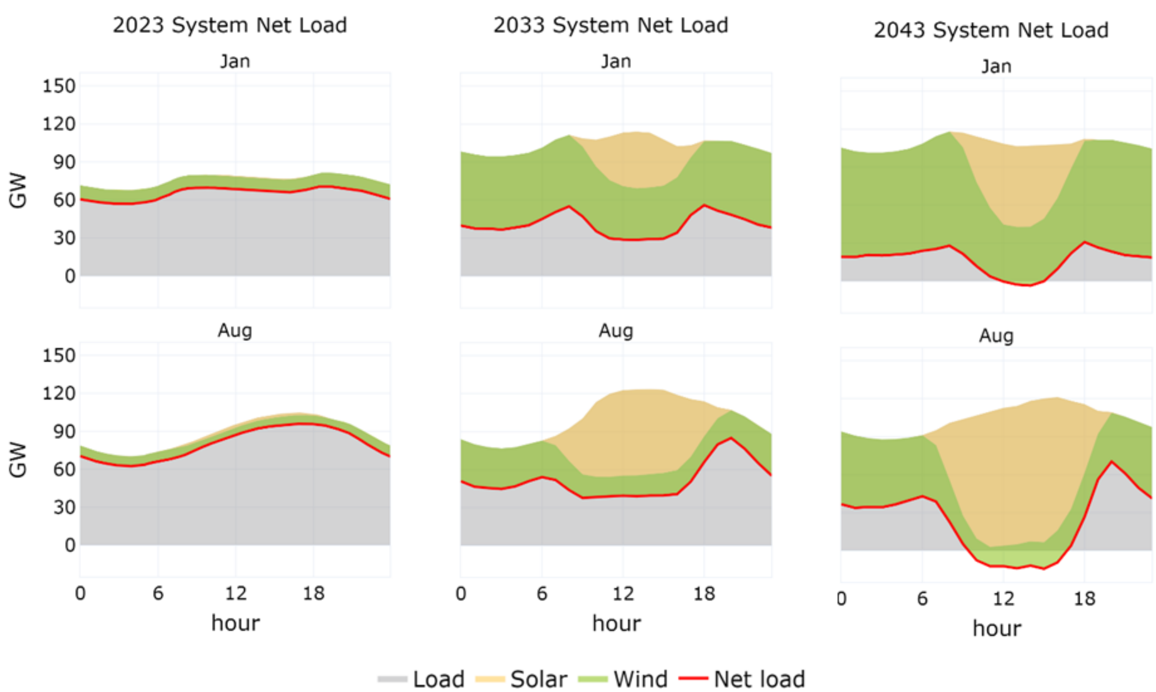


Figure 7: Projected changes in system net load profile from 2023 to 2043

Historically, the MISO region has had two diurnal (daily) net load peaks in winter months. The first occurs in the morning as people wake up, followed by a midday dip in demand, with load increasing again in the evening. In summer months, the region has historically seen a single daily net load peak in late afternoon hours. As integration of solar and wind increases, RRA modeling indicates that the region's net load profile will increasingly morph into a "duck curve" shape. The term duck curve, which is well-known in the industry, features a prominent drop in net load in midday due to high solar production. Then in the evening as solar becomes unavailable and demand increases, there is a critical need for dispatchable resources that can rapidly ramp up and inject energy into the system.

As shown in Figure 8 below, RRA modeling indicates that by 2033, the region will need more than three times 1-hour up-ramp capability compared to 2023, increasing to six times more by 2043. RRA modeling also indicates that increasing reliance on solar will shift the region's daily net load peak to post-sunset hours later in the day, and will also increase the total number of stressed hours on the system.

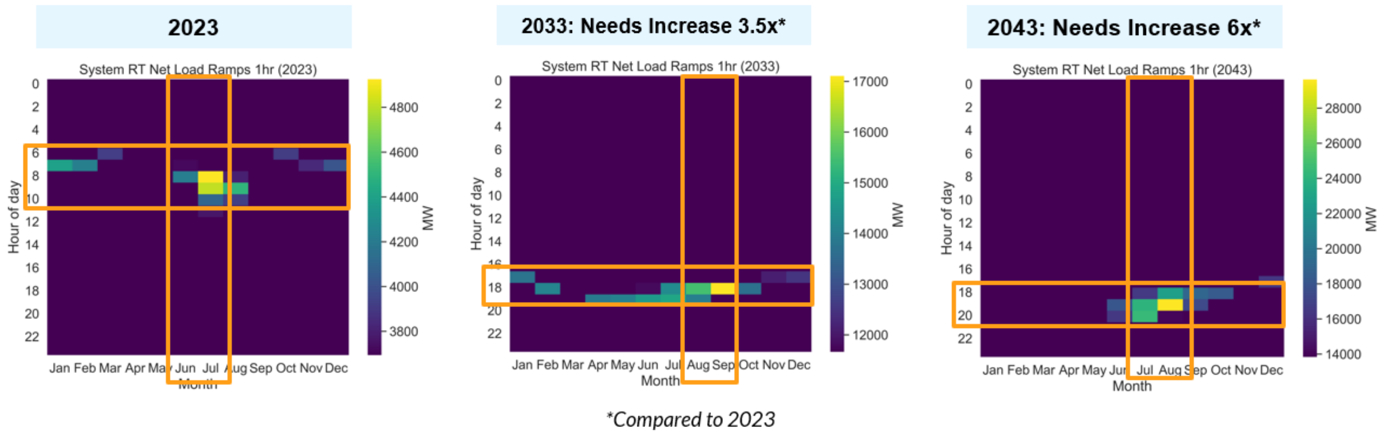


Figure 8: Highest 10th percentile of 1-hour net load ramps

RRA AND THE OMS-MISO SURVEY

As noted in the Preface of this report, the results of this year's RRA differ from this year's OMS-MISO Survey. The RRA projects capacity surpluses in 2030 and beyond, whereas the 2024 OMS-MISO Survey forecasted a range of possible outcomes, varying from capacity deficits beginning in 2025 to capacity surpluses through 2029.

As discussed in the Preface, this is because the RRA and the OMS-MISO Survey were designed for different purposes and use different data inputs, methodologies, assumptions and time horizons. For example, the RRA uses computer modeling to predict additional resources that members and states may choose to build to achieve their policy objectives, over-and-above members' and states' publicly announced resource plans. By contrast, the OMS-MISO Survey does not conduct this type of resource-expansion modeling, and only counts resources that members and states report themselves.

MISO is exploring ways to integrate and align the RRA and the OMS-MISO Survey, as well as the MISO Futures. MISO will keep stakeholders informed of this work.

Introduction

UNDERSTANDING THE RRA

The Regional Resource Assessment (RRA), a periodic study that MISO launched in 2021, models how the portfolio of generating resources in the MISO region might evolve over a 20-year time horizon. In the assessment, MISO analyzes the goals that MISO members and states have publicly announced to reduce the carbon emissions and/or increase the renewable energy levels of their fleets, as well as announced retirements of specific existing resources and the building of new resources. Since 2022, MISO has used an RRA-specific survey instrument to collect information directly from MISO members, which results in high-quality data quality and robust stakeholder engagement.

> The resource expansion component of this year's RRA runs from 2024 through 2043. But because the RRA is designed to focus on the long-term time horizon as opposed to the near term, this year's RRA results are generally reported beginning in 2029. The region's primary nearer-term resource assessment is the OMS-MISO Survey, which MISO administers in partnership with the Organization of MISO States (OMS).

In keeping with industry practices, MISO members and states engage in long-term resource planning, but do not typically announce decisions about specific resource retirements and new resource builds 20 years in advance. To complete the 20-year RRA outlook, MISO uses computer models to identify additional potential resources its members may choose to build to economically and reliably achieve their decarbonization and renewable energy goals and meet planning reserve margin requirements. That step, called the Resource Expansion, produces a forecasted future generation portfolio that includes both publicly announced and model-selected resources.

The Resource Expansion portfolio then undergoes two different types of analyses. The **Resource Adequacy Analysis** performs a LOLE assessment to explore potential seasonal risk drivers in future years, and seeks to understand capacity value trends over time, particularly of weather-dependent resources. The **Flexibility Assessment** evaluates how sources of expected variability and unforeseen uncertainty are increasing the operational complexity of the grid, expanding periods of system stress and driving a need for greater system flexibility such as dispatchable fast-ramping resources. Figure 9 below illustrates the basic structure of the RRA.

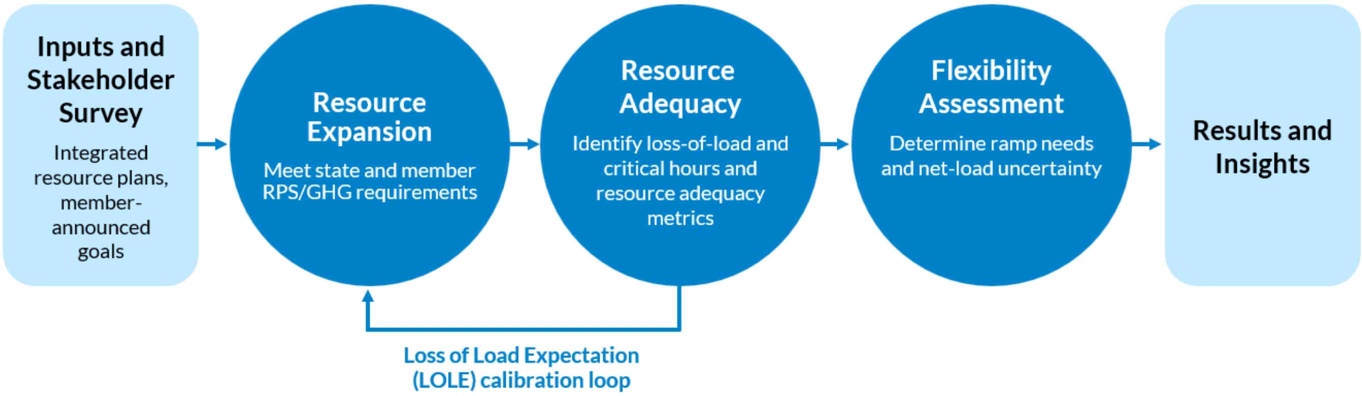


Figure 9: Basic structure of the RRA

This year's RRA utilizes the **Direct Loss of Load (DLOL)**-based accreditation methodology for accrediting resources that MISO intends to implement beginning in the 2028-2029 Planning Year.[5] DLOL-based accreditation differs significantly from MISO's current accreditation practices, and the DLOL-based accreditation results in this year's RRA are intended to help inform the resource-planning decisions that members and states make going forward. Details about how DLOL methodology was used in this year's RRA are included in this report, and a more thorough explanation is provided in an associated RRA Technical Appendix.

The results of this year's RRA are generally described at the region-wide level. Supplemental charts and data are provided on MISO's website, along with the Technical Appendix noted above. The website also hosts an RRA-based interactive emissions dashboard and the online portal for the RRA's survey tool.

NEW MODELING SOFTWARE AND PROCESS IMPROVEMENTS

The Resource Expansion component of this year's RRA uses software called PLEXOS, which has enabled several process improvements from previous versions of RRA modeling, as shown in Figure 10 below.

Process improvement	Previous Versions of RRA	2024 RRA	Enabled by switch in resource expansion software
Reliability Requirement	Annual/PRM	Seasonal PRMR based on LOLE Calibration loop	✓
Accreditation	Annual/Average ELCC based on "previous year" RRA	DLOL vs. Installed Capacity (ICAP) function based on LOLE calibration loop	✓
Renewable Portfolio Standard (RPS) & CO_2 modeling	Aggregated approach	Disaggregated Approach	✓
Resource adequacy	1 calibration	Several calibrations	
Chronology	Not captured	Included (3 days/month)	✓
Flexibility Assessment	Included	Included	

Figure 10: Process improvements in this year's RRA

CHANGING PLANNING PARADIGM

There was little need for a study like the RRA when the MISO region had robust reserve margins and a generation mix that was predominately comprised of conventional thermal resources with expected availability. Both load (with a predictable summer peak) and generation (with non-correlated outages) were relatively consistent, bolstering system reliability. MISO members and states planned for the future within the confines of their own needs and policy objectives.

Today presents a much different situation. The energy industry is evolving in profound ways, with MISO members and states retiring existing resources due to changing economics, environmental regulations, technological advancements, state and federal policies, and consumer preferences for cleaner energy.

[5] MISO Planning Years begin on June 1 of a given calendar year and run through May 31 of the following calendar year.

MISO members and states are primarily replacing retired thermal resources with renewables such as wind and solar, augmented with smaller quantities of battery storage. Meanwhile, demand is increasing due to the construction of new data centers and other energy-intensive facilities, even as severe weather events are becoming more frequent and severe, increasing the risk of outages.

These and other trends create new challenges and complexities in the realm of resource planning. Before, planning was a relatively well-understood task, akin to arranging generally uniform building blocks. Now, planning is far more complicated, like assembling a jigsaw puzzle with many disparate pieces. For example, renewables share a common risk driver — regional weather patterns — and therefore have correlated outage risks. As a result, when renewables are not available or their output is reduced, MISO members may need to rely on the MISO market more than they have historically. The RRA increases visibility across the region so that members and states, who have jurisdiction over resource planning, can make better-informed decisions.

MISO does not have authority over generation resource planning or procurement, yet MISO relies on transparent, forward-looking insight into the generation planning activities of its members and states to effectively carry out its responsibilities as a federally designated ISO and RTO. The RRA aims to help members and states identify potential resource gaps and associated reliability issues years before they materialize, creating a window to develop cost-effective solutions.

FOCUS ON THE TRANSITION, NOT JUST THE END STATE

Many industry discussions focus on the end state of decarbonization with less talk about the path to get there. Emerging technologies such as long-duration energy storage and green hydrogen show great promise, but these resources are still nascent, making it difficult to confidently predict their timeline to commercial viability, much less deployment at the scale required to meet MISO's challenges. As the transition planning continues, it is imperative to balance three key priorities: reliability, affordability and sustainability.

MISO's chief concern with the transition is the potential for compromised electric system reliability. Key capabilities and attributes that are bundled with existing resources may become scarce as the resource fleet changes. For example, to compliment the continued growth of solar, MISO will increasingly need resources that can rapidly ramp-up to meet net load (load minus renewables). Reliably achieving the decarbonization targets set by many MISO members and states will require an accurate and collective view of how resource plans are evolving, and a shared understanding of the ways in which operational risks and needs will emerge and shift over time. MISO's RRA gathers that aggregate view and provides insights and technical findings that can help inform the work that members, states and MISO are doing both individually and collaboratively to plan ahead.

THE RELIABILITY IMPERATIVE AND RELATED MISO INITIATIVES

The RRA is one of several sources of data that MISO uses to support an umbrella initiative called the Reliability Imperative — the term MISO uses to describe the shared responsibility that MISO, members and states have to assess and proactively address the urgent and complex challenges to electrical system reliability in the region. In addition to the RRA, other sources of data that underpin the work that MISO and its stakeholders are doing under the Reliability Imperative include:

OMS-MISO Survey

In partnership with the Organization of MISO States (OMS), this annual survey asks members to provide information on new generation they plan to build and existing generation they plan to retire going forward. The survey focuses on the five-year forward view but does contain 10-year forward data with an understanding that uncertainty will increase in the latter five years. Unlike the RRA, the OMS-MISO Survey does not solicit members' decarbonization and renewable energy plans. Survey responses are confidential and may include plans that are not yet publicly available. Results of the 2024 OMS-MISO Survey are available here.

