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Long-Run Marginal CO_2e Emission Rates for End-Use Electricity Consumption in the State of Washington

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Context

This presentation contains estimates of long-run marginal emission rates for the electric sector in the state of Washington, based on prospective power sector scenarios generated with NREL's capacity expansion model, ReEDS.

This work was performed as part of the Cambium project, which is being conducted by the National Renewable Energy Laboratory (NREL). The purpose of the Cambium project is to use NREL's electric-sector models to develop and make public metrics that are useful for long-term power-sector planning. Initial data was publicly released in November of 2020 (cambium.nrel.gov), with plans to update and re-release the data annually. Subsequent work has included engagement with a wide variety of power sector stakeholders to identify how these data can be used in planning and identify additional metrics that could be useful in future data releases. This presentation documents a case study that explores how one of the metrics developed in the public Cambium data set can be used to inform a specific planning decision.

The analysis was performed within the context of the Washington State Building Code Council's update of the Commercial Washington State Energy Code, based on the best information the analysts had available and within timing constraints. The scope of technical assistance does not include specific legal or advisory support on the energy code itself, and does not constitute a comprehensive analysis of the decisions that this emission rate may be applied to, which may involve other considerations beyond the technical analysis described here.

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Method

Definition of a Long-run Marginal Emission Rate

This analysis estimates the *long-run marginal CO_2e emission rate* for electricity Washington. The long-run marginal emission rate is an estimate of the rate of emissions that would be either induced or avoided by a long-term (i.e., more than several years) change in electrical demand (Hawkes 2014).

The long-run marginal rate explicitly takes into account both the underlying evolution of the electric grid, as well as the potential for an incremental change in electrical demand to influence the structural evolution of the grid (i.e., the building and retiring of capital assets, such as generators and transmission lines). It is therefore distinct from the more-commonly-known short-run marginal, which also identifies the marginal generator but treats the grid assets as fixed (Azevedo et al. 2020).

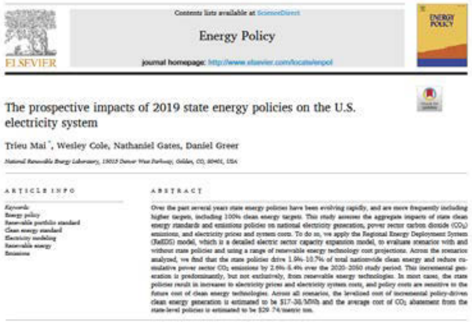
The long-run marginal emission rate has been projected as typically lower then the short-run marginal emission rate, for the contiguous United States (Gagnon et al. 2020). This is because, when the potential for structural change is neglected (i.e., the short-run), the marginal generators are predominately natural gas and coal generators, whereas when structural changes are included (i.e., the long-run) the mixture often includes a greater contribution from wind and solar generators, resulting in a lower emission rate.

The Regional Energy Deployment System (ReEDS)

This analysis was performed using the Regional Energy Deployment System model (ReEDS), a publicly available capacity expansion model developed by NREL (Brown et al. 2020).

ReEDS is built to project the evolution of electric sector in the contiguous United States. Given a set of assumptions about the future market conditions, including fuel and technology costs, ReEDS solves a linear program to find the investment and operational decisions that minimize the overall cost of the electric system, subject to policy and operational constraints.

The ReEDS model heritage traces back to NREL's Wind Deployment System (WindDS) model, which was developed in 2001 to examine the potential for long-term wind energy deployment in the United States (Short et al. 2003). The model has been under continuous use and development since then, being used for large-scale studies such as the *Renewable Electricity Futures Study* (NREL 2012) and the *Electrification Futures Study* (Murphy et al. 2021), as well as numerous more focused studies, such as *The Prospective Impacts of 2019 State Energy Policies on the U.S. Electricity System* (Mai et al. 2021).



Approach to Calculating the Long-run Marginal Emission Rate (LRMER)

The approach described in *Long-run Marginal CO_2 Emissions Factors in National Electricity Systems* (Hawkes 2014) was used for this analysis.

A LRMER was calculated for ten different scenarios, which varied in their assumptions about the future (slide 9). For each scenario, these steps were followed:

1. A baseline run of the ReEDS model was performed, projecting the evolution and operation of the electric grid in the Western Interconnection from present day through 2050.
2. Six additional runs were performed (the "perturbation runs"), where the end-use load in the State of Washington was increased by 5%, 6%, 7%, 8%, 9%, and 10% (relative to the end-use load in 2024), starting in 2024 and persisting through 2050.
3. Because the only difference between the baseline and perturbation runs was the increase in load in Washington, any change in emissions was attributable that load. Given this, we determined the difference in total CO_2e emissions across the Western Interconnection from 2024 through 2043 (i.e., 20 years) between the baseline and each of the perturbation runs and divided that increase by the change in load to arrive at a CO_2e rate for each of the six perturbations.
4. The six CO_2e rates for each of the perturbation runs were then averaged together, and the result was taken as the estimate long-run marginal emission rate for a change in end-use electrical demand under that scenario.

