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# Renewable Resources of the Northern Half of the United States; A Pathway to Total Renewability ?

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### Abstract

We previously presented a model for deep penetration of renewables in the electricity sector of the southern half of the United States (Khoie and Yee, 2015). In this paper, we present a strategy for the northern half of the United States to utilize its available renewable resources to gradually decrease its reliance on fossil fuels in electricity generation and develop energy portfolios with increasing share of renewables. Using the electricity generation data from the U.S. EIA (U.S. Energy Information Administration, 2018a), and the renewable resource maps produced by NREL (National Renewable Energy Laboratory, Geospatial Data Science, 2018), we develop strategies for the states in the northern half of the U.S. We group these states into seven regions: West Coast, Mountain States, Middle West States, Lake States, Mid-Atlantic, South Atlantic, and New England states. For each region we determine when and if, the electricity generation from renewables will meet the region's electricity need while accounting for a 1% annual increase in electricity demand. The renewable resources included in our models are solar (photovoltaic), wind, hydro, biomass, and geothermal which vary greatly from region to region. We also include nuclear, coal, natural gas, and petroleum.

Keywords: *Pathway to total renewability, Renewable resources, Northern United States,*

## 1. Introduction

In 2017, the U.S. produced 4,015 billion KWh of electricity, of which 62.7% was generated from coal and natural gas and 20% from nuclear energy as shown in Fig. 1 (U.S. EIA, 2018b). In that same year, the renewables contributed 17.1% to the total generation of which 7.5% was from hydropower sources, 6.3% from wind, and a dismal 1.2% from photovoltaic solar cells. This level of utilization of renewables, especially wind and solar is extremely small compared to the level of natural abundance of these resources in the country. Although there has been a relatively significant increase in renewable electricity generation (roughly 5% increase from 2012 to 2017), the U.S. remains short of its true potential for a much deeper penetration of renewables in electricity generation over the next four decades. In fact, a study by the National Renewable Energy laboratory (NREL) has shown that even with the present state of the renewable


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technologies, the United States has the potential to adequately supply 80% of its electricity demand in 2050 by using renewable resources (Mai, 2012).

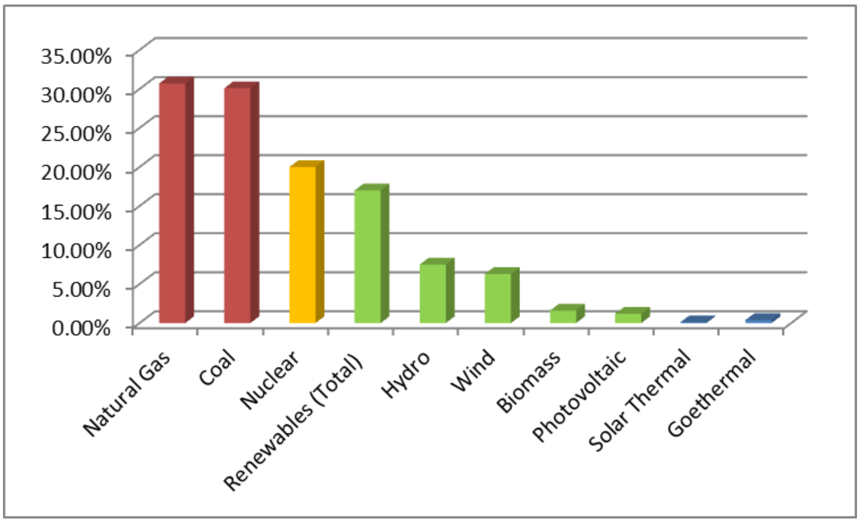


**Fig. 1: The energy portfolio of the U.S. electricity sector in 2017 (U.S. EIA, 2018b).**

The National Renewable Energy Laboratory has produced detailed maps of various renewable resources across the country. Referring to Figs 2 and 3, the United State has the following solar and wind resources (Hand, M. et. al., 2012):

- 80.000 GW of photovoltaic solar,
- 37,000 GW of concentrating solar thermal,
- 10,000 GW of wind,
- Furthermore, the distributed rooftop solar potential of the U.S. amounts to 700 GW.

