Pacific Northwest NATIONAL LABORATORY

PNNL-32933

Deep Electrification Analysis

The Role of the U.S. Power Grid for Sustainable Transportation

June 2022

Michael Kintner-Meyer
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Rani Murali
Sid Sridhar
Quan Nguyen

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Abstract

This project attempts to quantify the size of electric generation for the entire nation to transition from a fossil fuel based transportation sector to a zero GHG emission-based energy source. The scope of this analysis is limited to decarbonizing the transportation sector, leaving the remaining sectors, such as power (for those that are still fossil based), industry, and building sectors, for later phases of study.

The study year for this analysis is 2050, with expected escalation in transportation services and naturally occurring evolutions in the electric power sector and the entire economy. This analysis uses the projections of the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO 2020) Reference Case for study year 2050 [EIA/AEO2020] as a base-case. The transportation sector is disaggregated by the following modes and classes: (1) on-road (divided into light-duty, medium-duty, heavy-duty vehicles), (2) aviation, (3) maritime, and (4) rail. The decarbonization case was based on only 2 pathways: (1) electrification of on-road transportation except for 30% of heavy-duty vehicles, and (2) power-to-liquid for the remaining transportation modes. The study estimated for 11 US regions what the additional wind and storage capacities requirements are to replace the fossil-based fuels with renewable wind capacity. Considered were the utilization of the existing idle capacity particularly during the load valley at night and any additional new generation capacity in EIA projections for the reference case. To balance the additional wind capacity required significant energy storage capabilities which were estimated in terms of power capacity (GW) and energy capacity (GWh). The paper further characterizes the energy requirements by a relation of power capacity to duration, allowing the analyst to gain insights into what the best technology portfolio might be to meet the new balancing or flexibility needs.

Summary

The results for the US indicated, that a transition from fossil-based transportation to clean renewable fuels-based might require as much as 1.8 TW of additional wind generation capacity and over 640 GW of storage with varying duration of up to 3 weeks. These figures are staggeringly large and exceed current manufacturing and deployment capabilities in the US or any country on Earth. Particularly, on the storage deployment, the technology is currently not mature to deploy long-duration energy storage at the scale the US needs to meet a carbon-free transportation services. The investments in technology and infrastructure development will range in the trillions of dollars.

Acknowledgments

This research was supported by the Energy and Environmental Directorate (EED) Mission Seed, under the Laboratory Directed Research and Development (LDRD) Program at Pacific Northwest National Laboratory (PNNL). PNNL is a multi-program national laboratory operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute under Contract No. DE-AC05-76RL01830.

Acronyms and Abbreviations

AEO	Annual Energy Outlook
PJM	U.S. electric grid operator covering Pennsylvania, New Jersey, Maryland, and other Mid-Atlantic states
SERC	Southeastern Reliability Corporation

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1.0 Introduction

States, counties, and cities have pledged to abide by the Paris Protocol to keep the global mean temperatures under 2°C, which requires at least an 80% reduction of the greenhouse gas (GHG) emissions relative to 1990 levels by 2050. Except for California, which has several laws in place to drive the emissions from transportation, power generation, and building sectors to carbon neutral by 2045, no other state has enforceable legal frameworks in place to direct consumer, industry, and energy infrastructure owners and operators to reduce GHG emissions. However, there is increasing interest by states to become more actionable with legal and regulatory frameworks to set enforceable emissions goals such that the investors can make informed decisions for transitioning away from fossil fuels. Washington State, for instance, is currently undergoing a study to look at policy levers to achieve net zero carbon by 2050. For WA State, with the nation's lowest carbon intensity for electricity generation, the large contributors to GHG emissions are the transportation, industrial and building sectors. Other states with more fossil fuel based generation mix have added burden to transition to clean electricity, in addition to addressing the necessary emission reductions in the transportation, industrial and the building sectors. This paper will attempt to quantify the magnitude of investment in electric generation for the entire nation to transition from a fossil fuel based transportation sector to a zero GHG emission-based energy source. The scope of this analysis is limited to decarbonizing the transportation sector, leaving the remaining sectors, such as power (for those that are still fossil based), industry, and building sectors, for later phases of study.