Crucially, this method captures the total effect of the change in load across the Western Interconnection – i.e., it captures the potential for policy leakage related to the Clean Energy Transformation Act (CETA). As an example, if Washington is induced to consume more hydropower, and as a result exports less hydropower to neighboring states, it is possible that the neighboring states (not being subject to CETA) may choose to increase the utilization of their coal and natural gas generators, to make up for the reduction in hydropower. In this manner, an increase in load in Washington can result in an increase in emissions, even if the electricity being purchased by the utilities serving Washington is entirely clean. Almost all of the emitting generation sources shown in the results of this analysis are a result of this type of policy leakage.

This method produces a long-run marginal CO_2e emission rate for electricity consumed in the state of Washington. The estimate is made for an electric load introduced in 2024 and evaluated over a 20-year horizon.

The CO_2e rate reported in this analysis only includes emissions from direct combustion. It does not include upstream emissions from the fuel cycle, or the emissions associated with commissioning and decommissioning capital assets.

Caveats and Limitations

The ReEDS model is, necessarily, a simplification of reality and produces results about an inherently uncertain future. The following are some of the major caveats that are helpful to keep in mind when interpreting the results.

- ReEDS is a system-wide, least-cost optimization model. Therefore, it generally produces results that are more optimistic about coordination (both inter- and intra-regional) then what is typically observed in reality, where market friction and information deficits exist.
- ReEDS represents the contiguous United States as 134 modeled Balancing Areas. While these BAs are selected to reflect the physical reality of the electric sector, this level of aggregation obscures some intra-BA constraints such as transmission limits.
- The scenarios examined here do not represent the full possible range of future scenarios.
- While ReEDS is annually updated to reflect announced builds or retirements of generators, it is likely that the list is incomplete. Additionally, only announced retirements are prescribed in the model -- all other retirements are made on an endogenous, economic basis.
- The global energy economy and adjacent sectors, including electricity demand from the adjacent sectors, are represented as exogenous inputs into ReEDS.

Scenario Descriptions

Scenarios

In order to characterize how the LRMER could vary under different futures, a range of scenarios were modeled that varied in their assumptions about three important parameters: the price of natural gas, the cost of renewable energy technologies, and the demand for clean energy beyond currently-enacted legislation. Three natural gas price trajectories were used, three renewable energy cost trajectories, and two trajectories for clean energy demand, for a total of ten scenarios. As described on slide 6, each scenario was analyzed by performing a baseline run and six perturbation runs.

Scenario Name	Natural Gas Prices	Renewable Energy Costs	Increase in Clean Energy Demand
Reference, Increasing CED	AEO Reference	ATB Moderate	Increasing
High NG Prices, Increasing CED	AEO Low Oil and Gas Supply	ATB Moderate	Increasing
Low NG Prices, Increasing CED	AEO High Oil and Gas Supply	ATB Moderate	Increasing
Low RE Costs, Increasing CED	AEO Reference	ATB Advanced	Increasing
High RE Costs, Increasing CED	AEO Reference	ATB Conservative	Increasing
Reference, Conservative CED	AEO Reference	ATB Moderate	Conservative
High NG Prices, Conservative CED	AEO Low Oil and Gas Supply	ATB Moderate	Conservative
Low NG Prices, Conservative CED	AEO High Oil and Gas Supply	ATB Moderate	Conservative
Low RE Costs, Conservative CED	AEO Reference	ATB Advanced	Conservative
High RE Costs, Conservative CED	AEO Reference	ATB Conservative	Conservative

NG = natural gas; RE = renewable energy; CED = clean energy demand
AEO = annual energy outlook (EIA 2020a); ATB = annual technology baseline (NREL 2020)

Assumptions

Natural Gas Prices: Drawn from the Energy Information Administration's 2020 Annual Energy Outlook (EIA 2020a)

Renewable Energy Costs: Drawn from NREL's 2020 Annual Technology Baseline (NREL 2020)

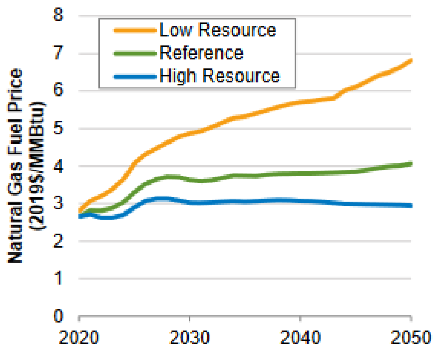
Clean Energy Demand (CED):