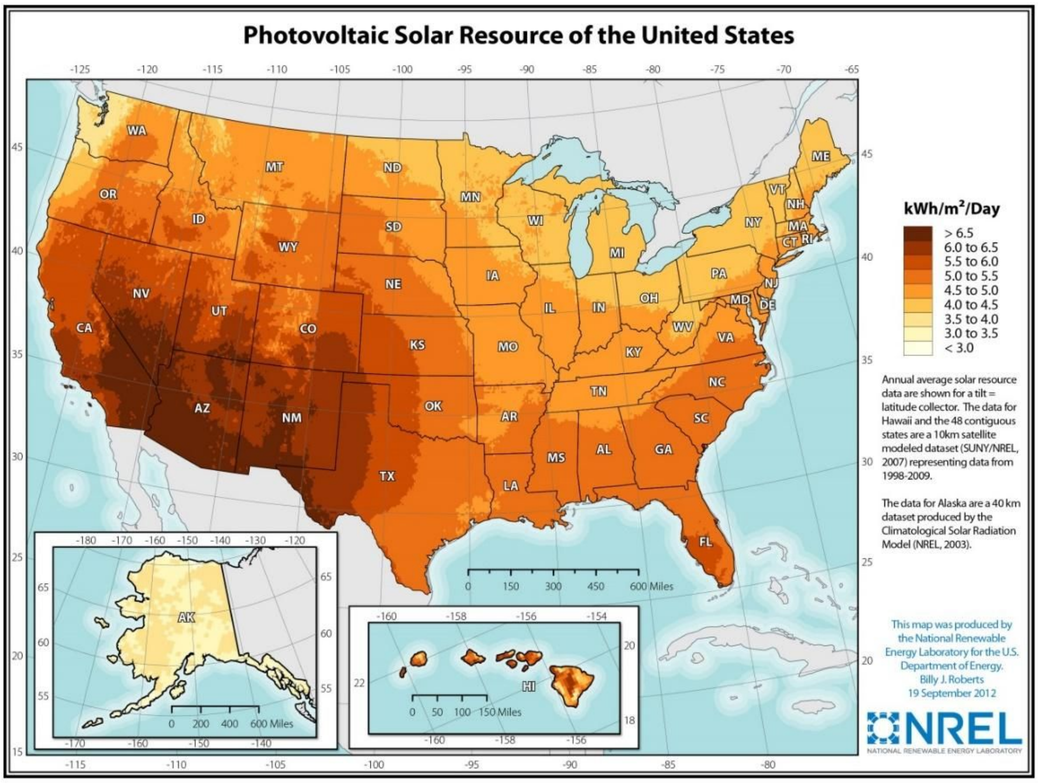


**Fig. 2: Photovoltaic resources of the United States (NREL 2018a).**

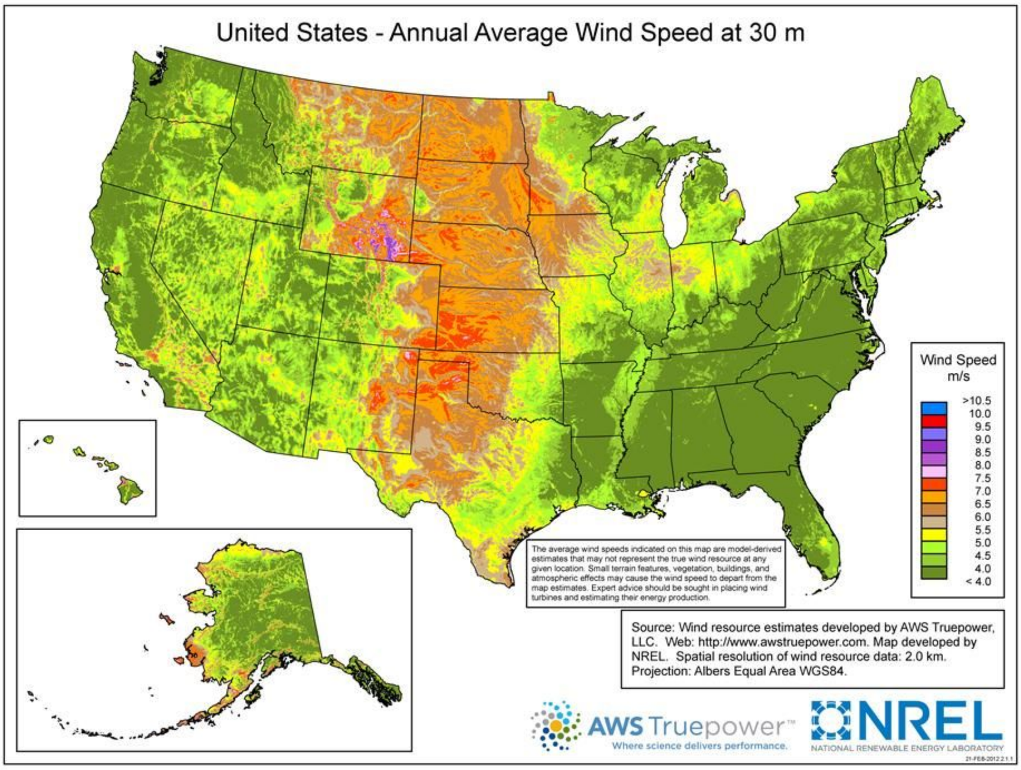

**Fig. 3: Wind resources of the United States (NREL 2018b).**

Additionally, the U.S. has roughly 500 GW of geothermal, 100 GW of biomass, and estimated 12 GW of non-powered dams (NDP) hydropower (Oak Ridge National Laboratory, 2018). The above represents a total potential capacity of more than 128,000 GW of renewable power. Comparing this colossal abundance of renewable resources to the roughly 1000 GW of electricity demand in the U.S., one wonders why we produce only roughly 170 GW of our electricity from renewables.

The southern half of the U.S. enjoys abundance of solar (especially southwest region) and wind (especially panhandle of Texas). (See Khoie and Yee, 2015). The northern half of the U.S. also has great potential in renewable generation. In this paper, we examine scenarios under which the northern states can gradually increase utilization of their renewable resources and reach energy portfolios in which the renewables are providing the fuel for either 100% of their electricity generation or a large portion of it.

## 2. 2. Regions in the Northern Half of the United States

We group the 28 northern states into seven regions as follows:

- The West Coast States: OR, and WA.
- The Mountain States: ID, MT, and WY.
- The Middle West States: ND, SD, and NE.
- The Lake States: MN, WI, MI, IA, IN, IL, and OH.
- The Middle Atlantic States: NJ, NY, and PA.
- The South Atlantic States: MD, VA, WV, and DE.
- The New England States: CT, ME, MA, NH, RI, and VT.

For each state in the regions, we determine the state's total electricity demand and its energy portfolio in electricity generation in the year 2013 from the data published by the U.S. EIA. A sample of such data for the State of Oregon is shown in Fig. 4. We also determine the maximum renewable potential of each state from the data available from NREL. We then set out to determine the rate of growth in renewable penetration in the electricity sector of each state based on the model described below.