MISO Futures

The MISO Futures utilize a range of economic, policy and technological data and assumptions to develop three future scenarios that "bookend" what the region's resource mix might look like in 20 years. MISO uses the Futures to inform the development of transmission plans and other MISO processes. Both the RRA and Futures incorporate and reflect MISO members' publicly announced plans and goals, and some input data is shared between the project teams. The RRA considers only public information from members and is intended to be refreshed more frequently. The Futures use different modeling assumptions in some key areas, such as decarbonization levels and electrification load growth to create a wide range of possible outcomes for use in robust, least-regrets planning activities. More information on Futures development is available here. As described earlier in this report, MISO is exploring ways to integrate and align the RRA, the OMS-MISO Survey and the Futures. MISO will keep stakeholders apprised as this work progresses in 2025.

Reliability Attributes work

In 2022, MISO launched an initiative to identify which system attributes may become scarce due to the region's rapidly evolving generation mix. Attributes such as voltage stability have historically been supplied by conventional resources, and their increased scarcity in pockets of asynchronous generation pose a potential reliability risk. Continued investigation in this area will quantify the size, timing and impact of critical reliability attribute gaps such as gaps in availability, ramp-up capability, rapid start-up, long duration energy at high output, and fuel assurance. The work will also explore the best means of ensuring sufficient reliability attributes, whether through greater visibility, new requirements, optimizing existing market products or developing new products. The RRA is well-positioned to support the attributes initiative by providing insight into future system needs and timing considerations. More information about the attributes framing is available here.

Planning Resource Auction (PRA)

The PRA is a voluntary capacity auction that MISO members may elect to participate in to meet their resource adequacy requirements. The auction results in a commitment of capacity to the MISO region for the upcoming planning year, including performance obligations. The PRA presents a different picture of the region's capacity position compared to the PRA. This is due to different base datasets and assumptions that are explained in more detail in the Resource Expansion section of this report. PRA results for the 2024-2025 Planning Year are available here.

RRA Survey and Stakeholder Engagement

The RRA is based on forward-looking resource plans, decarbonization goals and other information in the public realm that MISO members voluntarily share with MISO through an online survey tool. The survey is hosted on an interactive website designed in partnership with Meier Engineering Research LLC, using a platform called Juicebox. The 2024 survey opened on March 4, 2024, and closed on March 29, 2024.

Other details about the 2024 RRA Survey include:

- **Plans and goals cut-off date:** The survey requested information on plans and goals that members publicly announced prior to February 29, 2024. Plans or goals announced after that date will be considered in future iterations of the RRA.
- **Types of information requested:** The survey asked for information on planned generation additions; planned retirements; historic emissions for the years 2000, 2005 and 2023; renewable energy and emissions goals; published Integrated Resource Plans (IRPs); and annual peak load (MW) and energy (GWh) forecasts.
- **Confidential information:** The survey allowed stakeholders to submit proxy information on planned resources on a confidential basis. RRA reporting aggregates generator data to the footprint or LRZ-level, which maintains the confidentiality of unit addition and retirement data.
- **Target audience:** MISO distributed the survey by sending an email to three groups of stakeholders: (1) those on the Resource Adequacy Subcommittee email list; (2) those on the Planning Superlist; and (3) those on the OMS-MISO Survey distribution list. The email contained a hyperlink to the online survey, along with instructions on how to complete it.
- **Quality control:** Once the survey closed, MISO reached out to individual members to review their submittals prior to finalizing the data and beginning the analysis.

SURVEY ENGAGEMENT

The 2024 RRA Survey had a record-high participation rate, with seven more members participating compared to 2023, as shown in Figure 11 below. Respondents provided varying levels of detail, reflecting differences in regulatory processes and availability of planning information.

Based on responses to the 2024 RRA Survey, as well as publicly announced clean-energy goals of entities that did not participate in the survey, MISO estimates that 98% of the total electricity load in the MISO region is served by entities that have adopted policies to reduce their carbon emissions, or increase their use of renewable energy, or both.

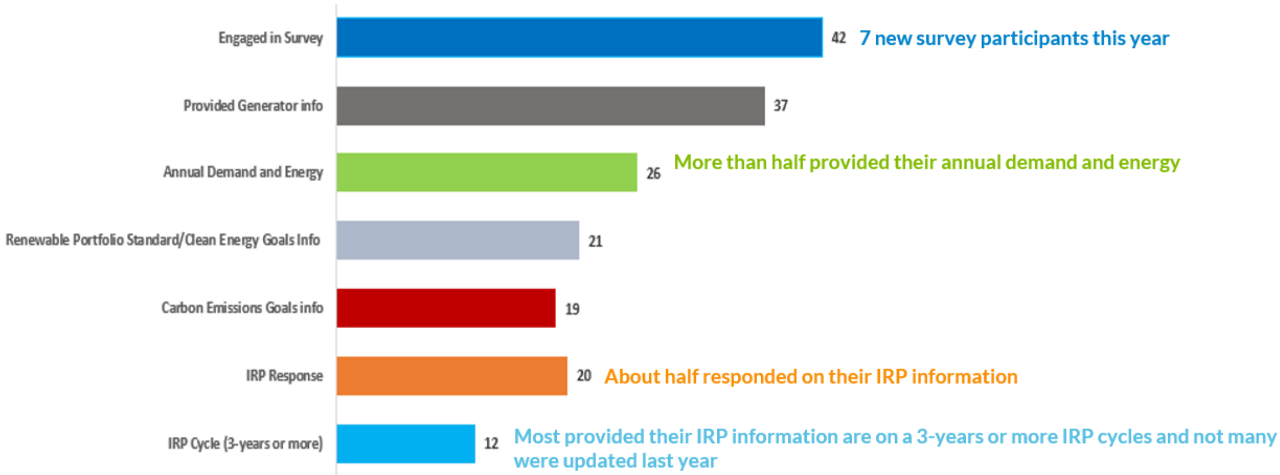


Figure 11: Number of MISO Members that participated in various aspects of the 2024 RRA Survey

SURVEY RESULTS

Based solely on 2024 RRA Survey responses, members and states currently plan to add about 137 GW of new resources on an installed capacity (ICAP) basis going forward. That is an increase of about 25GW, or 22%, above the 112 GW of new ICAP resources that members and states reported in their responses to the 2023 RRA Survey.

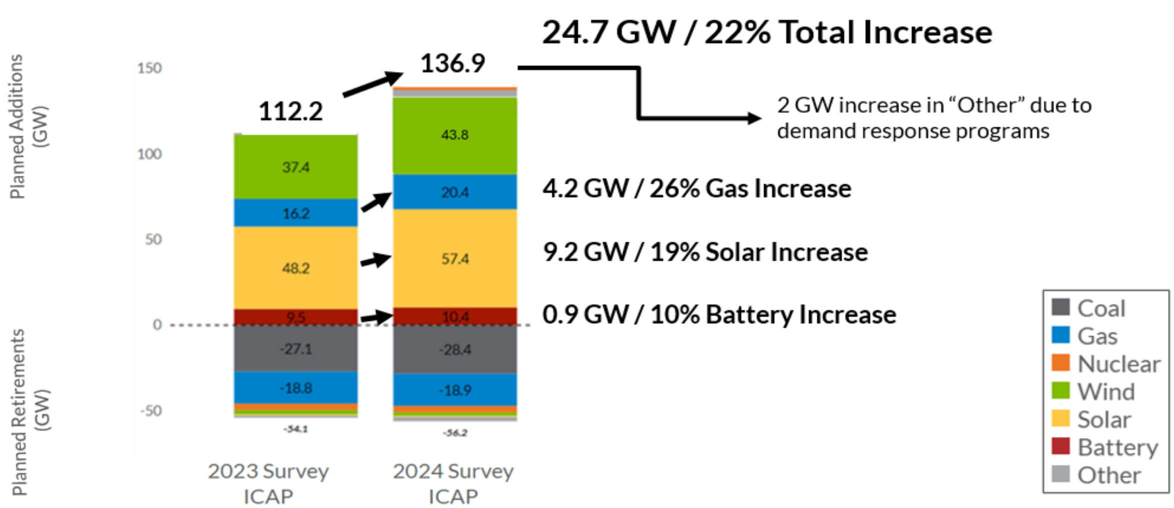


Figure 12: Planned additions and retirements (growth from the 2023 RRA Survey to the 2024 Survey

As Figure 12 indicates, solar comprises the single largest portion (57.4 GW) of all planned resource additions reported in the 2024 RRA Survey, followed by wind at 43.8 GW. Planned natural gas additions total 20.4 GW in the 2024 RRA Survey, which is considerably less than either planned solar or wind.

Notably, the level of planned gas resources increased by 26% compared to what members and states reported in the 2023 RRA Survey.

> **Please note:** Figure 12 does not reflect about 26 GW of planned resource additions that members and states did not include in their responses to the 2024 RRA Survey, but which either (1) have signed Generator Interconnection Agreements that allow them to connect to the grid once they are built, or *(2)* were identified in publicly announced plans, such as IRPs, for members who did not engage with the RRA Survey. A manual process of mapping units submitted in the survey to units in the queue was undertaken to ensure there were no duplicates. MISO added in these resources after the RRA Survey closed, which brings this year's total planned resources to 163 GW. Figure 2 on page 4 of this report and Figure 16 on page 21 of this report reflect that 163 GW figure.

The 2024 RRA Survey also asked members and states about existing resources they plan to retire in the next 20 years. Planned coal retirements increased by about 5% in ICAP terms compared to last year's RRA Survey.

Figure 13 shows how planned resource additions and retirements play out over the next 20 years. The figure also compares how those approximate timelines compare to the information that members and states provided in the 2023 RRA Survey.

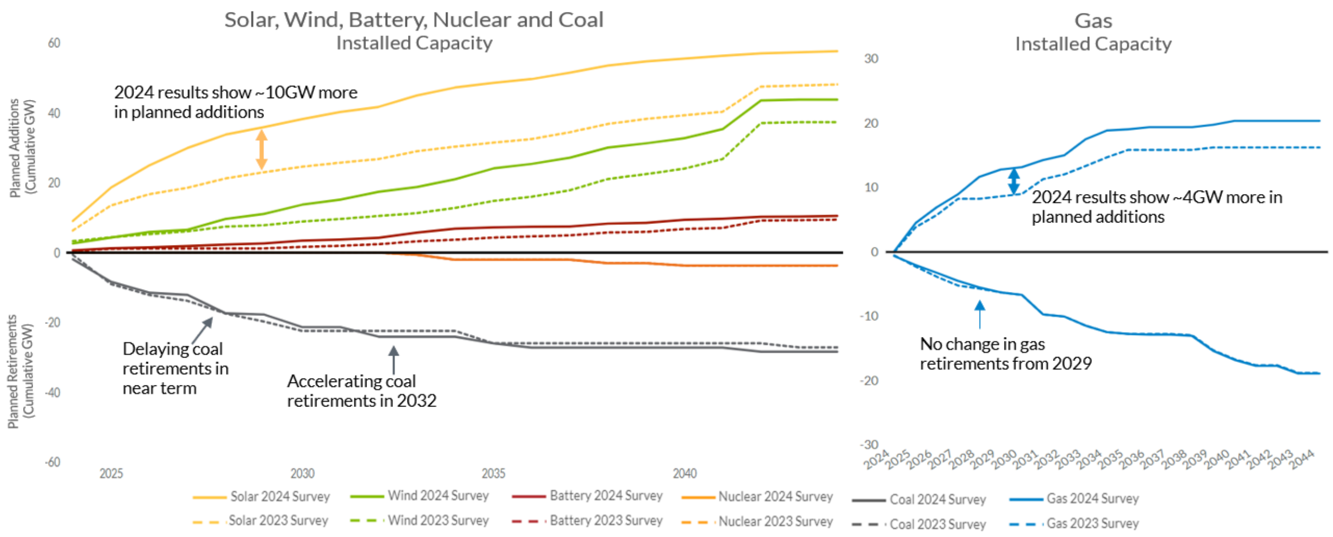


Figure 13: Planned additions and retirements as reported by participants in the 2024 RRA Survey

As Figure 13 indicates, members and states now plan to add about 10 GW more solar in the early years of the RRA's study window (prior to 2030) compared to last year's RRA Survey. Planned gas additions are also up by about 4 GW year-over-year, with most of the increase occurring in the 2028-2030 timeframe. In terms of retirements, planned coal retirements show a slight delay in the near term compared to last year's RRA Survey, but they also accelerate slightly beginning in 2032 compared to last year. Planned gas retirements also show a slight near-term delay this year compared to last year, but they return to last year's timeline in 2029 and beyond.

Resource Expansion (Modeling)

PURPOSE AND METHODOLOGY

Because it is not typical electric industry practice to develop detailed resource plans 20 years in advance, MISO's RRA Survey does not account for the full portfolio of resources that members and states will need to achieve their policy goals for all 20 years of the RRA's study period. This apparent gap is entirely "informational" in nature and does not reflect deficiencies in resource planning.

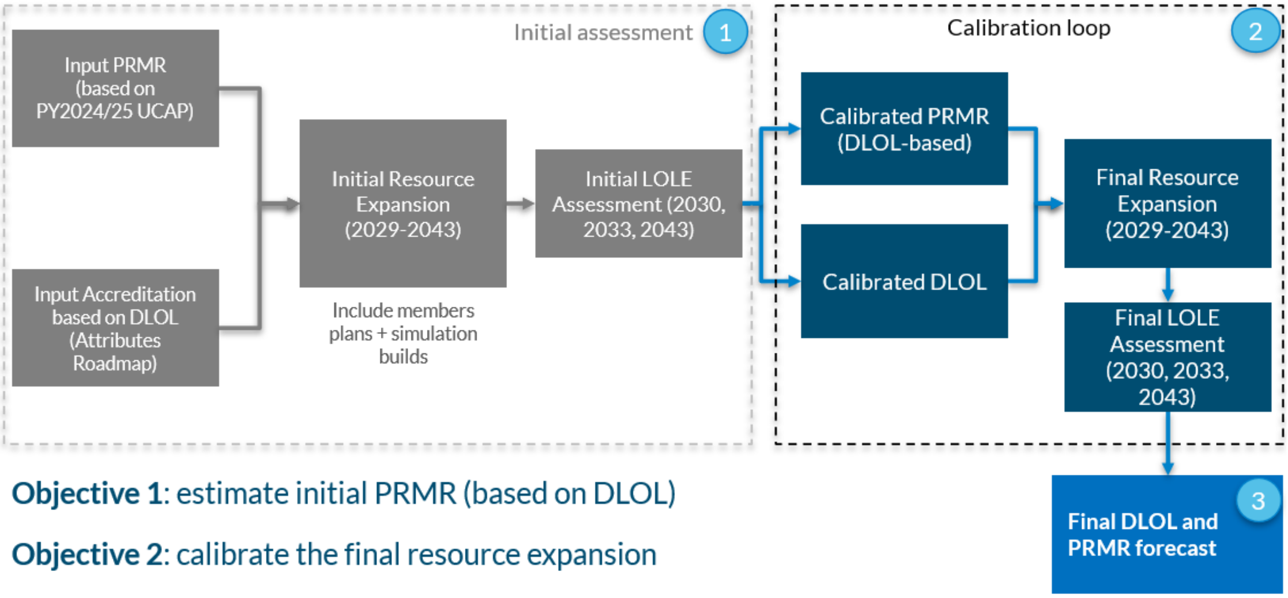
To close the informational gap, MISO uses computer software to model additional resources members and states might choose to build to achieve their policy objectives and satisfy reliability requirements. This step of the RRA, called the **Resource Expansion**, produces a portfolio of existing, planned and "policy-driven" resources. This year, MISO conducted the Resource Expansion with software called PLEXOS, which enabled several process improvements from previous versions of RRA.