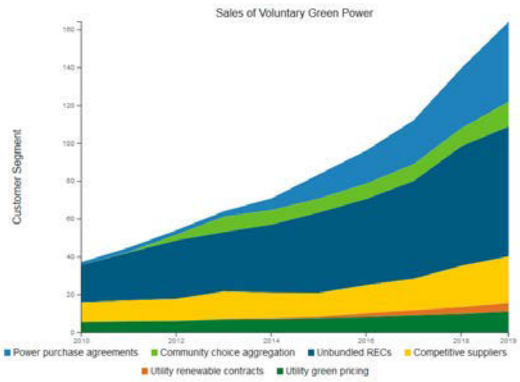
- In this analysis, the demand for clean energy comes from two sources: explicit representation of currently-enacted state portfolio standards, and a generic representation of additional demand meant to represent actions by other entities such as cities or utilities, federal action, voluntary procurement by end-users, and the possible introduction of new portfolio standards in states that do not have them or the increase in stringency of standards where they already exist.
- In both the "conservative" and "increasing" trajectory, all state portfolio standards are represented as they are currently enacted, based on the representation in NREL's 2020 Standard Scenarios (Cole et al. 2020).
- In the "conservative" trajectory, the component of additional demand starts at 4.3% of retail sales in 2020 and increases at a rate of 0.4% of retail sales per year, based on observations of voluntary procurement markets (Heeter and O'Shaughnessy, 2020). This scenario can therefore be interpreted as representing the clean energy demand from existing state legislation and a projection of the current trends in voluntary procurement markets, but neglecting the other possible sources of clean energy demand listed above.
- In the "increasing" trajectory, the component of additional demand also starts at 4.3% of retail sales in 2020 but increases at a faster rate of 2% of retail sales per year through 2030 and 0.5% of retail sales beyond 2030. This is intended to represent the possible sources of clean energy demand listed above, as well as the potential for market frictions that could result in eligible generation not being applied to CETA (e.g., a nominally eligible hydropower resource not being acquired for CETA compliance).
- The combined clean energy demand from both legislation and this additional demand cannot exceed 100% of retail sales in any one state.

Other assumptions: All other assumptions are the same as in the "Mid-case" of NREL's 2020 Standard Scenarios (Cole et al. 2020), and do not vary across the ten scenarios.

Context for interpreting the scenarios and corresponding assumptions:

- These assumptions were selected to give an understanding of the sensitivity of emissions factors to three influential assumptions. This is not intended as an exhaustive set of possible future scenarios.
- Projected natural gas prices under the AEO Reference cases have tended to exceed realized near-term future NG prices (EIA 2020b).
- Because of CETA, the "clean energy demand" assumption has little impact on the modeled demand for clean energy within Washington, which reaches 100% of retail sales by 2030 regardless and the demand is never binding prior to 2030.





https://www.nrel.gov/analysis/green-power.html

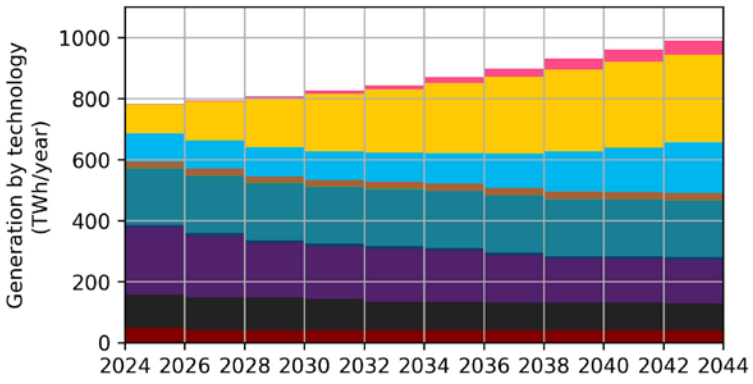
Results

Summary of Results

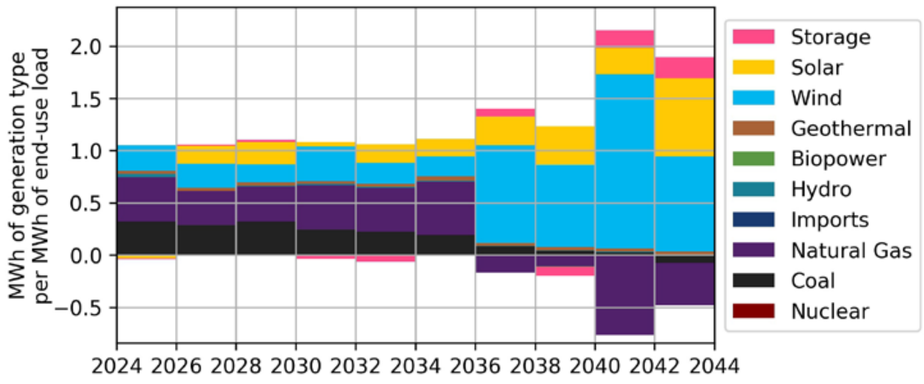
Scenario Name	Long-run marginal emission rate (CO2e lb./kWh of end-use electric load)
Reference, Increasing CED	0.44
High NG Prices, Increasing CED	1.58
Low NG Prices, Increasing CED	0.27
Low RE Costs, Increasing CED	0.13
High RE Costs, Increasing CED	0.79
Reference, Conservative CED	1.01
High NG Prices, Conservative CED	1.71
Low NG Prices, Conservative CED	0.92
Low RE Costs, Conservative CED	-0.20
High RE Costs, Conservative CED	0.80