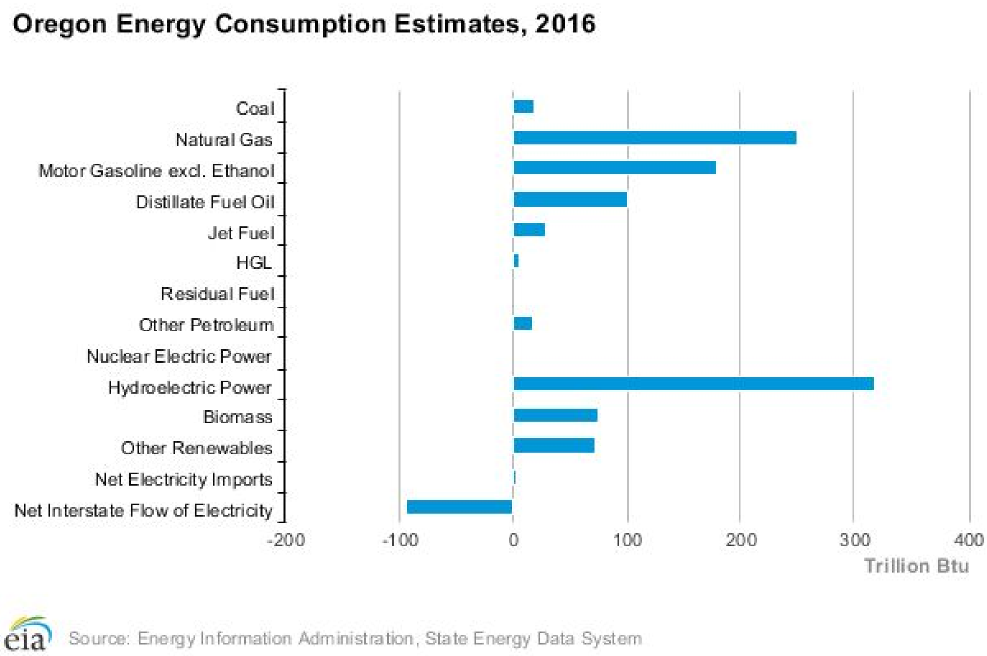

**Fig. 4: Total energy consumption of Oregon in 2016 (U.S. EIA 2016a).**

## 3. 3. Model

We use a simple model in which the energy portfolio of each region is determined annually by increasing the renewable shares at appropriate annual rates (depending on the abundance of each of the renewable source in the region) while decreasing the non-renewable resources to meet the demand. The United States' electricity consumption is expected to increase from about 3,873 billion KWh (3873 x $10^9$ KWh) in 2008 to about 5,021 billion KWh in 2035, roughly a 1% annual increase over the next 3 decades (U.S. EIA, 2010). As such, the regions' electricity demand of each year, $E_{demand}(t)$ , is increased by 1% a year over the previous year:

$$E_{demand}(t) = E_{demand}(t-1) + 0.1 * E_{demand}(t-1) \qquad eq.\ (1)$$

To meet the demand, the electricity produced in each year $(t)$ is determined from the previous year $(t-1)$ as given by:

$$E_{produced}(t) = E_{solar}(t) + E_{hydro}(t) + E_{wind}(t) + E_{biomass}(t) + E_{geothermal}(t) + E_{coal}(t-1) + E_{natural\ gas}(t-1) + E_{petroleum}(t-1) +$$

Where the renewable production is increased annually as given by:

$$E_{renewable}(t) = E_{renewable}(t-1) + C_{renewable} * E_{renewable}(t-1) \qquad eq.\ (3)$$

Where $C_{renewable}$ is a constant for each renewable resource, and is determined based on the available renewable resource of the region, the electricity demand of each region, and how long it will take the region to taper off of fossil fuels and produce its entire electricity from its renewable resources. The parameter $C_{renewable}$ has different values for each renewable resource in each region. Depending on the circumstance, $C_{renewable}$ takes values ranging from 0.01 to 0.05. Considering the cost associated with deep penetration of wind and solar (the most abundant resource relative to the demand in the region), the constant $C_{renewable}$ for wind and solar in all regions is never above 0.03. The target year for total renewability is set at 2050, and depending on the region's abundance of renewable, total renewable generation may occur prior to 2050, or in some cases, it may never occur.

If the electricity produced in a given year is less that the demand for that year, the difference will be made up by increasing the natural gas, as given by:

$$E_{natural\ gas}(t) = E_{natural\ gas}(t) + E_{consumed}(t) - E_{produced}(t) \qquad eq.\ (4)$$

If the electricty produced in a given year is greater than the demand, the difference will be subtracted from the fossil fuels in the order of coal, petroleum, and then natural gas. Once the natural gas contribution reaches zero, the electricty produced will be allowed to surpass the demad. The simualtions are performed in a matlab program, using EIA's Electric Power Monthly for April 2016 (EIA, 2016b).

## 4. 4. Results

The results for all seven regions are shown in Figs. 5 through 11. In these figures, in the top graphs, the blue line is the total electricity generation in the region, the dashed red line is the electricity demand of the region, and the green line is the electricity produced from renewable resources in the region. In the bottom graphs, the contributions of nine resources to the total electricity generation of the region are shown and they include contributions from coal, petroleum, natural gas, (fossil fuels), nuclear, hydro (mostly run of river) , wind, solar (photovoltaic), biomass, and geothermal. Note that in all these plots, the year (if any) that the renewable curve intersect the demand curve is the year the region will be able to produce its entire electricity demand from its renewable resources, beyond which the region is able to produce additional electricity to be used in other energy sectors, including transportation by electric vehicles.

