Reaching a Zero CO_2 Emission Electric Sector: Technology Opportunities and System Impacts

A scenario-based analysis of Minnesota's electric sector through 2050

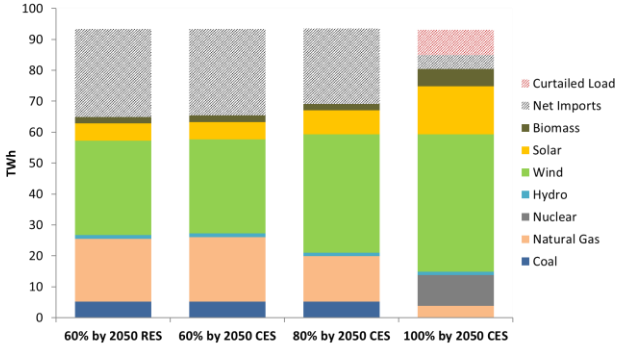
Key Insights

- **Minnesota can repower and expand in-state wind, expand solar, and extend other existing zero-CO_2 generation operations,** to cost-effectively meet stringent clean energy standards (CES) and reduce CO_2 emissions from its electric sector.
- **Achieving a 100% CES by 2050** in the presence of strict in-state physical or policy-induced technology constraints could be very costly—in a scenario with no option for fossil to contribute to MN's reserve needs; deployment limits to MN wind (10GW) and solar (6GW) capacity; and no available in-state CCS, hydrogen, energy storage, or other new zero-CO_2 generation resources, load for nearly half the year cannot fully be met with modeled existing and future technologies at less than $50,000/MWh.
- **Approximately 6 GW of battery energy storage** could help Minnesota more cost-effectively comply with 2050 clean energy standards—including a 100% CES; however, storage does not fully displace fossil resources in any scenario.
- **Minnesota renewable energy deployment is similar** under traditional renewable energy standards and potential technology-neutral clean energy standards of equivalent moderate stringency
- **Income opportunities across all zero-CO_2 generation resources in Minnesota are higher under stringent clean energy standards** than under a moderate renewable energy standard; the opposite holds for the state's fossil resources.

This research uses the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to explore a range of future policy scenarios for reducing CO_2 emissions from Minnesota's electric sector. US-REGEN is a long time-horizon generation capacity expansion planning and economic dispatch model with regional aggregation within the United States; it is a model used to study the evolution of the electric sector under a wide range of policy, technology, and market scenarios. For this study, scenarios are designed to represent a series of increasingly stringent clean energy standard (CES) policies toward meeting 100% of Minnesota's electric load by 2050 from carbon-free generation resources. The analysis compares generating fleet evolutions, regional electricity trade, policy compliance choices, technology costs and generation capacity income streams, the potential role for energy storage, and other electric system impacts across the scenarios between 2020 and 2050.

Scenario	*Description*
Reference 60% RES	MN adopts a 60% by 2050 Renewable Energy Standard
60% by 2050 CES	MN adopts a Clean Energy Standard (CES) that meets 60% of MN load using carbon-free resources by 2050
80% by 2050 CES	MN adopts a CES that meets 80% of MN load using carbon-free resources by 2050
100% by 2050 CES	MN adopts a CES that meets 100% of MN load using carbon-free resources *and* eliminates the option for fossil to contribute capacity towards MN's reserve margin by 2050

Notes: For all scenarios: (1) the rest of the country proceeds with business as usual policies; (2) purchased (electrically-connected) out-of-state renewable- and/or zero-emission-based electricity can be used for policy compliance; (3) new coal, new nuclear, and hydrogen-based generation is not considered for MN; (4) CCS technologies are assumed to be unavailable within MN due to relatively poor geologic storage opportunities; and (5) MN wind and solar capacity is capped at 10GW and 6GW, respectively, to reflect potential siting and permitting limits.



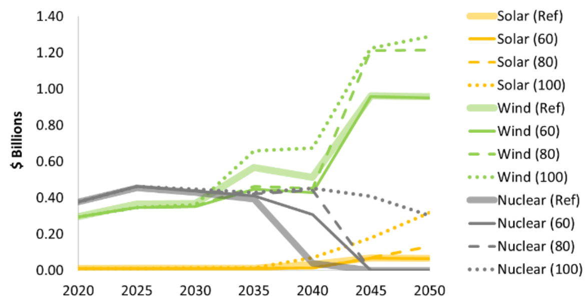
Minnesota Electricity Generation and Net Imports by Scenario (2050)

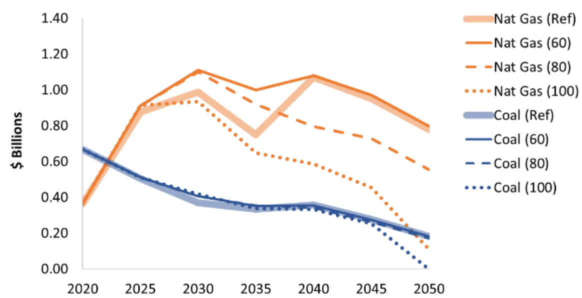
Results suggest that under moderate policy stringency (60% by 2050), when transitioning from a renewable energy standard (RES) to a technology-neutral clean energy standard (CES) that qualifies additional non-renewable carbon-free generation resources for compliance, wind (and solar) continue to be favored among the least-cost set of resources to meet load and policy requirements. This is observed in the similarity between the first two bars in the chart above. Additionally, results show that more stringent CES policies can incentivize significant additional in-state wind and solar deployment, as well as gas retirement, when compared to more moderate standards. Under an 80% and 100% CES, Minnesota installs approximately 20% and 60% more wind, and 80% and 480% more solar, respectively, on a capacity basis. Note, however, that while the study represents inter-regional transmission and a standard cost for renewable energy interconnection, it considers neither *intra*-regional transmission constraints nor other state-specific interconnection challenges with deployment levels of this magnitude.

Under a 100% CES, the state's existing nuclear also extends into 2050, when fossil capacity is assumed as no longer viable to provide reserve margin capacity in this scenario. These scenario-based zero-carbon generation technology opportunities are further illustrated through their respective income potentials in the right-hand charts. For example, wind (and solar) witness income growth over time as their capacities increase, but also at a faster rate as policy stringency increases, while the opposite generally holds true for fossil.

Overall net renewable power purchases (mostly from the Dakotas) are tracked in the analysis and continue to be a significant and cost-effective source of policy compliance, although the magnitude of imports decrease with increasing policy stringency as Minnesota installs additional in-state zero-emitting resources to meet its capacity needs. Additionally, under the applied modeling assumptions, achieving a 100% CES requires significant additional investment in non-specific load-reducing technologies, transmission, and/or new non-emitting generation resources to simply meet load and other minimum system needs. Under the 100% CES scenario, the analysis indicates approximately 2 GW of load for 3900 hours—nearly half the year—in 2050 that could not be served with modeled existing and future technologies at less than $50,000/MWh.

Finally, modeling results indicated that deployment of approximately 6 GW of 2-3 hour battery storage (by 2050) may support optimal expansion of Minnesota's renewables fleet, and facilitate cost-effective policy compliance by substituting for a portion of the gas-fired fleet and mitigating potentially expensive load curtailments under a 100% CES policy.





Generation Technology Income Streams by Scenario

Notes: Income streams shown are the sum of energy, capacity, and policy compliance instrument (REC or 'zero-CO_2' energy credit) incomes.

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