Each value reported in the above table is the average of the LRMER of the six perturbation runs.
The following ten slides show the buildouts in the Western Interconnect for each scenario, as well as the average fuel mixtures induced by the perturbations.

Reference, Increasing Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Reference, Increasing Clean Energy Demand* scenario



Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Reference, Increasing Clean Energy Demand* scenario**

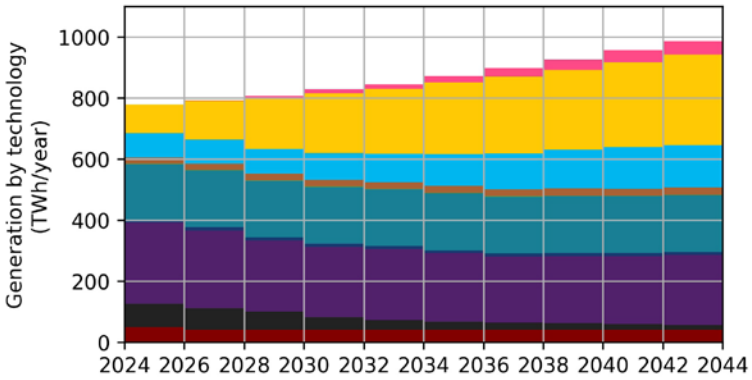
Comments:

- Long-run marginal CO_2e emission rate: 0.44 lb per kWh of end-use electrical load
- CETA becomes analytically binding* in 2034 in this scenario

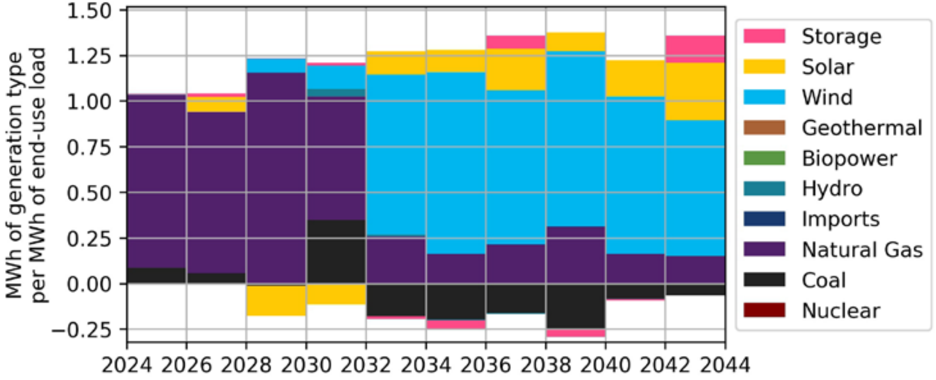
* In this analysis we use the term *analytically binding* to indicate when CETA's requirements could not be met by resources that would have been built even in absence of the policy. In ReEDS, this is identified by a non-zero shadow price on the constraint representing CETA.

** The difference figures (right) were calculated by subtracting the annual generation by technology for the baseline run from each of the perturbation runs, and dividing the technology's generation difference by the change in end-use load for that perturbation run. The results – differences in generation by technology per unit change in end-use load – were then averaged across the six perturbation runs to get the final values visualized here. These values were only generated for visualization purposes, with the reported LRMER values calculated from differences in emission rates as described previously on slide 6.

Low Natural Gas Price, Increasing Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Low Natural Gas Price, Increasing Clean Energy Demand* scenario

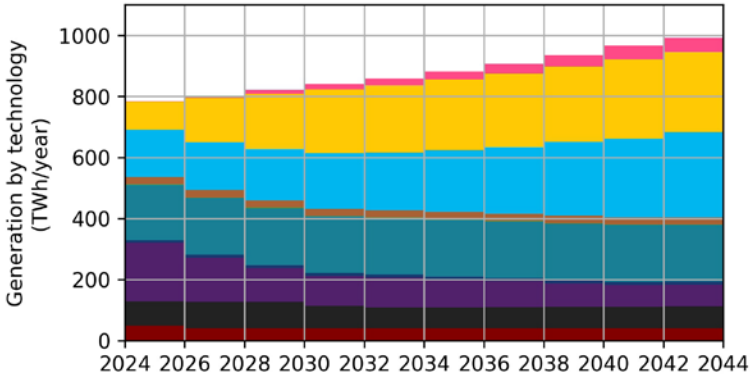


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Low Natural Gas Price, Increasing Clean Energy Demand* scenario