To execute the Resource Expansion, PLEXOS used MISO-developed assumptions about load, resource accreditation, and Planning Reserve Margin Requirements (PRMRs), among many other inputs and assumptions detailed in the Technical Appendix. The load assumption for this year's RRA is based on a MISO planning scenario called Future 2A. Resource accreditation and PRMR values are provided for each of the four seasons in accordance with the seasonal resource adequacy construct that MISO began implementing last year.

This year's RRA uses the **Direct Loss of Load (DLOL)**-based accreditation methodology that MISO intends to implement beginning in the 2028-2029 Planning Year.[6] DLOL-based accreditation methodology differs considerably from MISO's current accreditation practices, and the DLOL-based insights in this iteration of the RRA are intended to help members and states to prepare for the new methodology to be used in MISO's Planning Resource Auction (PRA), markets and elsewhere. DLOL uses a two-step process, with the first step calculating probabilistic, resource-class average accreditation values using LOLE modeling. The second step tailors class-level accreditations to individual generators based on their availability during normal operating conditions and high-risk hours, with more weight given to high-risk hours. The DLOL forecast in this RRA focuses on the class-average accreditation values (step 1).

[6] MISO Planning Years begin on June 1 of a calendar year and run through May 31 of the following calendar year.

Figure 14 below shows how MISO developed seasonal DLOL-based resource class accreditation values for this RRA. As the figure shows, MISO first input class-level values from the 2023 Attributes Roadmap and then refined them in a calibration loop that considers another major part of the RRA called the Resource Adequacy Analysis. This calibration loop was also used to refine the seasonal PRMR values in this year's RRA. Please see the RRA Technical Appendix for more details.



DLOL: *Direct Loss of Load;* ***ICAP***: *Installed Capacity;* ***PRMR***: *Planning Reserve Margin Requirement;* ***LOLE***: *Loss of Load Expectation ;* ***PY***: *Planning Year*

UCAP-PRMR is substituted with DLOL-PRMR to acknowledge the underlying accreditation assumptions assumed in the PRMR calculations

Figure 14: LOLE calibration loop

RESOURCE EXPANSION INSIGHTS

Members and states may need to add capacity at an unprecedented rate of 17 GW/year — over three times the recent average of 4.7GW/year* — for 20 years to meet Future 2A demand and policy goals. Achieving this pace will require overcoming delays related to supply chains, permitting, labor and interconnection queues.

Results

- Members have planned 163 GW of additional installed capacity by 2043.**
- Members-only portfolio shows a need for additional resources to meet policy objectives with Future 2A load.
- Expansion simulation selects an additional 180 GW of resources to meet objectives, resulting in a total of 343 GW of additional capacity by 2043 (Avg 17 GW/year).
- Wind and solar account for 62% of installed capacity and 87% of annual energy served by 2043 in the resulting portfolio.

Drivers

- Informational gap rather than member/state planning gap.
- Difference in load expectation.
- 98% of the load in the MISO region is served by members who have publicly stated carbon goals, renewable goals, or both. This is a 13% increase from the 2022 RRA survey.

Approach

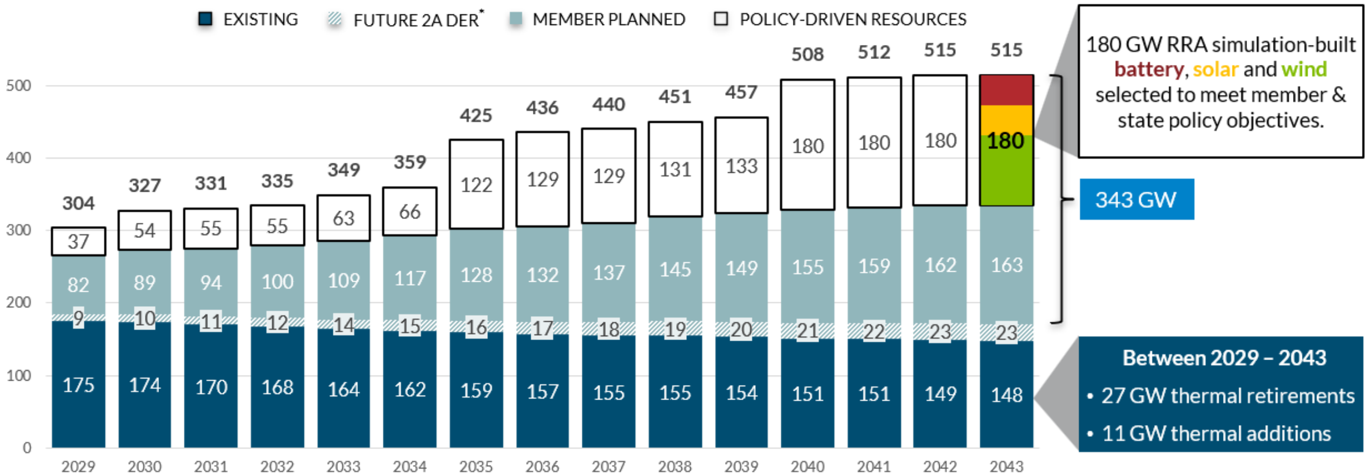
- 20-year chronological expansion simulation with resources selected to satisfy policy objectives and calibrated PRM not yet met with member planned and existing portfolio.
- Assumptions include:
  1. Members plan to meet individual goals with their own generation or PPAs they've identified in the survey; and
  2. Simulation-built resources contribute to individual goals based on load-ratio share.

** 4.7 GW/year reflects average from PY20-22 of projects that have communicated a commercial operation date to MISO. Projects include, but are potentially non-exhaustive of surplus, replacement, generator uprates, ERIS to NRIS interconnection upgrades, and external capacity returning to MISO. MISO COD Tracker*

** As identified by the RRA 2024 Survey, signed Generator Interconnection Agreements, and publicly announced plans.*

Figure 15: Summary of the 2024 RRA Resource Expansion (Insight 1)

MISO members and states that participated in this year's RRA Survey indicated they plan to build 163 GW of new resources on an installed capacity (ICAP) basis by 2043. Those planned resources are shown in the teal-colored segments of the bars in Figure 16 below. Similarly, the dark blue segments of the bars in Figure 16 indicate that members and states plan to keep 148 GW of existing ICAP online through the RRA's 20-year study period.

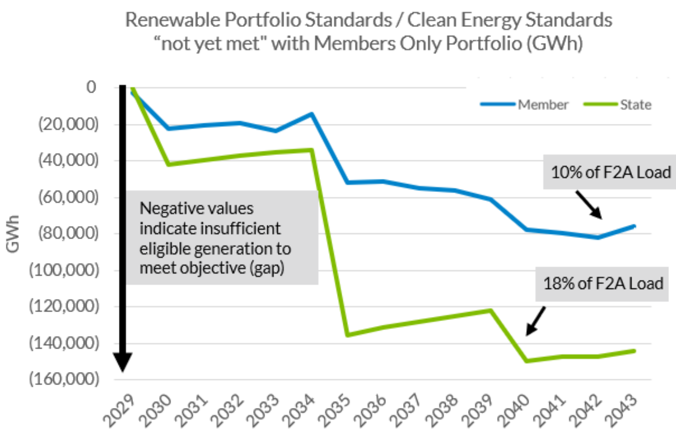


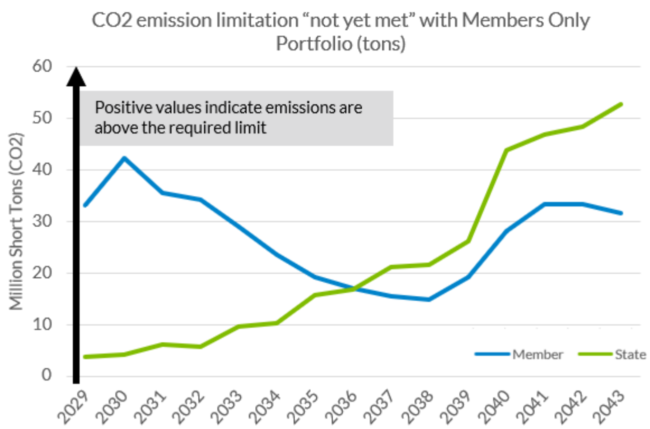
** Future 2A DER: The 2024 RRA utilizes Future 2A load assumptions. Future 2A assumptions for distributed energy resources (DER), developed by Applied Energy Group based on DER technical potential during Series 1, include Demand Response (DR), Energy Efficiency (EE), and Distributed Generation (DG). For the 2024 RRA, Energy Efficiency and Utility Distributed Generation (UDG) was netted from load; DR and DGPV are reflected as resource additions.*

Figure 16: Total Installed Capacity (ICAP) in Gigawatts (GW)

RRA modeling indicates that members and states will not be able to achieve their renewable energy or decarbonization goals using only the 163 GW of planned resources they have publicly announced to date and the 148 GW of existing resources they intend to keep online for the next 20 years. However, it is important to understand that this apparent gap is **not an actual resource shortfall** either now or in the future. Instead, it should be thought of an informational gap that members and states may elect to address as they continually refine their resource plans, policy goals and investment decisions.

With that caveat in mind, the left portion of Figure 17 below illustrates the RRA's snapshot-in-time projection of how members and states would fall short of their publicly announced renewable energy goals if they stopped refining their resource plans going forward — which, as explained above, is not expected industry practice.





Member and state policy objectives were modeled individually at the entity level; "member" and "state" aggregates are for reporting only and do not reflect constraints as modeled. Given overlap, member deficits and state deficits are not additive.

Figure 17: Member and state policy goals not yet met with publicly announced + existing resources

RRA modeling assumes members and states will use their own generation or publicly announced Power Purchase Agreements to meet their renewable energy goals. As the left side of Figure 17 indicates, the projected deficits in renewable generation increase sharply in 2030, 2035 and 2040 as member and state policy objectives become more stringent.

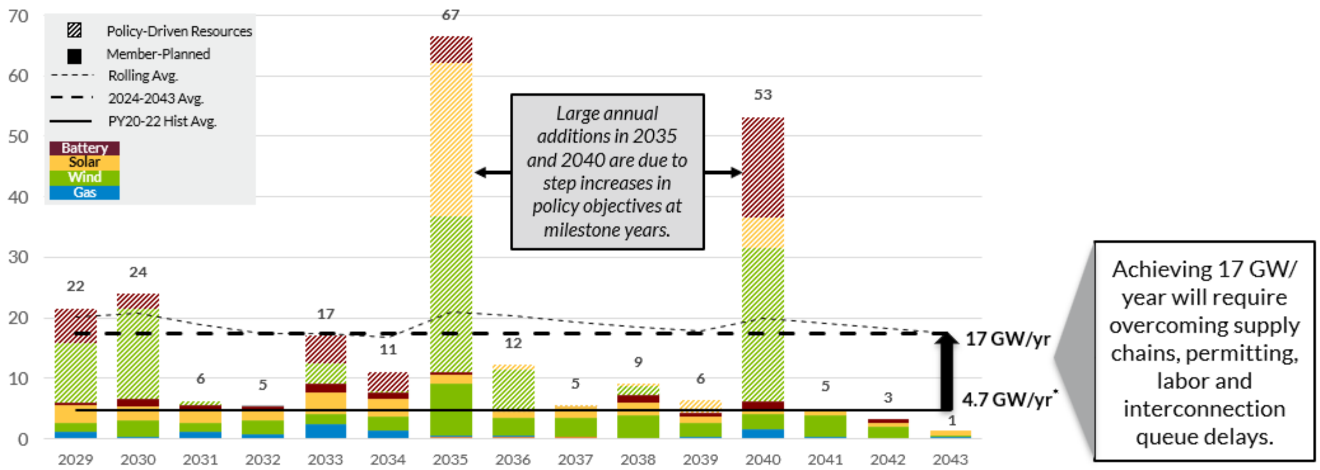
Similarly, the right side of Figure 17 illustrates the RRA's projections regarding how members and states will emit more carbon dioxide than their policy objectives allow. The reduction in members' carbon emissions from 2030 to approximately 2038 is due to members' plans to add more zero-carbon resources during that timeframe. But RRA modeling indicates that members' emissions will rise sharply after 2038 as their carbon-reduction policy goals become more stringent.

*** **IMPORTANT NOTE** ***

To reiterate, the apparent gaps the RRA identifies in member and state plans are **not actual resource shortfalls** in either the present time or the future. Instead, the RRA identifies informational gaps that members and states may choose to address as they continually refine their resource plans, policy goals and investment decisions.

To fill these informational gaps, the RRA uses computer model-identified additional resources members and states might choose to build to achieve their policy goals. As Figure 16 indicates, a total of 180 GW of policy-driven capacity was added throughout the RRA's 20-year study period to achieve policy objectives that are not met with members' and states' publicly announced resource plans alone.

If members and states attempted to achieve their policy goals by adding the 180 GW of policy-driven ICAP selected by RRA modeling to the 163 GW of new ICAP they already plan to build, they would have to add a total of 343 GW of new capacity by 2043 — an average of 17 GW/year for 20 consecutive years. As Figure 18 illustrates, that rate of new resource additions would be unprecedented and extraordinary for the MISO region, since the region's actual pace of new ICAP additions has only averaged 4.7 GW/year in recent years (Planning Years 2020-2022).



** See Footnote 2 on page 3 for more details*

Figure 18: Annual Additions (ICAP, GW)

The RRA did not impose any modeling constraints on how much new capacity members and states could build every year to meet their policy objectives. As Figure 18 illustrates, RRA modeling indicates that additions of new capacity would far exceed the 17-GW average in some years, most notably in 2035 and 2040. This is because 2035 and 2040 are milestone years in which many member and state policy objectives become more stringent.

Building an average of 17 GW of new capacity every year could be very challenging due to supply chain delays, permitting problems and other factors beyond the control of members, states and MISO. As Figure 19 indicates, of the 55 GW of fully-approved projects in MISO's Generator Interconnection Queue as of mid-2024, nearly half — 26 GW — were delayed by supply chain issues and other factors.