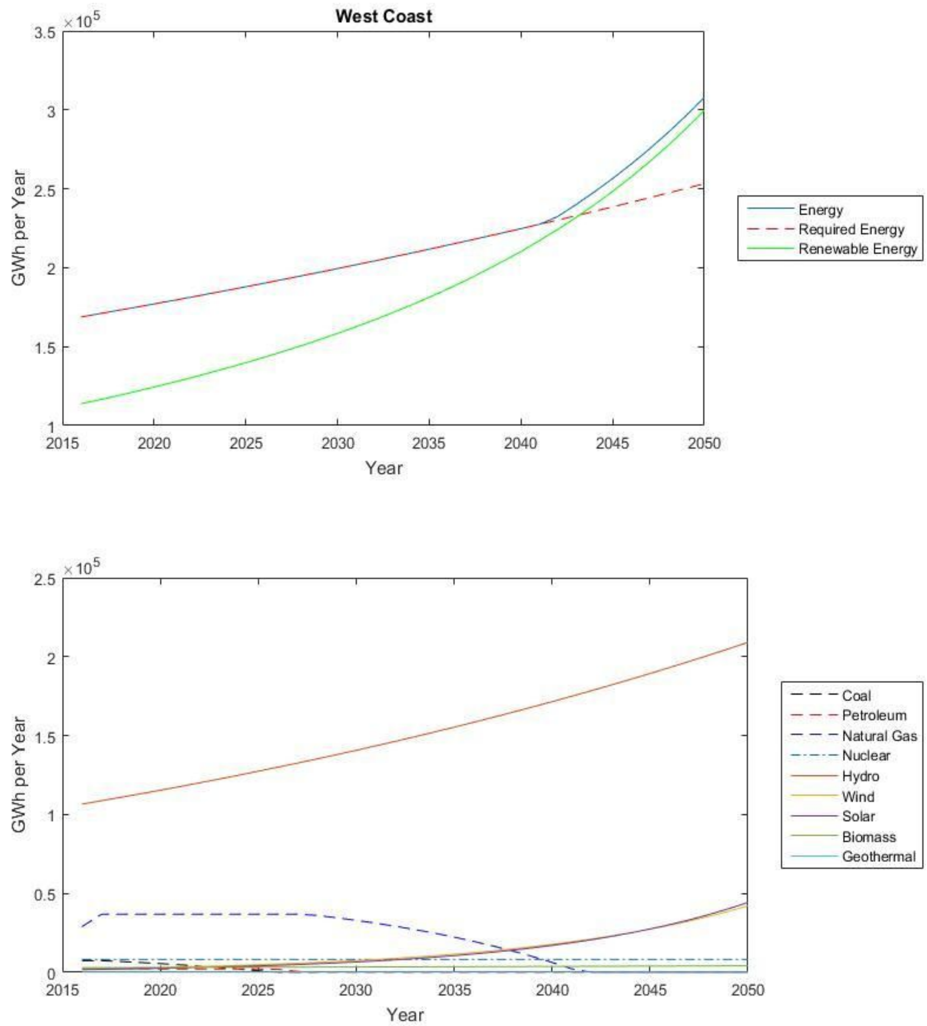


**Fig. 5: Electricity generation from all resources in the West Coast States through 2050.**

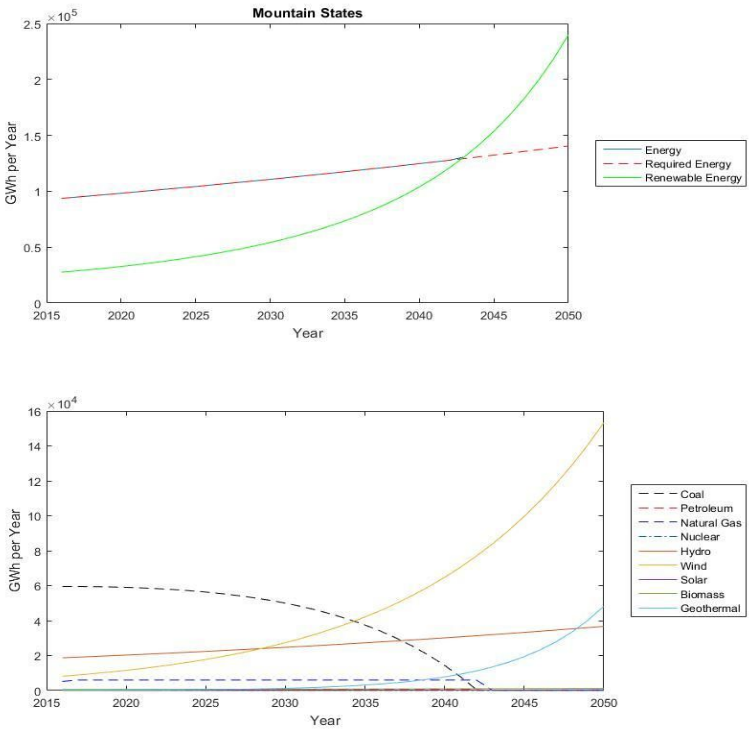


**Fig. 6: Electricity generation from all resources in the Mountain States through 2050.**

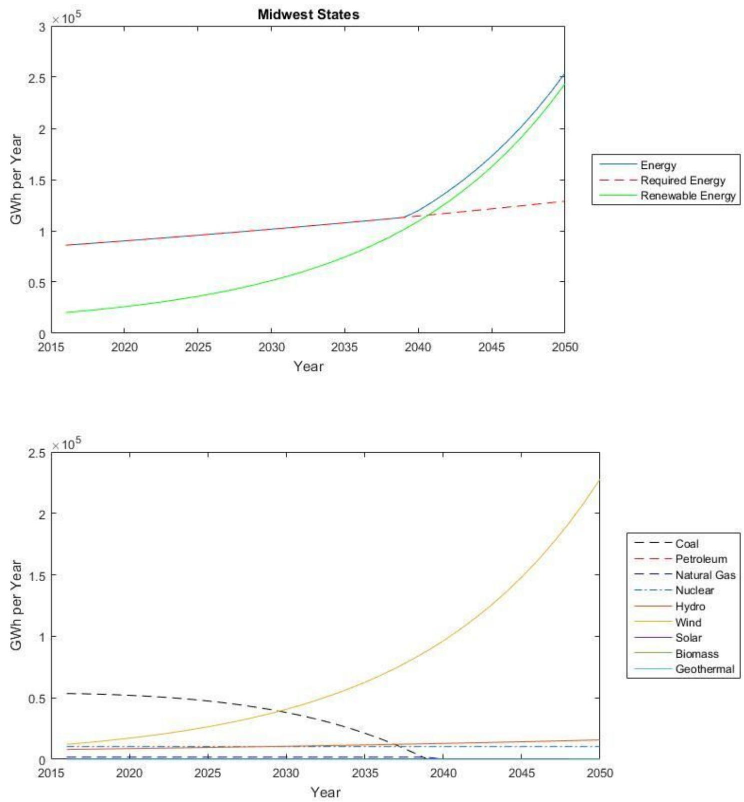


**Fig. 7: Electricity generation from all resources in the Middle West States through 2050.**

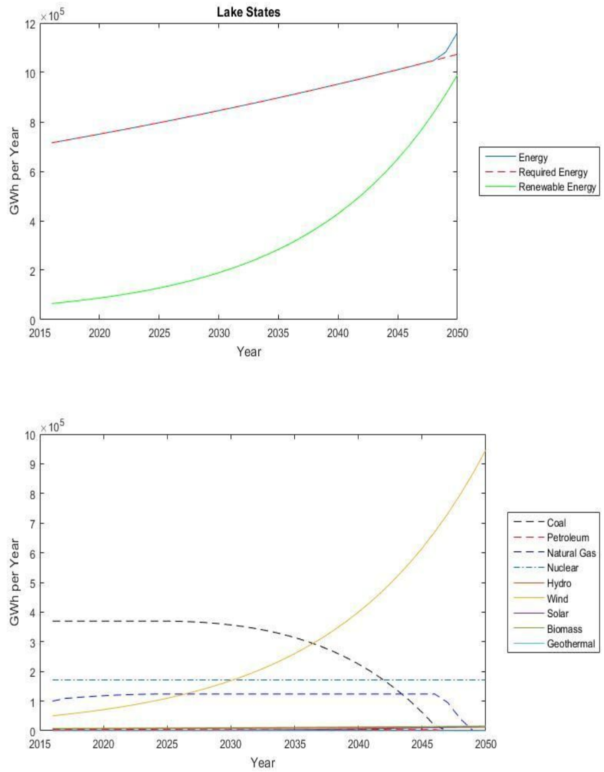


**Fig. 8: Electricity generation from all resources in the Lake States through 2050.**

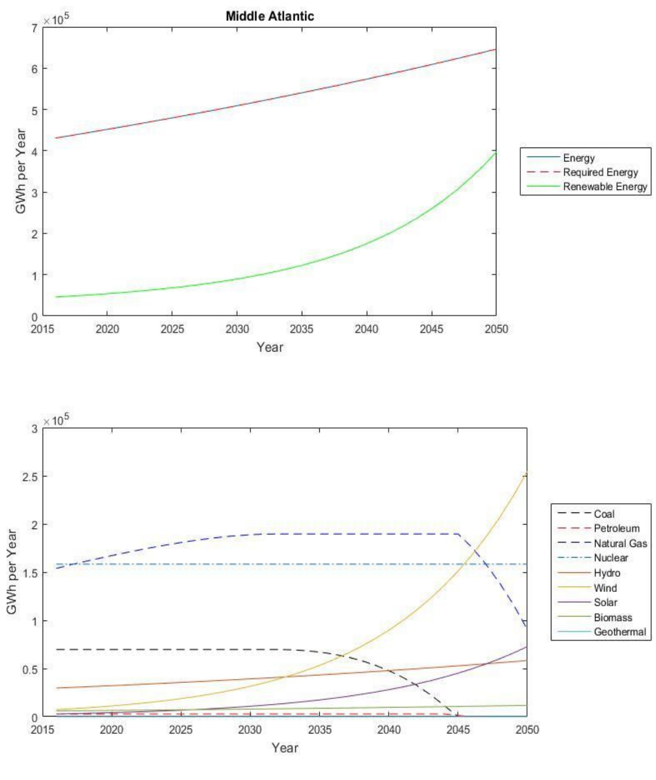

**Fig. 9: Electricity generation from all resources in the Middle Atlantic States through 2050.**

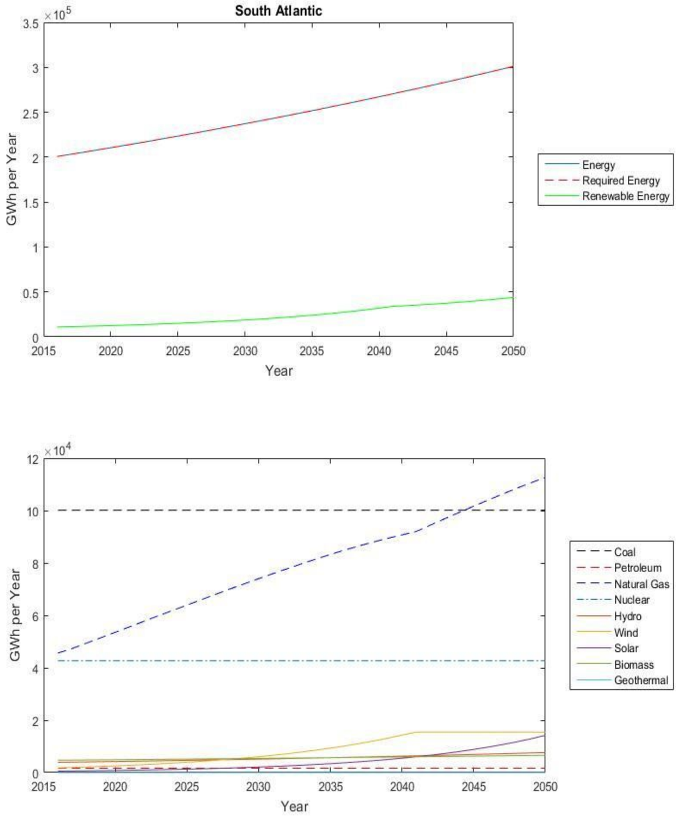


**Fig. 10: Electricity generation from all resources in the South Atlantic States through 2050.**

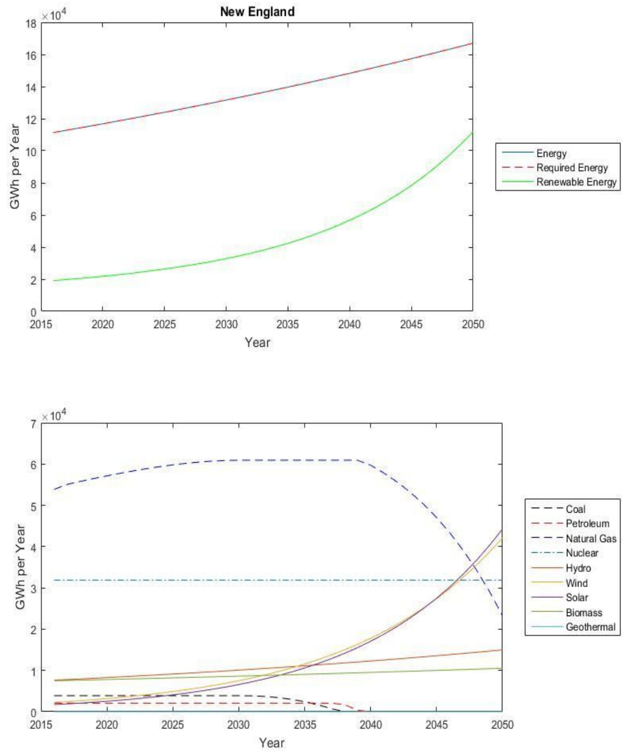


**Fig. 11: Electricity generation from all resources in the New England States through 2050.**

- The West Coast States: OR, and WA: This region with its vast hydro resources can become 100% fossil-fuel-free in as early as 2041, at which time the wind and solar will also be major contributors to its electricity production. Continued utilization of its renewables, the West Coast states would be able to produce roughly 45,000 GWh of surplus electricity.