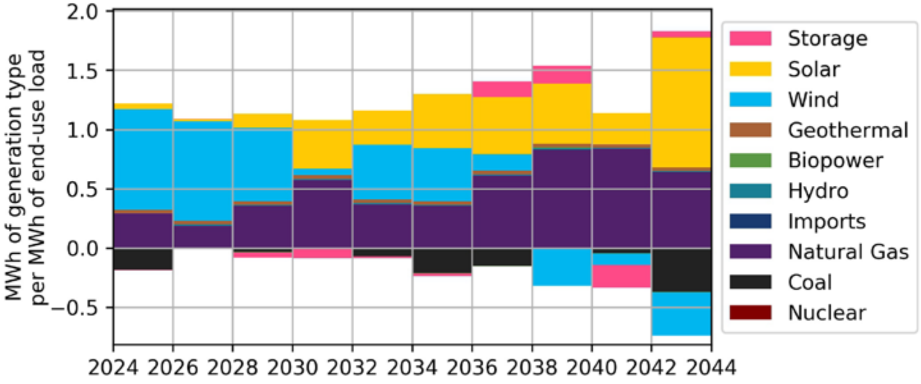
Comments:

- Long-run marginal CO_2e emission rate: 0.27 lb per kWh of end-use electrical load
- CETA becomes analytically binding in 2030 in this scenario

Low Renewable Energy Cost, Increasing Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Low Renewable Energy Cost, Increasing Clean Energy Demand* scenario

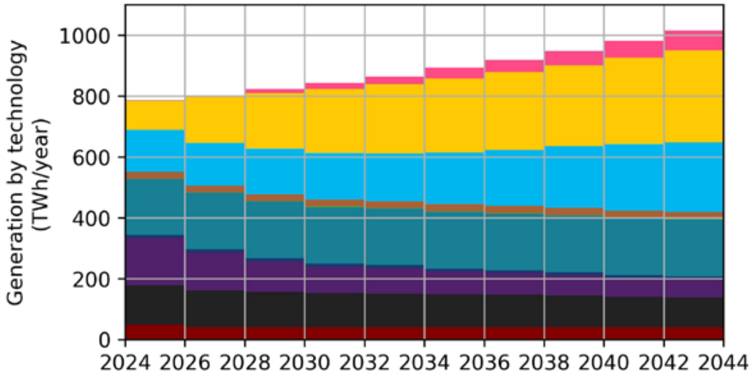


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Low Renewable Energy Cost, Increasing Clean Energy Demand* scenario

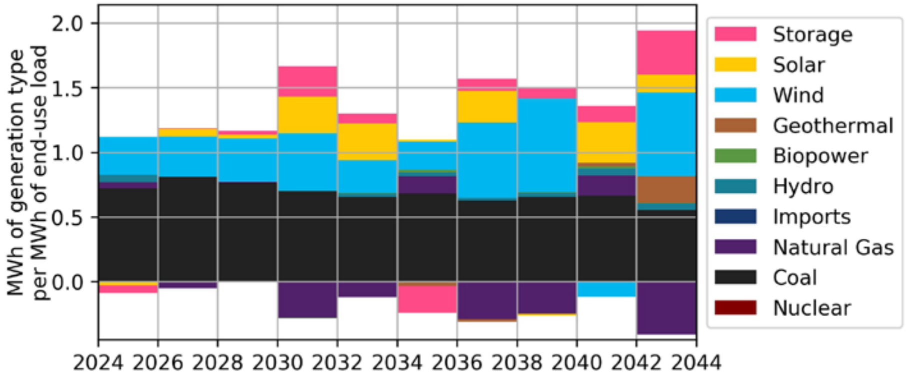
Comments:

- Long-run marginal CO_2e emission rate: 0.13 lb per kWh of end-use electrical load
- CETA does not become analytically binding in this scenario

High Natural Gas Price, Increasing Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *High Natural Gas Price, Increasing Clean Energy Demand* scenario

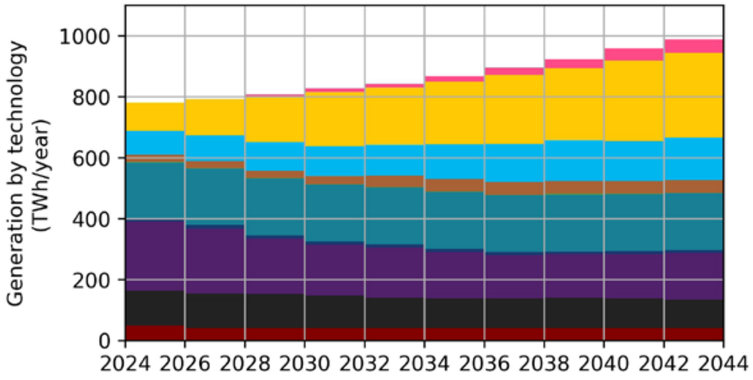


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *High Natural Gas Price, Increasing Clean Energy Demand* scenario