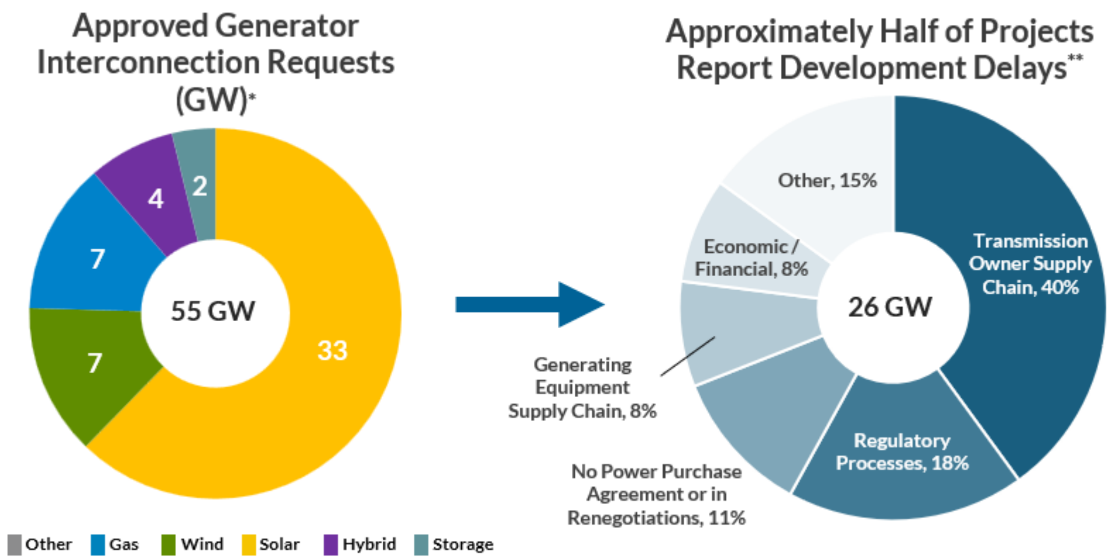


Figure 19: Delayed projects in MISO's Generator Interconnection Queue

The situation could be further exacerbated by the large load additions the MISO region is expected to see in the next few years. As previously noted, load assumptions for this RRA are based on MISO Future 2A, which assumes net demand will increase over 20 years by a compound annual growth rate (CAGR) of 0.82% (1.14% gross demand). However, as Figure 20 below shows, that is far below the updated load forecast that MISO published in December 2024, which estimates the incremental load growth the region could see due to recent developments in building electrification, artificial intelligence (AI) and data centers and other factors.

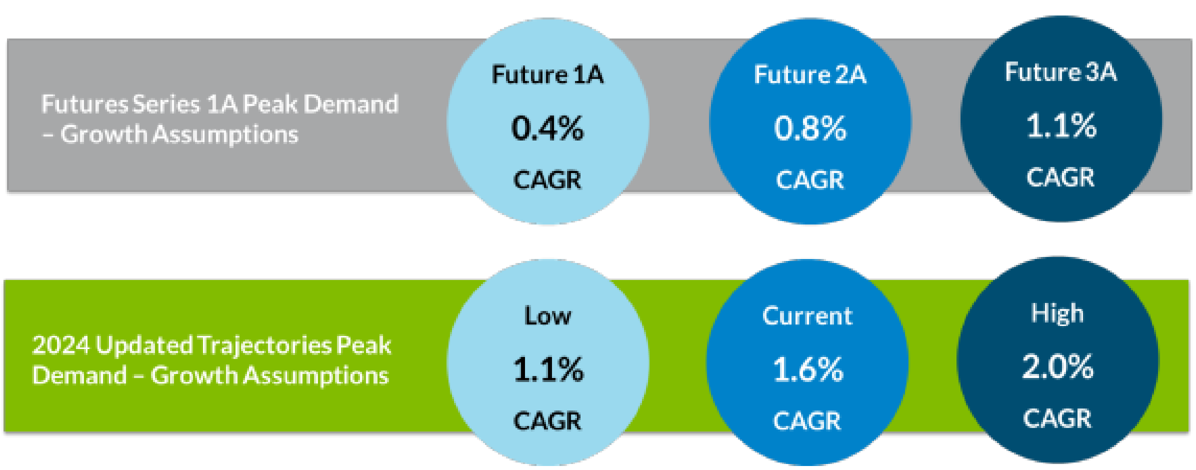


Figure 20: Comparison of MISO load forecasts
Source: Long-Term Load Forecast whitepaper, December 2024

Figure 21 divides the region's total anticipated new load growth into six specific sectors, with the key drivers and expected levels of certainty for each.

Sector	Projected Energy Demand Increase (TWh)	Level of Certainty High to Low	Key Drivers
Building Electrification	36-43		State and federal incentives, including adoption of heat pumps, and appliances.
AI and Data Centers	149-241		Expansion of data centers driven by AI and cloud computing needs.
Electric Vehicles	54-91		IRA incentives, declining battery costs, and rapid EV adoption between 2030-2044.
New Industry & Reshoring	21-105		Electrification in oil and gas, CHIPS Act, and reshoring of industries.
Green Hydrogen	26-95		Electrolysis-based hydrogen production contingent on sustained IRA incentives.
Distributed Energy Resources (DERs)	69-78		Growth in rooftop solar, energy storage, and demand response via DERs.

Figure 21: Projected load growth by sector and level of certainty
Source: [Long-Term Load Forecast whitepaper](), December 2024

Other notable take-aways from the Resource Expansion component of this year's RRA pertain to the types of resources that members and states may elect to build to achieve their policy objectives. As Figure 22 indicates, RRA modeling projects that wind and solar resources combined will account for 62% of the region's installed capacity and generate 87% of the region's energy by 2043.

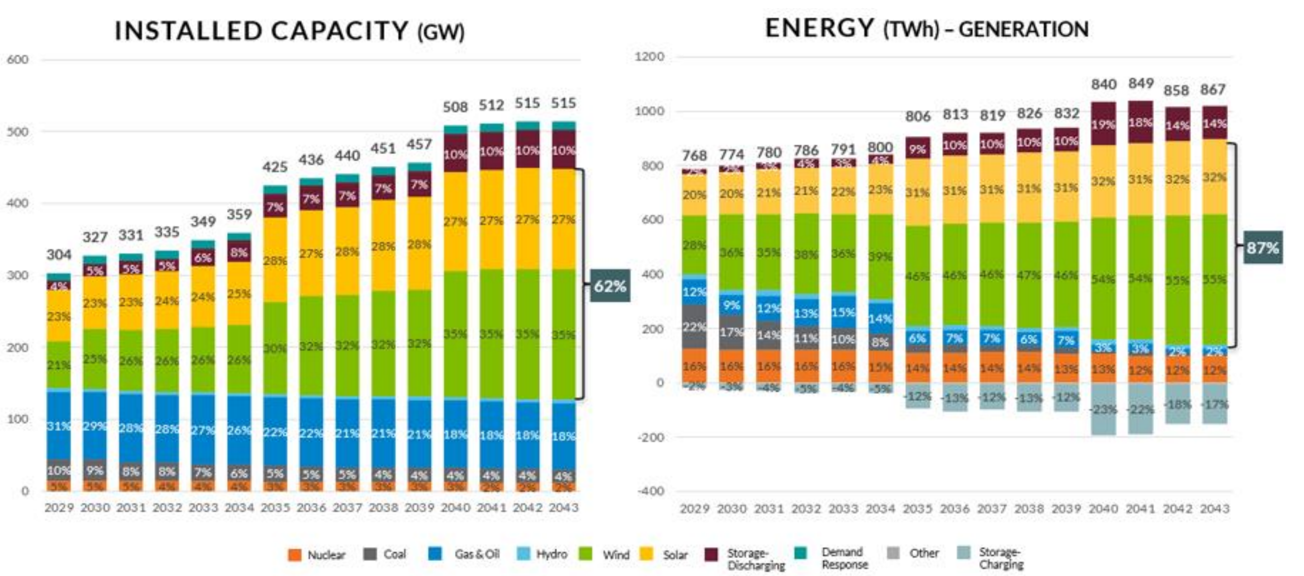


Figure 22: Projected yearly ICAP and energy values by resource type based on members' and states' resource plans and policy objectives

Such a large degree of increasing reliance on wind and solar could have major implications for the MISO region. For example, while wind and solar excel at producing zero-carbon energy that members and states need to achieve their policy objectives, they lack certain key reliability attributes that are needed to keep the grid reliable every hour of the year. This is discussed in detail in the Resource Adequacy and Flexibility sections of this report.

Currently, a key reason that RRA modeling predicts that wind and solar will be heavily used to achieve clean-energy goals going forward is that both wind and solar are technologically proven and economically viable at grid scale. However, other emerging clean-energy technologies are currently being developed that show promise of providing the critical reliability attributes the grid needs, such as system adequacy, system stability, and flexibility, as MISO discussed in its 2023 Attributes Roadmap report. Promising emerging clean-energy technologies include long-duration energy storage, small modular nuclear reactors, hydrogen systems, and carbon-capture and storage, among others. As these and other emerging technologies continue to mature, they could reduce the degree to which the MISO region grows increasingly reliant on wind and solar.

Battery storage resources in this RRA are modeled to have a discharge duration of 4 hours (which is generally not considered long-duration storage). As Figure 22 shows, increases in battery capacity and dispatch mirror the growing penetration of wind and solar, with the largest jumps in cumulative battery capacity and annual discharge occurring in years that correspond to interim targets or other milestones for member and state policy objectives. Storage discharge peaks in 2040 before declining slightly as renewable generation is utilized not only to meet policy objectives, but also to serve load in 2041 and beyond.

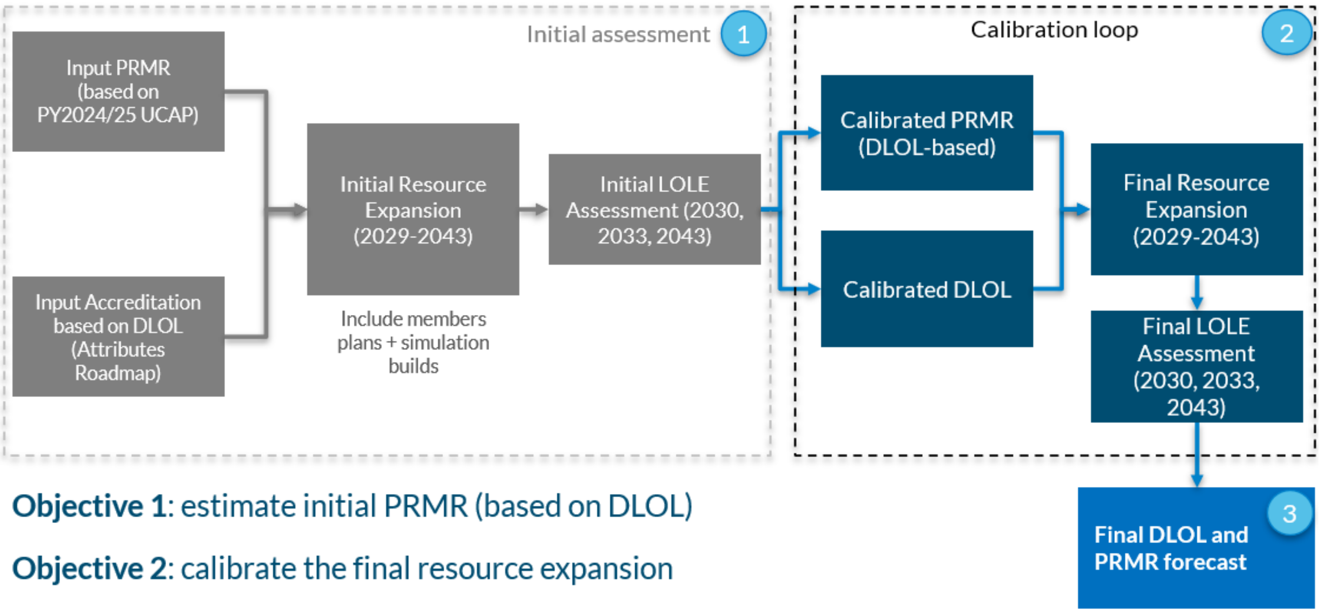
This year's RRA provides some interesting insights about natural gas resources going forward. As the left portion of Figure 22 shows, while gas capacity is forecast to decline over time, gas will still comprise 18% of the system's total capacity in 2043. However, as the right portion of Figure 22 indicates, gas is only expected to provide about 2% of the region's energy in 2043 due to member and state policies that require load to be served by zero-carbon resources.

Resource Adequacy Analysis

PURPOSE AND METHODOLOGY

As previously noted, this RRA uses the Direct Loss of Load (DLOL)-based methodology to accredit resources that MISO intends to implement in the 2028-2029 Planning Year. A key objective of this year's RRA Resource Adequacy Analysis is to provide forecasted DLOL-based accreditation values for different resource classes that members and states can consult for guidance when making investment decisions about their future resource portfolios. The analysis is based on the 1-in-10 loss-of-load expectation (LOLE) criterion that is commonplace in the industry.

The results of the Resource Adequacy Analysis are dependent on the resource portfolio that is produced by the Resource Expansion step of the RRA described in the previous section of this report. However, the Resource Expansion is also dependent on the accreditation and Planning Reserve Margin Requirement (PRMR) values that result from the Resource Adequacy Analysis. As Figure 23 shows, this RRA utilizes a LOLE calibration loop to accommodate the interdependency of the Resource Expansion and Resource Adequacy analyses. Please see the Technical Appendix for more details.



__DLOL__: Direct Loss of Load; __ICAP__: Installed Capacity; __PRMR__: Planning Reserve Margin Requirement; __LOLE__: Loss of Load Expectation ; __PY__: Planning Year

UCAP-PRMR is substituted with DLOL-PRMR to acknowledge the underlying accreditation assumptions assumed in the PRMR calculations

Figure 23: LOLE calibration loop

Figure 24 below compares the first iteration of DLOL and PRMR values the calibration loop produced to the second iteration. Seasonal PRMR values for 2030, 2033 and 2043 differed by less than 5% from the first iteration to the second. Similarly, for the most part, DLOL-based resource class accreditation values also changed little between iterations. The one exception was gas resources, which showed sensitivity to changes in net load, which resulted in lower DLOL values in the second iteration.

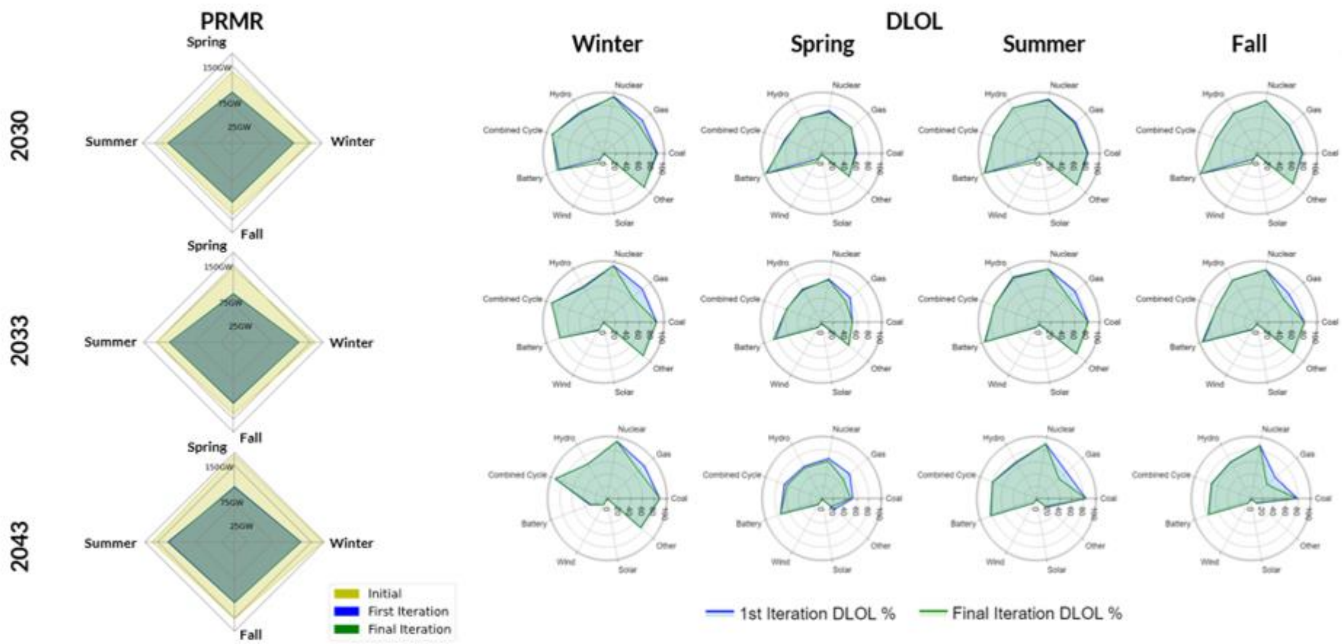


Figure 24: Differences in PRMR and DLOL values from the first iteration of the LOLE calibration loop to the second iteration

RESOURCE ADEQUACY ANALYSIS INSIGHTS

Under MISO's new DLOL accreditation methodology, thermal resources will continue to provide the bulk of the region's accredited capacity even while RRA modeling indicates that lower-accredited wind and solar will account for 62% of installed capacity and 87% of the region's energy by 2043.