2.0 Discussion of Results

The total additional wind generation capacity for the contiguous US is shown in the table below. The best- and worst-case scenarios bracket the range of required additional generation capacity. Similarly, we determined the required energy storage capacity necessary to balance the wind generation fluctuations throughout the year.

Table 1: Results of Additional Wind and Storage Capacity

Additional Installed Capacity									
Best case					Worst case				
Wind	Long Duration Storage (3 weeks)		Medium Duration Storage (3 days)		Wind	Long Duration Storage (3 weeks)		Medium Duration Storage (3 days)	
[GW]	[GW]	[GWh]	[GW]	[GWh]	[GW]	[GW]	[GWh]	[GW]	[GWh]
773	168	131,377	98	1,118	1,892	273	147,875	370	3,999

Only on-road electrification

This LDRD work developed new optimization techniques to size and operate various energy storage systems necessary to meet the 2050 electricity load assuming that all transportation services will be electrified either directly via electric drivetrains and batteries or by producing zero-emission sustainable fuel using a direct carbon capture to product carbon and electrolysis to produce hydrogen.

The following Figures shows the result of an optimal state of charge for two different US regions over a period of one year.

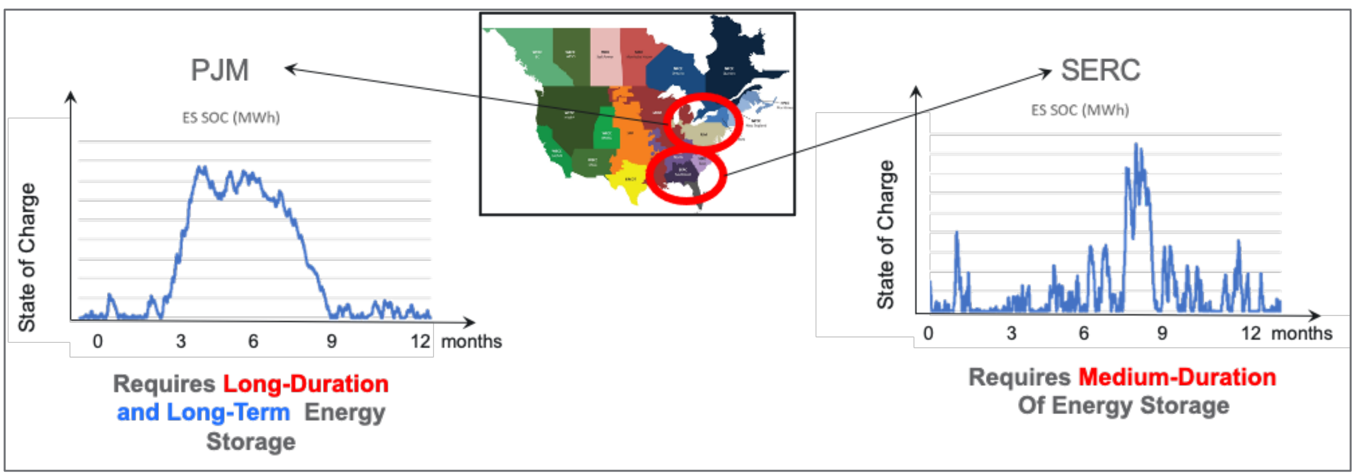

Figure 1: Optimal State of Charge over a Period of 1-year for two Regions

3.0 Outcome

This LDRD project provide new methodologies to estimate the demand for decarbonizing the US transportation services in 2050 as well as to estimate the size of new wind generation capacity and the associate energy storage requirements to balance the wind fluctuations.

4.0 References

EIA/AEO2020, Annual Energy Outlook 2020 with Projection to 2050. U.S. Energy Information Administration, January 29, 2020. Washington, D.C., Available at: https://www.eia.gov/outlooks/aeo/

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