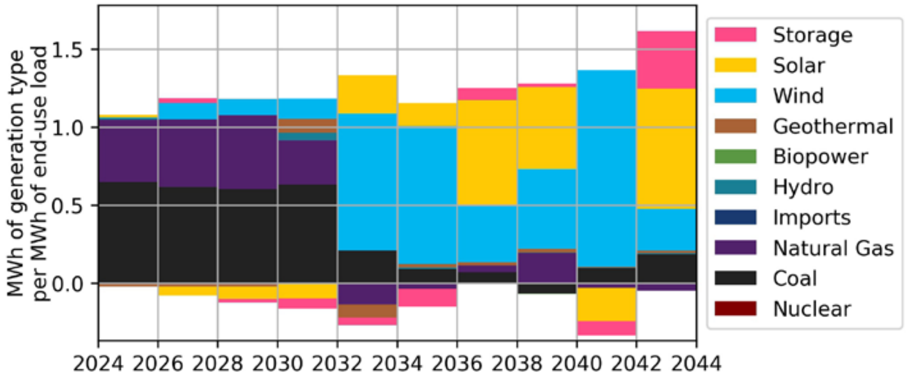
Comments:

- Long-run marginal CO_2e emission rate: 1.58 lb per kWh of end-use electrical load
- CETA does not become analytically binding in this scenario

High Renewable Energy Cost, Increasing Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *High Renewable Energy Cost, Increasing Clean Energy Demand* scenario

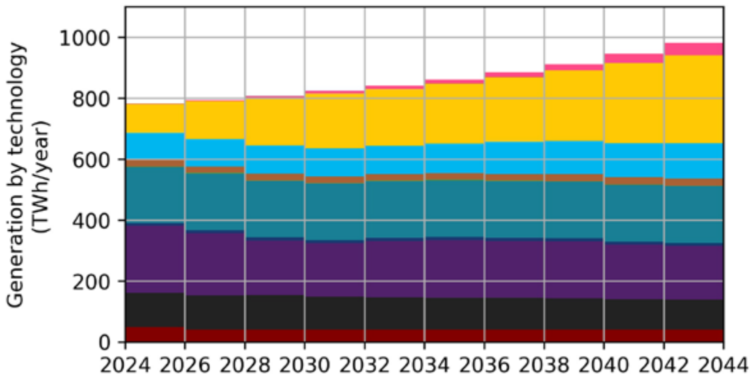


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *High Renewable Energy Cost, Increasing Clean Energy Demand* scenario

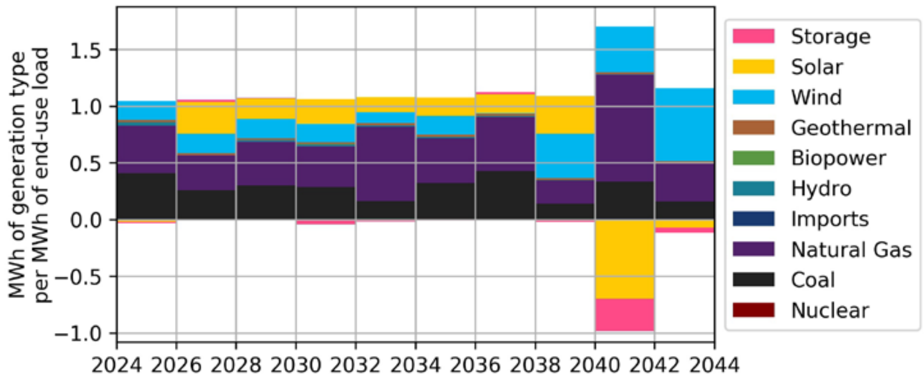
Comments:

- Long-run marginal CO_2e emission rate: 0.79 lb per kWh of end-use electrical load
- CETA becomes analytically binding in 2032 in this scenario

Reference, Conservative Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Reference, Conservative Clean Energy Demand* scenario

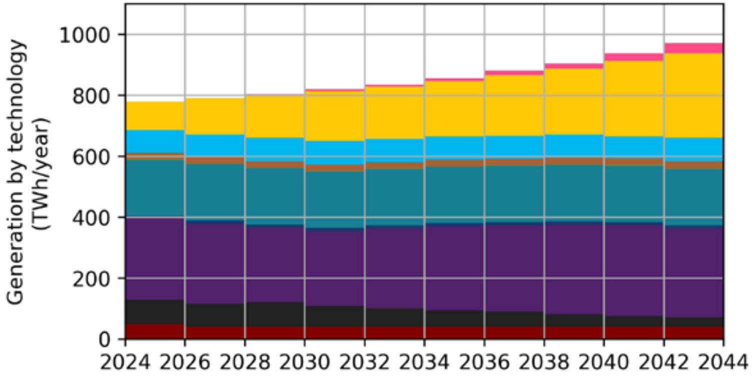


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Reference, Conservative Clean Energy Demand* scenario