Results

- As wind and solar increase in terms of installed capacity, their DLOL accreditation values decline
- Thermal accreditation shows sensitivity towards the fuel class's retirement and expansion
- Planning reserve requirements based on DLOL is smaller than legacy PRMR values

Drivers

- LOLE risk shifts toward risk periods when the availability of wind, solar and storage is low
- Adjustment needed to meet the LOLE targets increase, but the effects of lower accreditation (based on DLOL) outweigh its effects

Approach

- Sequential Monte-Carlo simulation using 14 weather years and 125 random outage samples
- Copper sheet; price-responsive storage modeling and economics included
- Seasonal LOLE criteria based on the risk distribution identified in the annual simulation

Figure 25: Summary of the 2024 RRA's Resource Adequacy Analysis (Insight 2)

Figure 26 forecasts how much DLOL-based resource class accredited capacity members and states will need to achieve their clean-energy goals in each season of the years 2030, 2033 and 2043. The chart also includes forecasted seasonal PRMR values that reflect the DLOL-based accreditation methodology.

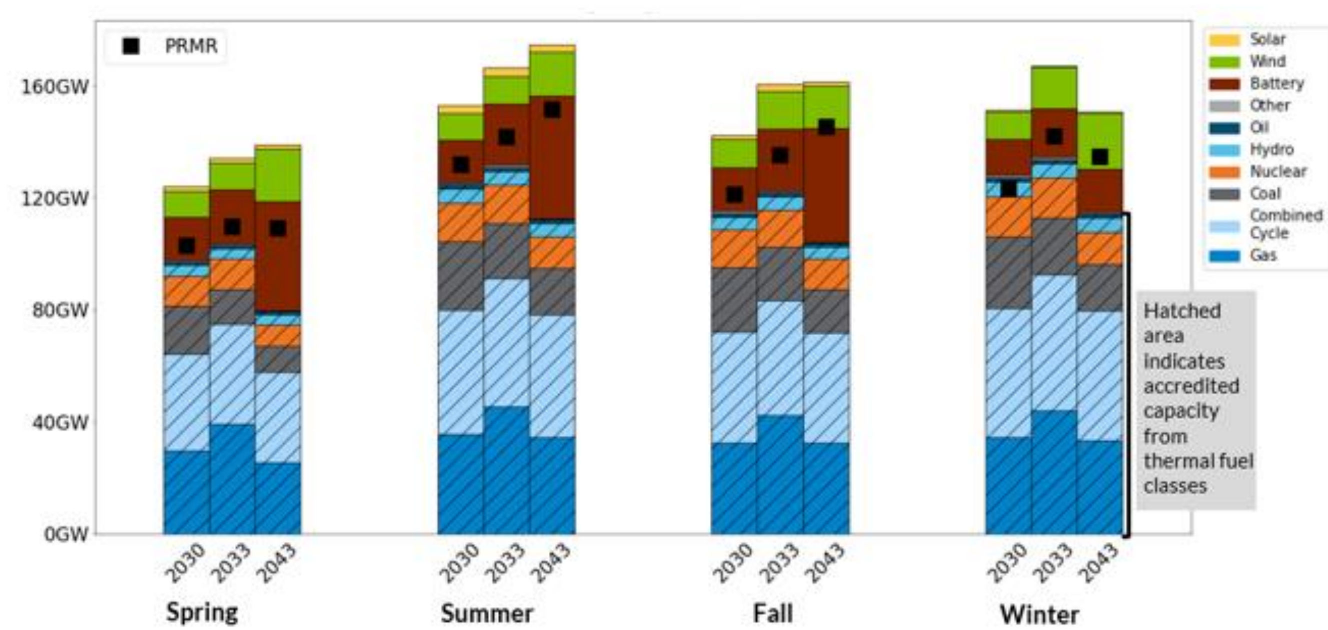


Figure 26: DLOL accredited capacity in 2030, 2033 and 2043

As Figure 26 shows, dispatchable thermal resources with high accreditation values, such as natural gas and coal, are forecast to provide a much larger fraction of the region's total needed accredited capacity compared to wind and solar, which have significantly lower accreditation values due to their weather-dependent nature and other factors. Battery storage is also projected to provide a significant portion of total accredited capacity.

Notably, RRA modeling also forecasts that low-accredited wind and solar will account for a full 62% of the region's installed capacity and 87% of the region's energy by 2043 (see Figure 22 on page 25 for more details). This illustrates how the many new wind and solar resources that members and states plan to build may yield large numbers in terms of installed capacity and energy, while simultaneously experiencing steep cuts in terms of accredited capacity.

Figure 27 below forecasts how seasonal DLOL-based accreditation values for different resource classes are expected to change over time as the region's resource mix continues to evolve to achieve member and state policy goals. These values are also presented in table form in the RRA Technical Appendix.

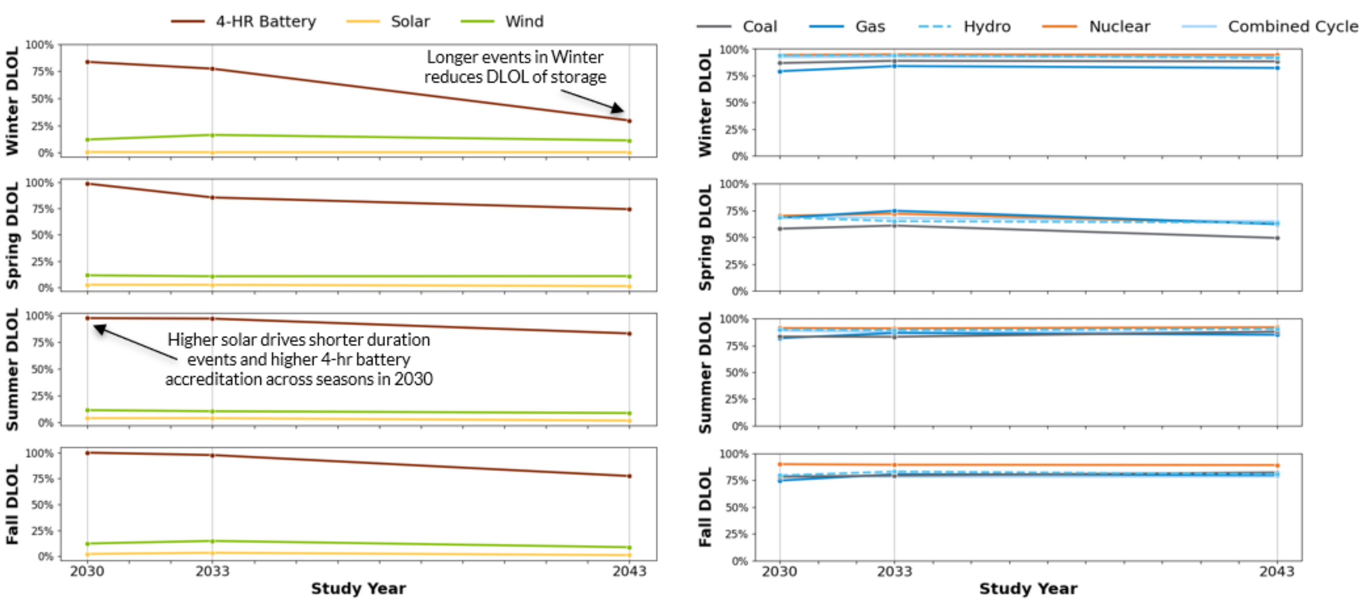


Figure 27: Change in resource class DLOL accredited value by study year

As Figure 27 indicates, solar and wind accreditation deviate little between 2030 and 2043. Wind accreditation in Winter generally sees a boost due to its consistent availability in all hours of the day, while other resource classes have difficulty showing up throughout longer-duration expected unserved energy (EUE) events. Battery accreditation is particularly impacted by the Winter seasonal trend of longer EUE events. Thermal accreditation in shoulder seasons (Spring and Fall) decreases as the RRA's study window goes forward due to the concentration of maintenance during these seasons.

Figure 28 below shows how seasonal DLOL-based accreditation values for solar, wind and 4-hour batteries may change as the ICAP levels of those resources increase.

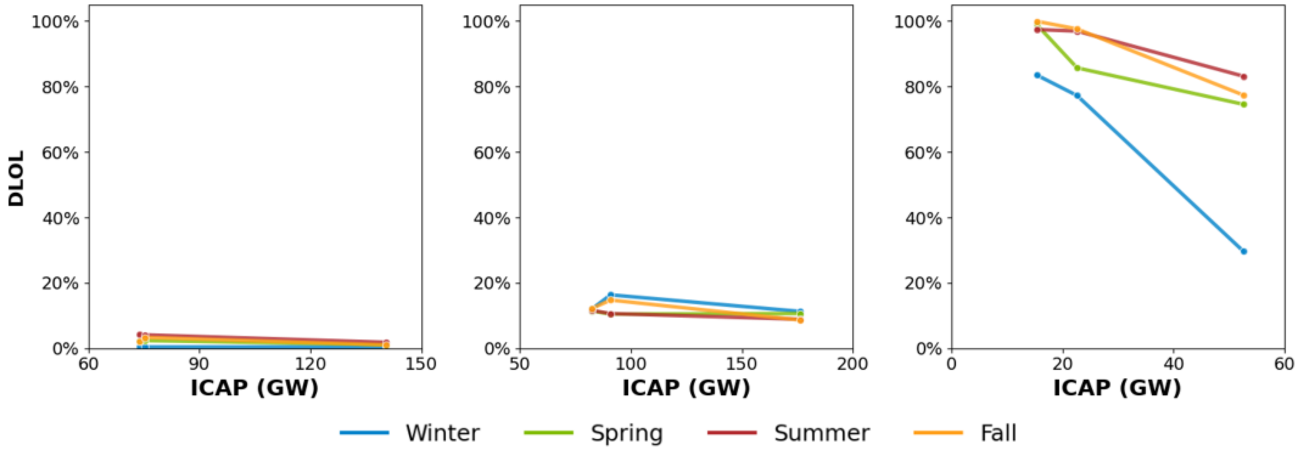


Figure 28: Change in DLOL-based accreditation values by installed capacity level of resource class

The changing resource mix is shifting the risk of loss-of load events to new hours of the day and seasons of the year. MISO's DLOL-based accreditation methodology is designed to accurately reflect how different types of resources contribute to system reliability during the new periods of highest risk.

Traditionally, the greatest risk of loss-of-load has been concentrated in summer afternoon hours, as the 2030 portion of Figure 29 below shows. But due to members and states increasingly replacing conventional resources with weather-dependent renewables to achieve their policy goals, along with other factors such as the electrification of the economy and more frequent and severe weather events, the risk of loss-of-load events is shifting outside of the traditional summer peak-load period.

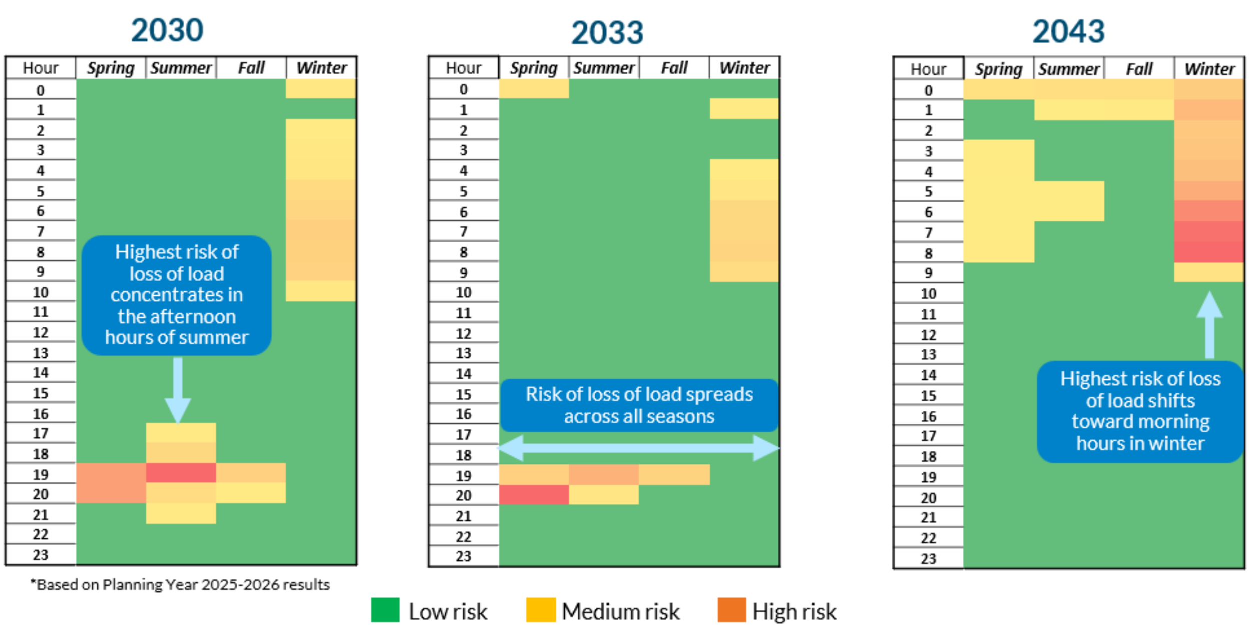


Figure 29: Projected shift in risk of loss of load between 2030 to 2043

By 2033, as Figure 29 shows, RRA modeling indicates that loss-of-load risks will spread across all four seasons of the year. By 2043, the greatest risk will be concentrated in the morning hours of the winter, when the availability of solar energy is particularly low in the MISO region.

Figure 30 below shows how the shifting risk of loss-of-load hours described above correlates with the forecasted growth of wind capacity in isolation, apart from other types of resources that members and states may build to achieve their policy objectives.