- The Mountain States: ID, MT, and WY: This region, in large part due to its abundant wind resources can produce its entire electricity demand from renewables by 2039. At that time, solar resources would also be contributing relatively greatly to its portfolio. The Mountain States will be able to produce roughly 100,000 GWh of electricity, which is roughly 80% more than its total electricity demand.
- The Middle West States: ND, SD, and NE: The vast wind resources of this region, if utilized at 1% a year, will make this region 100% renewable by 2038. Continued utilization of wind (and other renewables) will provide a 120,000 GWh of surplus electricity in this region.
- The Lake States: MN, WI, MI, IA, IN, IL, and OH: This region could reach 100% renewable just beyond 2050, at which time; fossil fuels will produce roughly 80,000 GWh of electricity. The available wind and solar resources of this region, although contributing a major portion to electricity generation, would be just short of 100% renewable production.
- The Middle Atlantic States: NJ, NY, and PA: Although solar and wind can contribute greatly to its electricity generation, by 2050, this region would need roughly 250,000 GWh of its electricity to be generated from its non-renewable resources mostly natural gas and nuclear.
- The South Atlantic States: MD, VA, WV, and DE. This region will remain mostly dependent on its nor-renewable resources and will have the largest shortage of renewable generation (roughly 260,000 GWh) to meet its projected demand in 2050. At that time, wind and solar will contribute about 3,200 GWh to its electricity generation, which remains a small portion of its portfolio.

- The New England States: CT, ME, MA, NH, RI, and VT: In 2050, these states will have a total electricity need of 168,000 GWh with renewables producing 57,000 GWh, leaving the balance to be produced from non-renewables.

## 5. 5. Conclusions

The results shown in Figures 5 thru 11 are summarized in Tab. 1, which lists the years that the regions can produce their entire electricity demand from renewable resources. The West Coast, Mountain, and Middle West regions has the potential to become 100% renewable in the years 2041, 2039, and 2038, respectively. This is mostly due to the great abundance of wind energy, especially in the states of Montana, North Dakota, and South Dakota. Furthermore, these three regions can produce significant surplus of electricity.

The other four regions, namely Lake, Mid Atlantic, South Atlantic, and New England states will not be able to reach 100% electricity generation from their renewable resources. This is in part due to relatively less available renewable resources and relatively high electricity demand in these regions. This is particularly true in the South Atlantic region (Maryland, Virginia, West Virginia, and Delaware) where the shortage of renewable resources is the greatest. It is ironic that this region has abundance of coal resources. The utilization of off-shore wind (not included in this model) and distributed generation by renewables can to an extent mitigate this issue.

**Tab. 1: The year the regions would be fossil fuel free in electricity generation (if ever).**

| Region | States | 100% Renewable by | Shortage of Renewables (GWh) |
|---|---|---|---|
| West Coast | OR, WA | 2041 | 0 |
| Mountain | ID, MT, WY | 2039 | 0 |
| Middle West | ND, SD, NE | 2038 | 0 |
| Lake States | MN, WI, MI, IA, IN, IL, OH | Just beyond 2050 | -80,000 |
| Mid Atlantic | NJ, NY, PA | Never | -250,000 |
| South Atlantic | MD, VA, WV, DE | Never | -260,000 |
| New England | CT, ME, MA, NH, RI, VT | Never | -111,000 |

## 6. 6. References

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