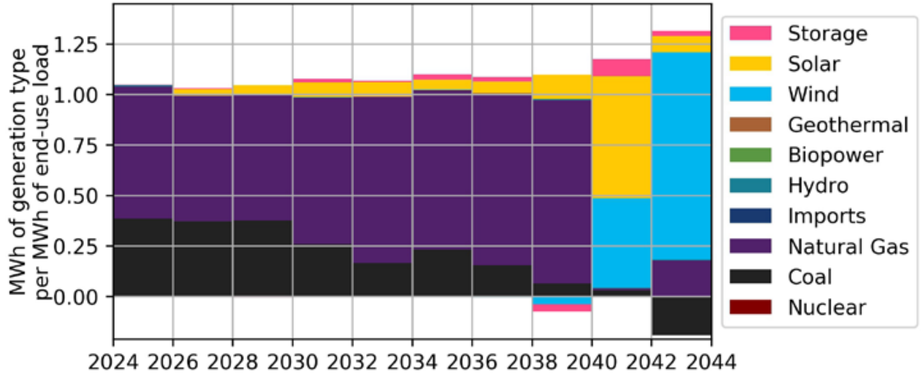
Comments:

- Long-run marginal CO_2e emission rate: 1.01 lb per kWh of end-use electrical load
- CETA does not become analytically binding in this scenario

Low Natural Gas Price, Conservative Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Low Natural Gas Price, Conservative Clean Energy Demand* scenario

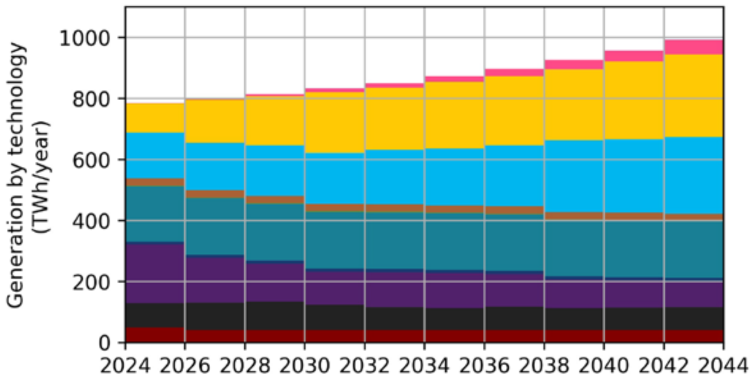


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Low Natural Gas Price, Conservative Clean Energy Demand* scenario

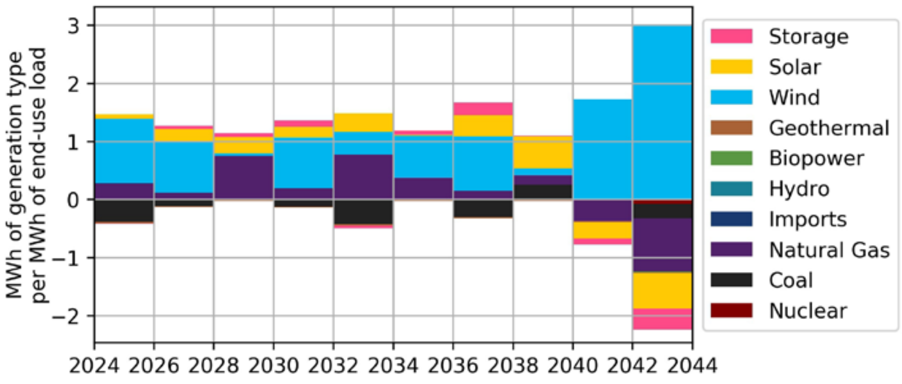
Comments:

- Long-run marginal CO_2e emission rate: 0.92 lb per kWh of end-use electrical load
- CETA becomes analytically binding in 2040 in this scenario

Low Renewable Energy Cost, Conservative Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *Low Renewable Energy Cost, Conservative Clean Energy Demand* scenario

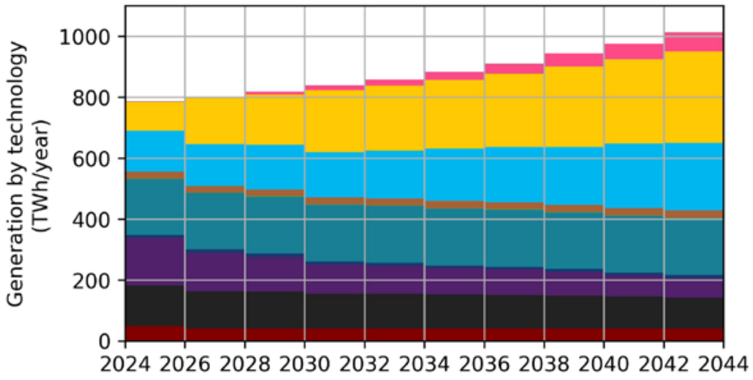


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *Low Renewable Energy Cost, Conservative Clean Energy Demand* scenario