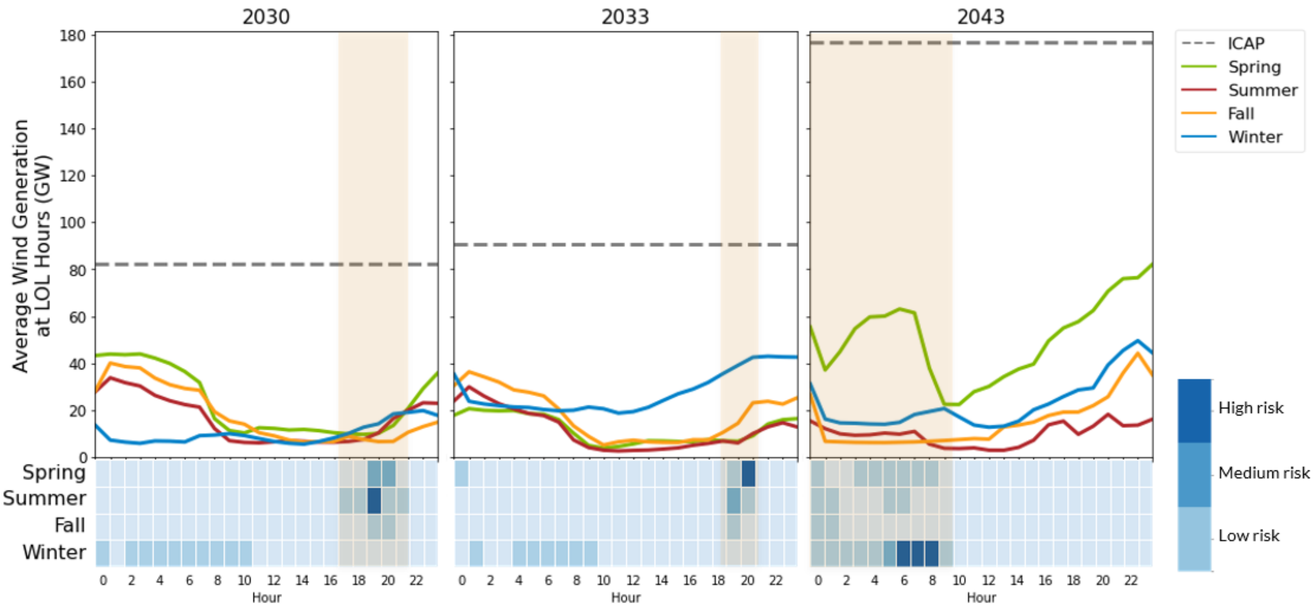


Figure 30: Correlation between increasing wind capacity and shifting risk of loss of load

In both 2030 and 2033, as Figure 30 indicates, the highest risk of loss of load will be concentrated largely (but not entirely) in evening hours of the Spring, Summer and Fall seasons. As the figure indicates, those highest-risk loss-of-load hours correlate to hours when average wind generation — as represented by the green, red and orange lines — is significantly below forecasted levels of total installed wind capacity (roughly 80 GW in 2030 and 90 GW in 2033, as represented by the grey dotted lines).

By 2043, as Figure 30 shows, RRA modeling forecasts that the region's total installed wind capacity will have increased dramatically, to roughly 180 GW. However, based on RRA modeling of past weather patterns and other factors, average hourly wind generation in 2043 will remain relatively flat in the Summer, Fall and Winter seasons compared to previous years, with only the Spring season showing significant increases. In other words, the dramatic increase in wind capacity by 2043 will make the region more reliant on wind as a resource, but the additional wind capacity will not necessarily result in more wind generation in all hours and seasons of the year. This phenomenon, along with other factors such as more frequent and severe winter weather events and the increasing use of electricity for home-heating purposes, is expected to shift the highest risk of loss of load to early morning hours of Winter by 2043, as Figure 30 indicates.

Figure 31 below shows how the forecasted growth of solar capacity correlates with the same shift in the risk of loss-of-load hours described above. As Figure 31 indicates, the highest-risk loss-of-load hours in 2030, 2033 and 2043 correlate with hours of the day and seasons of the year solar generation is either significantly reduced or not available at all.

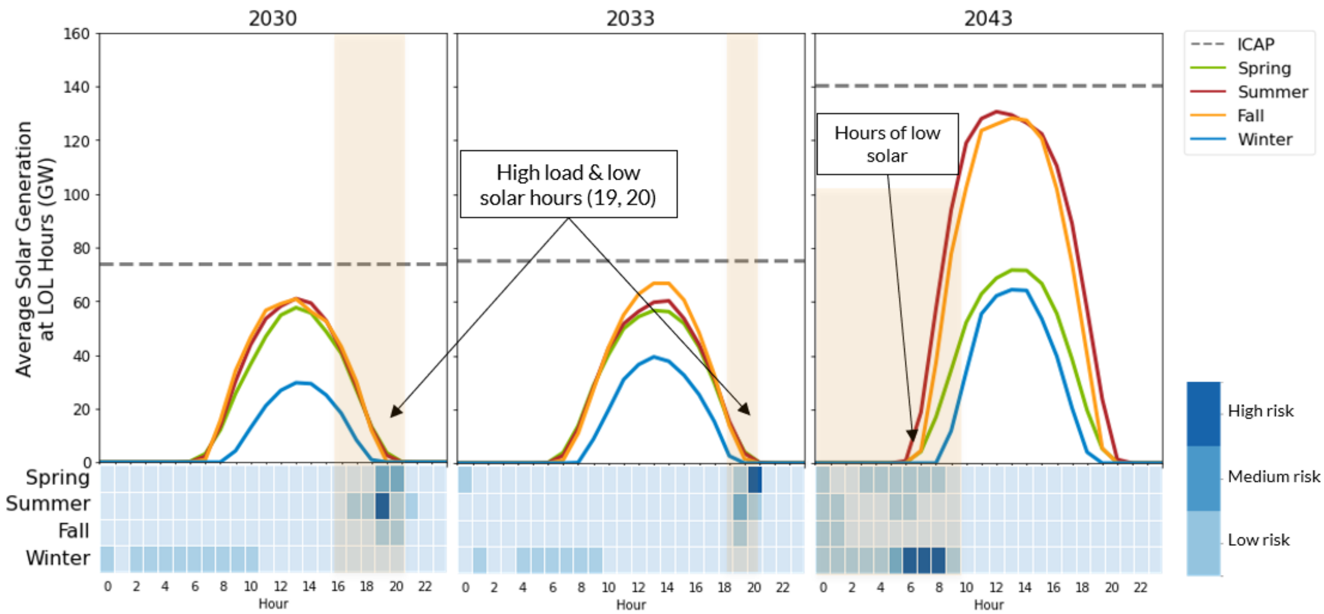


Figure 31: Correlation between increasing solar capacity and shifting risk of loss of load

Figure 32 below shows how the forecasted growth of 4-hour batteries correlates with the region's shifting risk of loss-of-load hours. In the figure, all portions of the colored lines above the "0" on the vertical axis represent batteries supplying energy to the grid, and all portions of the lines below the "0" represent batteries drawing energy from the grid to charge. For economic reasons, batteries generally try to charge when wholesale power prices are low and discharge when prices are high.

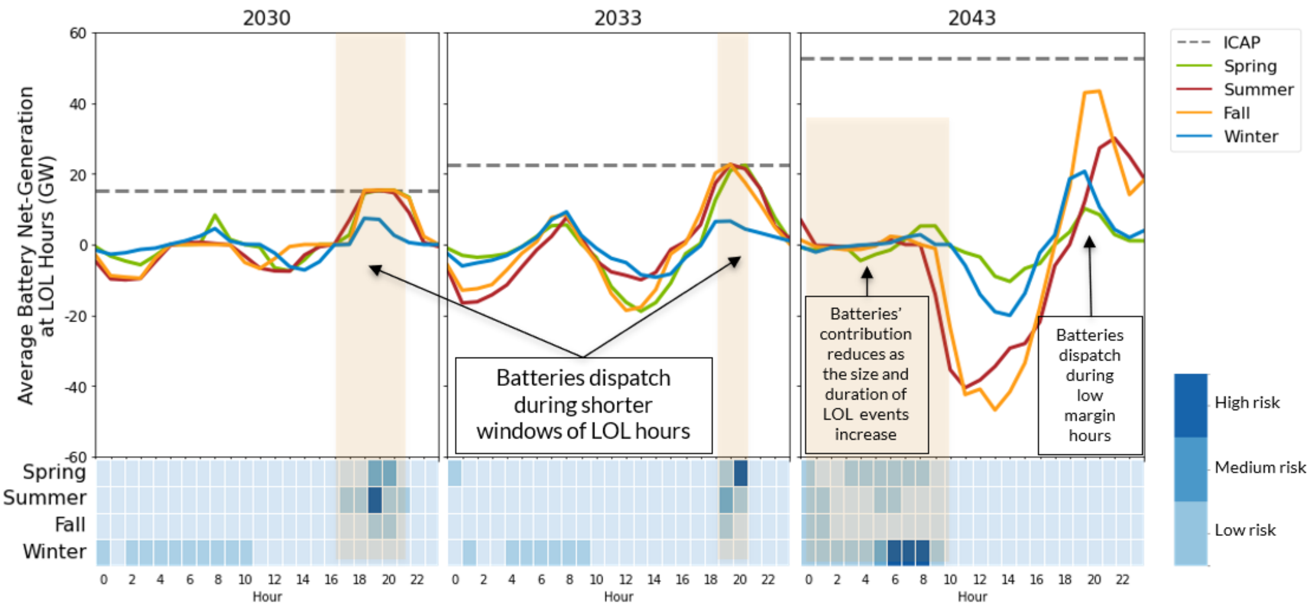


Figure 32: Correlation between increasing 4-hour battery capacity and shifting risk of loss of load

As the figure indicates, batteries will be well-suited to address the evening periods of highest risk in both 2030 and 2033, as those high-risk periods are not expected to exceed 4 hours. RRA modeling indicates that batteries will continue to be dispatched in evening hours of 2043 when reserve margins are relatively low and prices are relatively high. But by 2043, when the highest risk of loss-of-load shifts to winter mornings and grows longer in duration, the contributions that 4-hour batteries can make to grid reliability will be reduced relative to the contributions they made in 2030 and 2033, when the region's risk profile was different.

Flexibility Assessment

PURPOSE AND METHODOLOGY

The Flexibility Assessment evaluates how sources of expected variability and unforeseen uncertainty are increasing the operational complexity of the grid, expanding periods of system stress and driving a need for greater system flexibility, such as dispatchable fast-ramping resources. Historically, the largest contributors of variability and uncertainty in the MISO region have been outages, load, and net scheduled interchange (NSI), or energy flowing into and out of the region from neighboring grid systems. While these are still relevant, the region is now seeing new sources of variability and uncertainty, including:

- Increasing frequency and magnitude of system ramps, largely driven by increasing reliance on intermittent, weather-dependent resources
- Increasing volatility in load forecasts due to changing weather and demand patterns
- More volatile generator outages, particularly related to the aging of thermal units, extreme weather events and fuel supply challenges
- Greater uncertainty of available energy at low margin hours, particularly in winter/spring evenings, as the fleet becomes more weather-dependent

RRA analysis indicates these sources of increasing variability and uncertainty are driving a need for greater system flexibility, or the ability of the system to adapt to rapidly changing conditions.

FLEXIBILITY ASSESSMENT INSIGHTS

Greater reliance on solar power is shifting the net-load ramp from morning to evening and increasing the system's average 1-hour ramp need by 2-3 times by the early 2030s.

Results

Variability
- Hourly solar and wind variability may require rapid ramp response when misaligned with load changes
- The systemwide need for net load ramp increases in the future with 2043 having greater likelihood for extreme variability risks

Uncertainty
- Increased penetration of solar and wind adds forecasting complexity leading to greater uncertainty of renewable resource availability

Stressed Period
- Flexibility risks will spread out more across all seasons in the future, with increased number of stressed hours

Drivers

- High penetration of solar and wind drives ramping need from dispatchable resources especially during winter sunset hours
- Despite improvements in forecasting models, accurate solar/wind forecasts are difficult to achieve due to high variability in renewable output
- More operating hours in the future fall under high variability and high uncertainty range resulting in greater potential stressed hours

Approach

- Data analysis of historical and future load; wind and solar profiles at hourly granularity
- Net load calculated as the difference between gross load and wind & solar.
- Future 'forecast' of load, wind and solar assumed certain percentage of modeling improvements driven by potential technology enhancements
- Hours that exceed 95th percentile of net load uncertainty and 98th percentile of net load variability flagged as potential stressed hours

Figure 33: Summary of the 2024 RRA's Flexibility Analysis (Insight 3)

As noted above, the electric system's increasing reliance on intermittent, weather-dependent resources is emerging as a major source of variability and uncertainty in the MISO region. As Figure 34 shows, RRA analysis indicates that if MISO members and states achieve their policy objectives, about 22% of the region's annual energy could come from solar by 2033, increasing to about 32% by 2043. When wind is added in, the region could see 58% of its annual energy generated by weather-dependent renewables by 2033, increasing to 87% by 2043.

Figure 35 below illustrates how this increasing reliance on wind and solar is expected to change the region's net load profile, which refers to total system load minus generation provided by wind and solar.

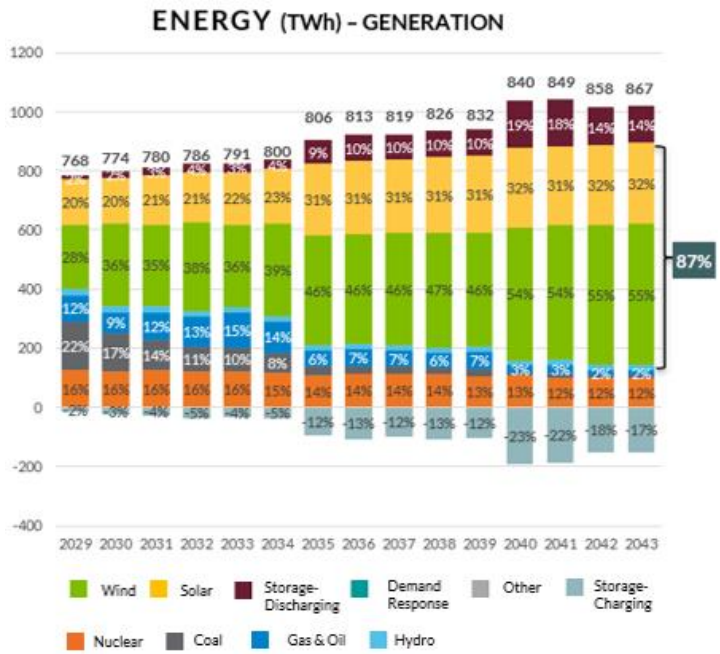


Figure 33: Projected energy values by resource type based on member and state resource plans and policy objectives

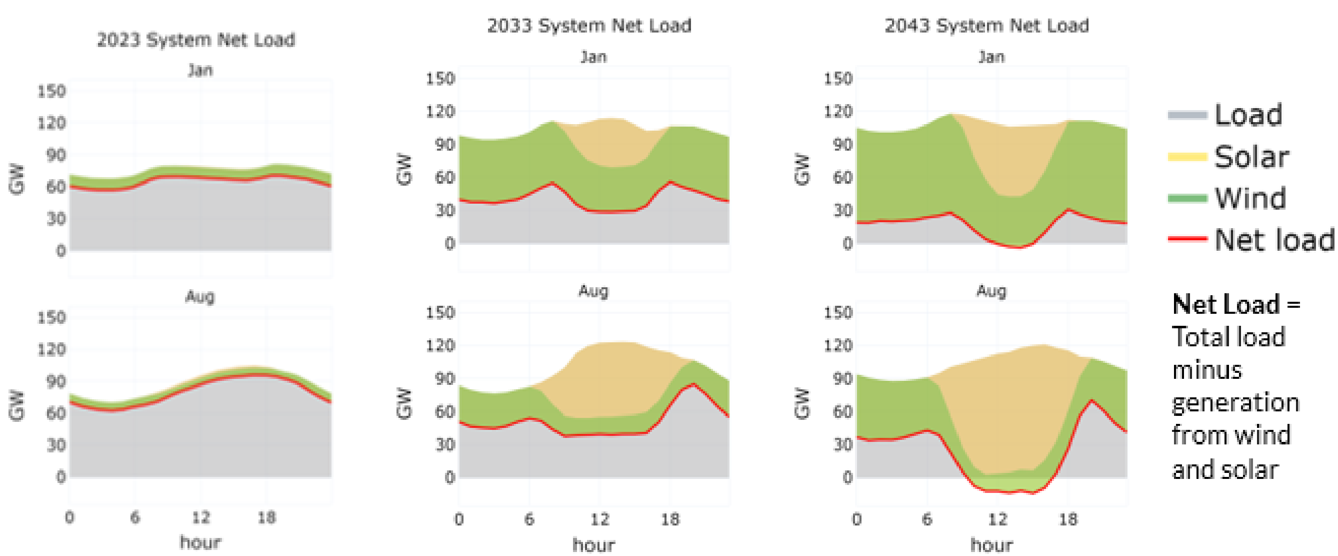


Figure 35: Changes in net load patterns by study year

Historically, the region has had two diurnal (daily) net load peaks in winter months. The first occurs in the morning as people wake up, followed by a midday dip in demand, with load increasing again in the evening. In summer months, the region has historically seen a single daily net load peak in late afternoon hours. As reliance on solar and wind increases, RRA modeling indicates the region's net load profile will morph into a "duck curve" shape. The term duck curve, which is well-known in the industry, features a prominent drop in net load in midday due to high solar production. RRA modeling even indicates the region could experience negative net load by 2043, meaning generation would exceed demand due to high solar production in the late morning/early afternoon hours. Then, as the sun sets, solar goes offline just as demand is rapidly increasing as people get home from work, resulting in the sharply upward-sloping "neck" part of the duck curve.

VARIABILITY

Figures 36a and 36b below show how the variability of solar and wind resources can be either desirable or undesirable from a system operations perspective, depending on whether the variability aligns with rapid load increases.

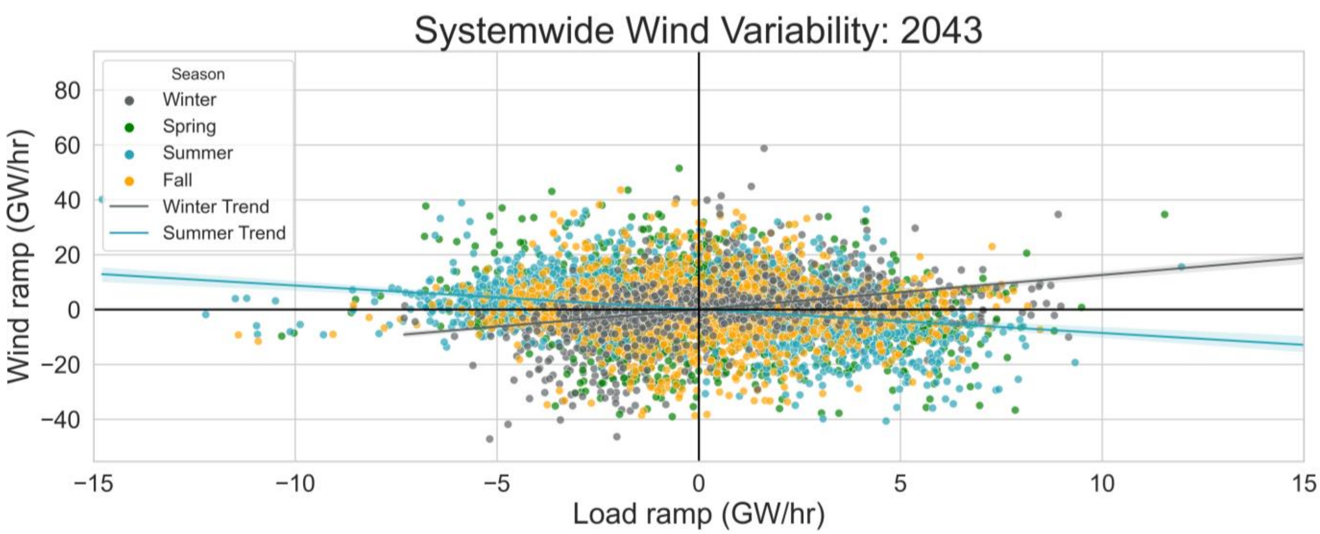


Figure 36a: Systemwide wind variability

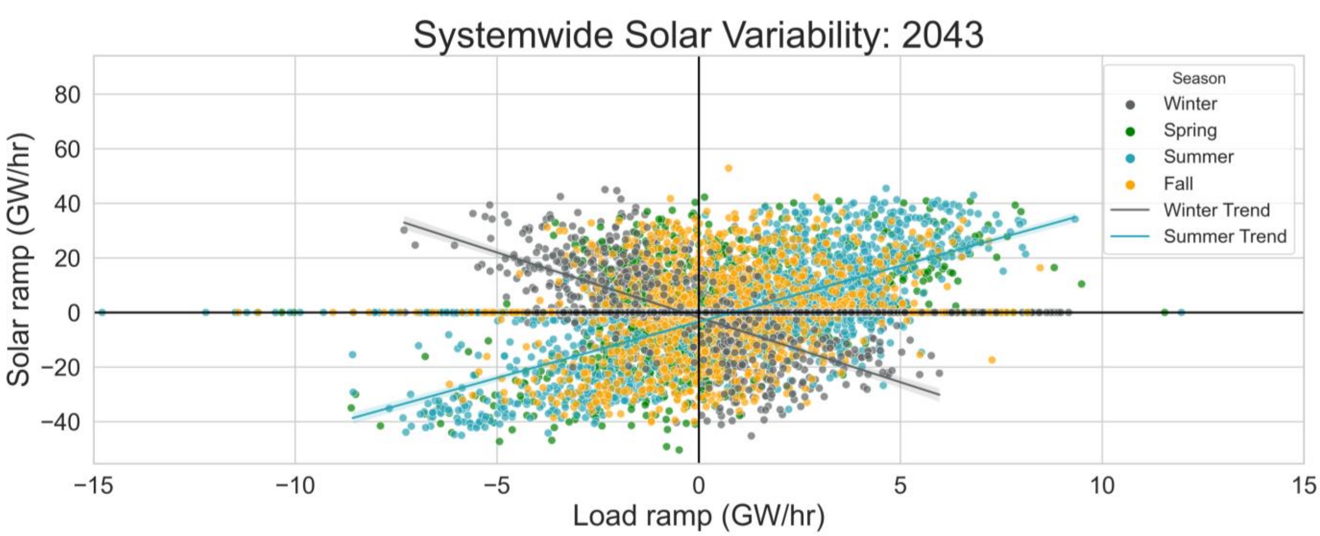


Figure 36b: Systemwide solar variability

The first and third quadrants of both figures illustrate instances in 2043 when variability in wind and solar generation <u>help</u> meet changes in load. More specifically, the first and the third quadrants show wind and solar generation ramping up or down in the same direction as the load ramps. The second quadrants show load decreasing and wind and solar generation increasing, which could be managed by curtailing excess renewable generation. By contrast, the fourth quadrants of both figures illustrate instances when wind and solar generation are decreasing at the same time load is increasing. These are the instances where the system would need additional fast-ramping dispatchable resources for reliability purposes.

The figures also illustrate the seasonal variability of solar ramp having stronger correlation with load ramp. The winter trend in Figure 36b illustrates that due to reduced solar generation, especially in the winter evening hours, the system requires a high ramping need to meet the loads peaking at sunset hours. Markers that lie on the horizontal axis in Figure 36b represent hours at night where the solar ramping is essentially zero.

Besides the 2043 plots above, the results indicate that in 2030, the maximum hourly solar ramp can be as high as 23 GW/hr., and the wind ramp can be up to 22 GW/hr. The maximum hourly solar ramp in 2033 can increase up to 27 GW/hr., and the wind ramp can be up to 30 GW/hr.

Figure 37 below forecasts how future net load ramps of three different durations — 1 hour, 2 hours and 4 hours — may vary in magnitude depending on the variability of wind and solar generation. The box plots show that the inter-quartile range (IQR), i.e., the height of the box of hourly net load ramps, consistently broadens across multiple durations, indicating more data dispersion. The box plots also show that the number of outliers may increase significantly, representing increased instances of rapid net load change. The system net load ramp data for 2043 shows a slight anomaly in terms of IQR range and has negatively skewed ramp distributions, which could be the case because the 2043 data indicate slightly more than 1,200 hours of negative net load.

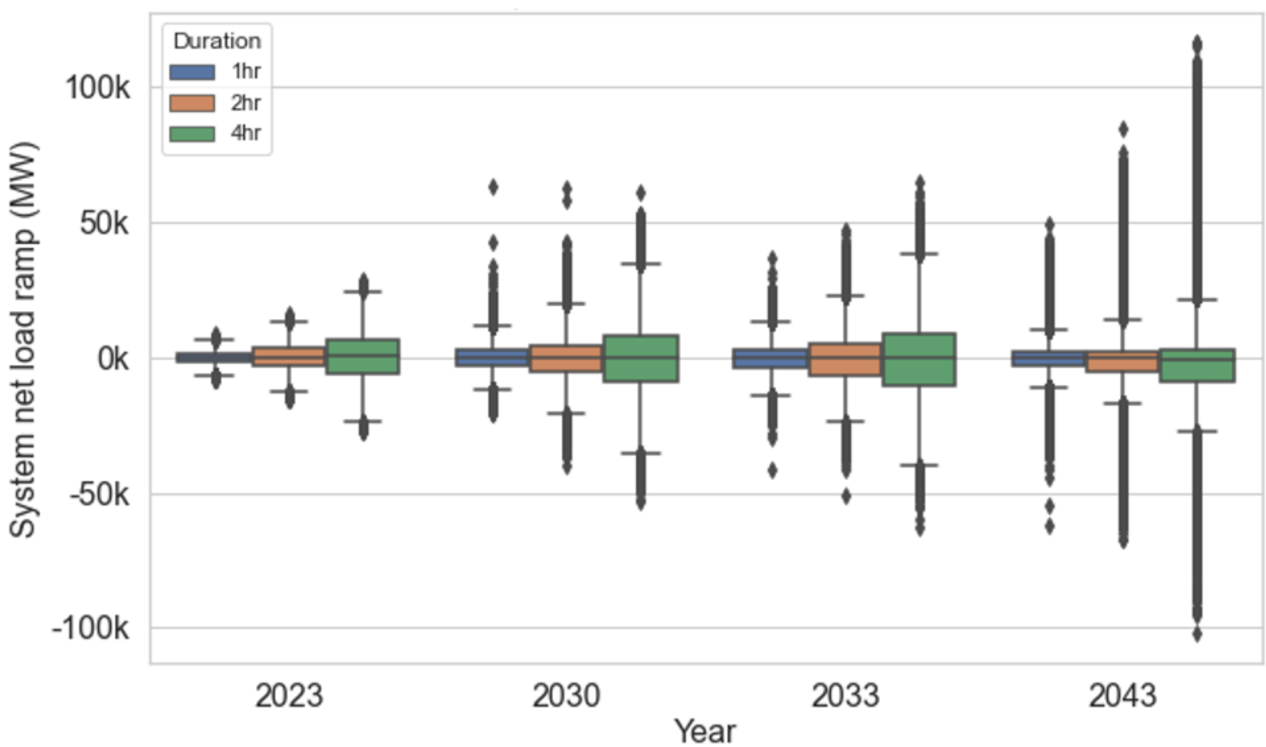


Figure 37: Net load ramp distributions for various durations

Figure 38 illustrates the probability density function (PDF) of 1-hour net load ramp for all the study years. PDF is a mathematical function that describes the likelihood of a continuous random variable falling within a specific range of values.

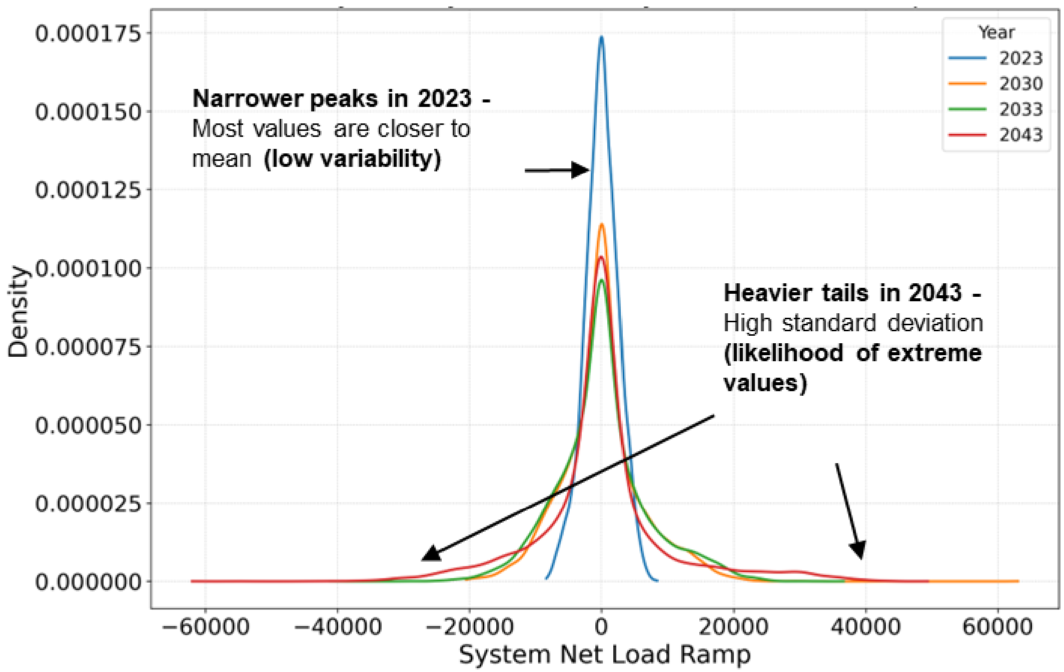


Figure 38: Probability density function of system net load ramp: 1 hr.