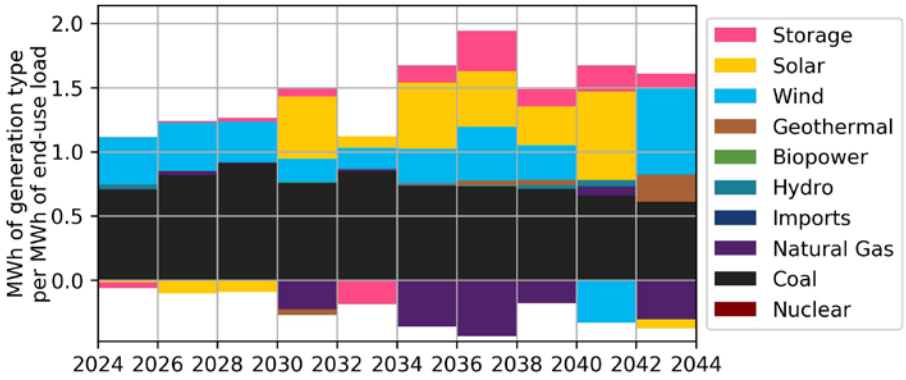
Comments:

- Long-run marginal CO_2e emission rate: -0.20 lb per kWh of end-use electrical load
- CETA does not become analytically binding in this scenario

High Natural Gas Price, Conservative Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *High Natural Gas Price, Conservative Clean Energy Demand* scenario

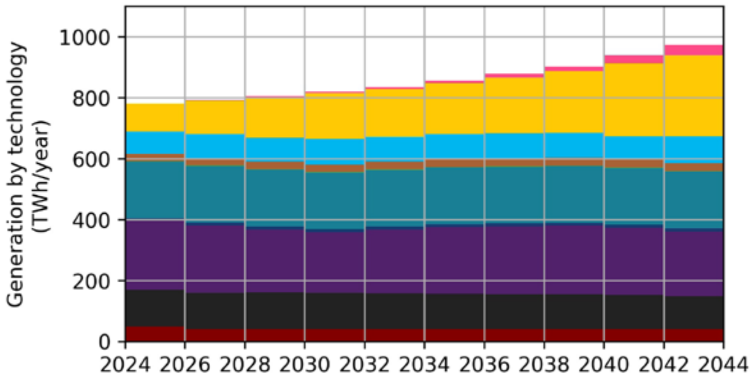


Difference between the generation mixtures of the baseline run and the load perturbation runs of the *High Natural Gas Price, Conservative Clean Energy Demand* scenario

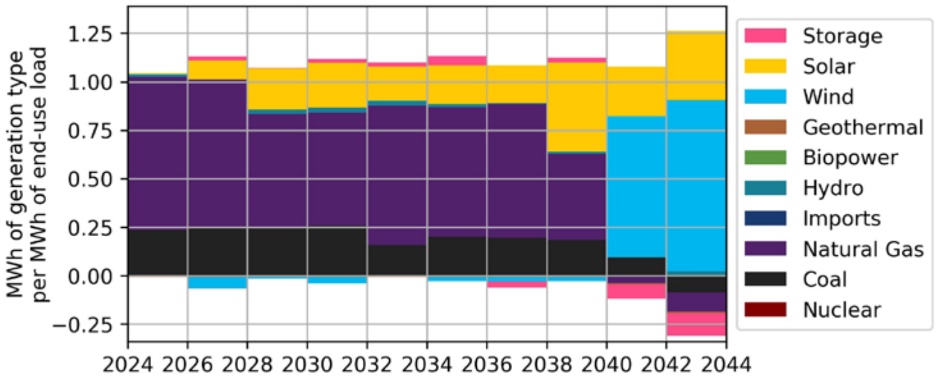
Comments:

- Long-run marginal CO_2e emission rate for the *Reference* scenario: 1.71 lb per kWh of end-use electrical load
- CETA does not become analytically binding in this scenario

High Renewable Energy Cost, Conservative Clean Energy Demand Scenario Results



Total generation by technology across the Western Interconnection, in the baseline run of the *High Renewable Energy Cost, Conservative Clean Energy Demand* scenario



Difference between the generation mixtures of the baseline run and the load perturbation runs of the *High Renewable Energy Cost, Conservative Clean Energy Demand* scenario

Comments:

- Long-run marginal CO_2e emission rate: 0.80 lb per kWh of end-use electrical load
- CETA becomes analytically binding in 2040 in this scenario

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