The 2043 curve shows a slightly narrower base just before the peak compared to 2030 and 2033, indicating that the data points are more concentrated around the mean. However, 2043 also has significantly heavier tails, highlighting a greater likelihood of extreme outliers. This suggests that while typical values are closer to the average in 2043, the occurrence of extreme ramping events is more

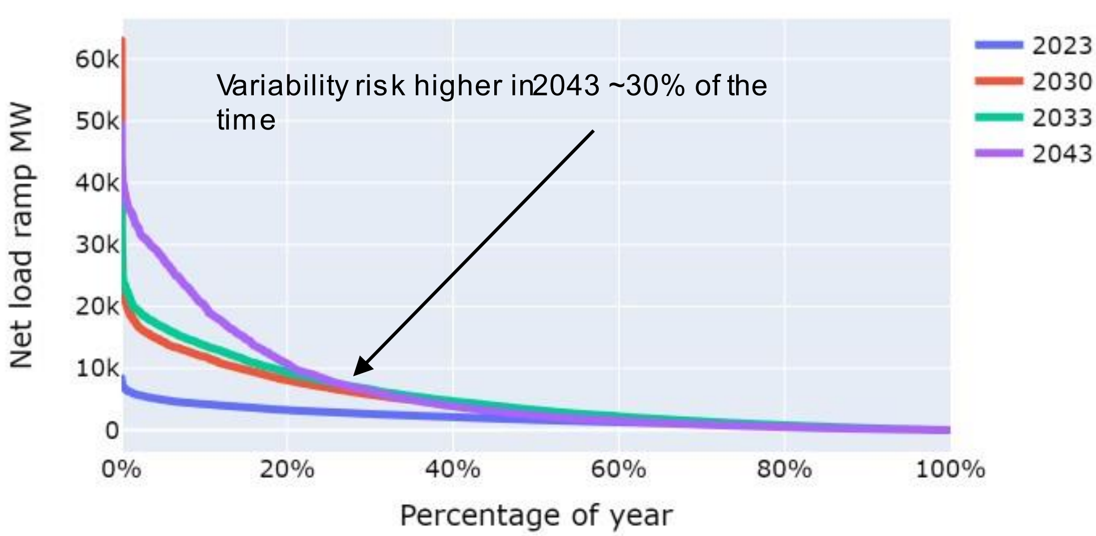


Figure 39: RT system net load ramp up curve: 1hr.

pronounced. As a result, Figure 39 highlights the increased variability risk in 2043, where approximately 30% of the time, the net load "up-ramp" capability may exceed that of the other study years.

Figure 40 below indicates that by 2033, the region will need three times more up-ramp capability compared to 2023, increasing to six times more by 2043. RRA modeling also indicates that increasing reliance on solar will shift the region's daily net load peak to post-sunset hours later in the day, and will also increase the total number of stressed hours on the system.

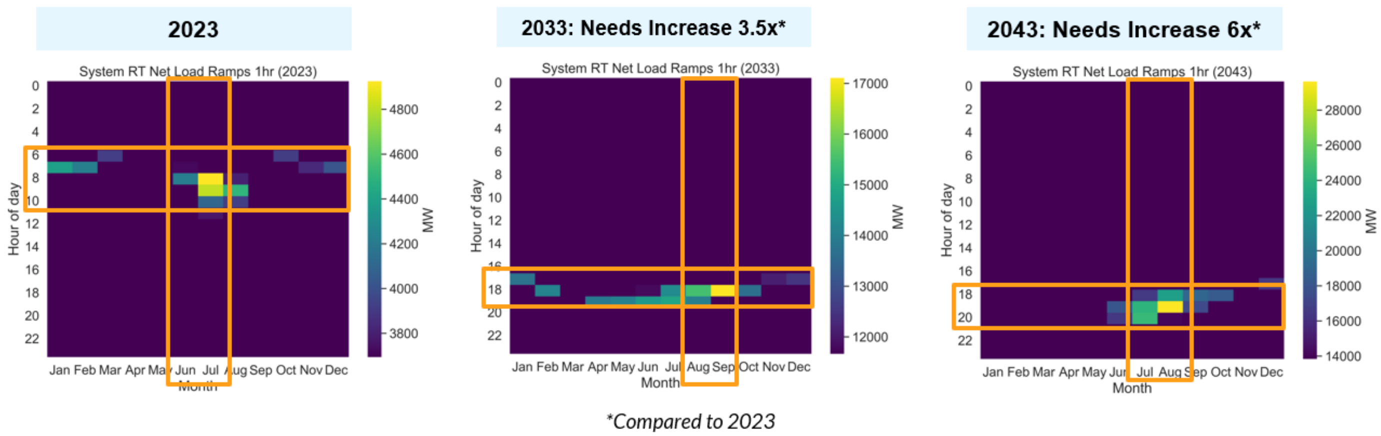


Figure 40: Highest 10th percentile of 1-hour net load ramps

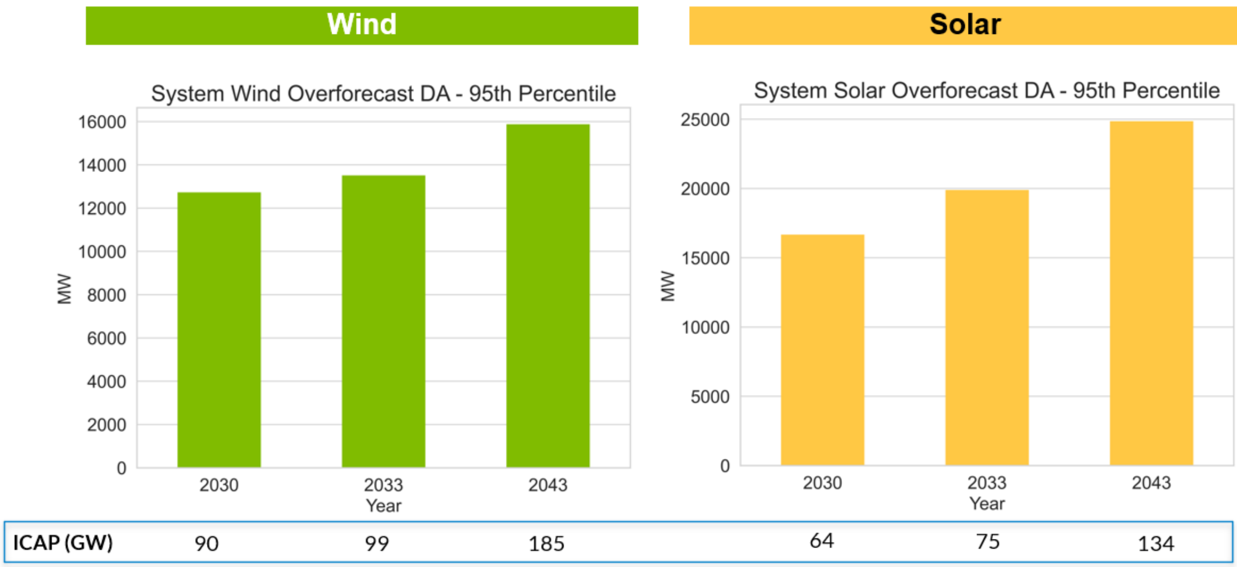
UNCERTAINTY

While sources of variability such as fluctuating wind and solar generation pose challenges for power systems because their outcomes cannot always be accurately predicted, these challenges are at least anticipated and expected. By contrast, challenges in the realm of uncertainty can manifest in unanticipated and unexpected ways.

One such uncertainty challenge that will become more difficult going forward is developing accurate day-ahead forecasts of how much wind and solar generation will be available the following day. Such day-ahead forecasts are critical so MISO can determine how much generation from other types of dispatchable resources it must commit to reliably serve load in the least-cost manner.

For this year's RRA, MISO generated the day ahead forecast of future wind and solar by scaling the total percentage errors calculated for 2027 from last year's System Attributes work.[7] MISO assumed its methodology for forecasting day-ahead renewable generation will improve by 5% in 2030 and 2033 and by 30% in 2043. But despite those assumed improvements, RRA analysis indicates that conducting day-ahead wind and solar forecasts will become increasingly complex and fraught with uncertainty as the region grows increasingly reliant on wind and solar, as shown in Figure 41.

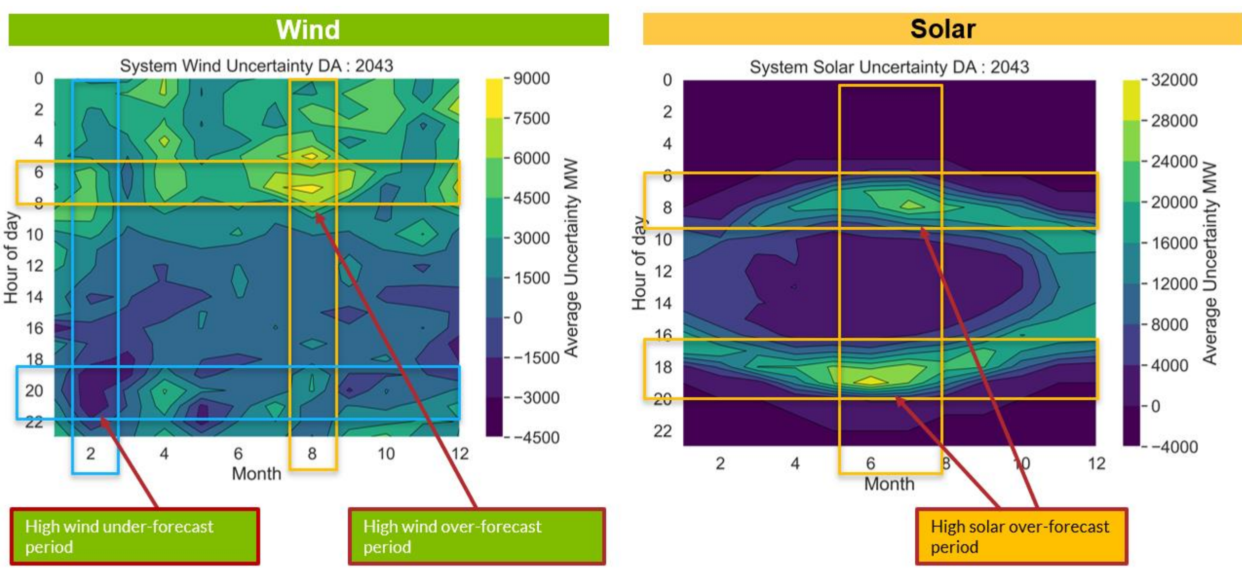
[7] System Reliability Attributes Workshop Presentation



DA = Day ahead. Over forecast DA = DA – RT. ICAP = Installed Capacity. Uncertainty calculation assumes 5% improvement in forecasting models in 2030/33 and 30% improvement by 2043 compared to 2027 Attributes model. Future ICAPs are from the first iteration expansion.

Figure 41: Magnitude of wind and solar overforecasts by study year

Figure 42 shows the hours of the day and the seasons of the year when forecasting errors for wind and solar are most likely to occur.



DA: day ahead. Over forecast DA = DA forecast – RT

Figure 42: Most likely hours of the day and months of the year for wind and solar overforecasts

As Figure 42 indicates, the largest over-forecasting errors for wind are most likely to occur during summer morning hours, while the largest over-forecasts for solar primarily occur during summer sunrise and sunset hours. Under-forecasting errors for wind are most likely to occur in afternoon to midnight hours, with the largest occurring around midnight of winter months.

Figures 43a and 43b represent a combined view of risks associated with both variability and uncertainty. In Figure 43a, hours marked in red exceed the 95th percentile of net load variability and the 98th percentile of day-ahead net load uncertainty. Hours that meet both of those criteria are called "system-stressed" hours. As the scatter plots indicate, system-stressed hours are expected to spread across all seasons in 2033, but with the largest number in the summer. Figure 43b looks backwards to show system-stressed hours in 2023, as well as forward to show forecasted system-stressed hours in 2030, 2033 and 2043. As Figure 43b indicates, total system-stressed hours are expected to increase going forward.

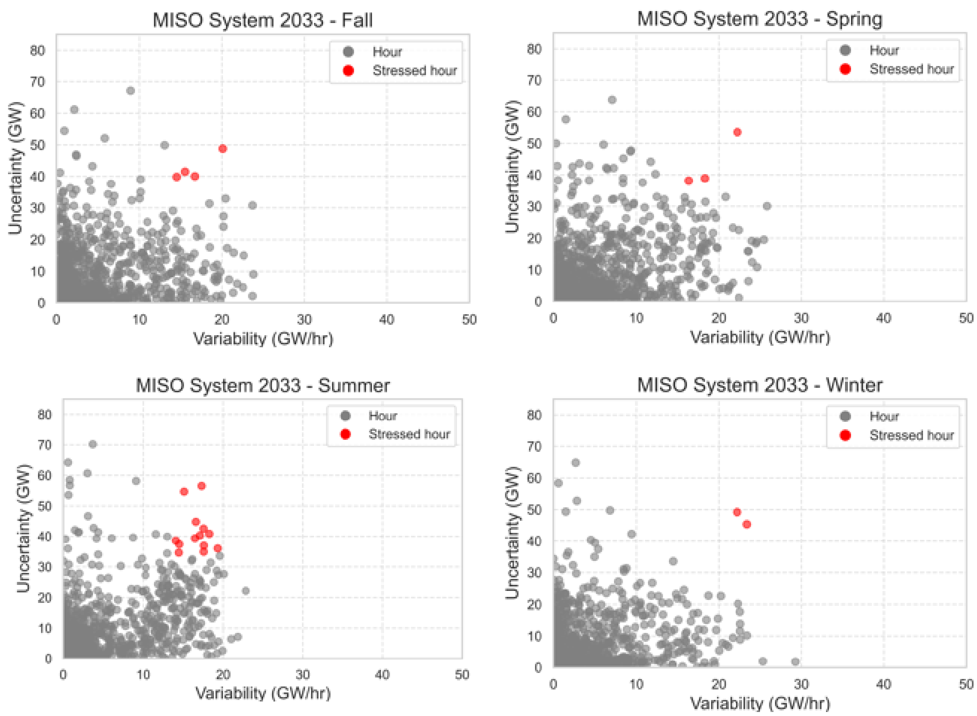


Figure 44a: Hours marked in red in the scatter plots exceed 95th percentile of net load variability (1 hr. ramp) and 98th percentile of day-ahead net load uncertainty

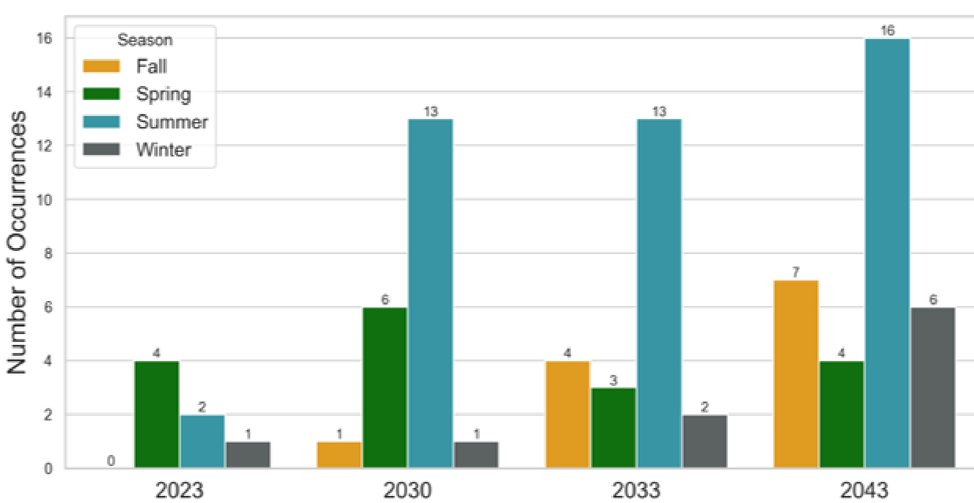


Figure 43b: System-stressed hours by study year and season