ENGR 014: US Power Sector Trends and Water Use

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***Abstract*—This paper examines energy consumption trends and their correlation with water usage from 2000 to 2020, utilizing bar graphs and pie charts for illustration. The analysis focuses on the transition towards renewable energy sources and its implications for water resources. Findings reveal a reduction in overall water usage, notably attributed to decreased reliance on coal-fired power generation. By 2050, renewable energy sources are projected to comprise 42% of total energy sources, up from 19% in 2020. This shift is expected to lead to a 15% reduction in water usage (in gallons) compared to 2020 levels. Challenges in transitioning to renewables, such as varying efficiency and high costs, are acknowledged. Despite obstacles, there is a discernible uptick in renewable adoption, particularly solar and wind energy.**

I. Introduction

The United States relies on a diverse array of energy sources to power its industries, homes, and infrastructure. These sources can be broadly categorized into two main groups: renewable and non-renewable. In this paper, we will delve into the intricacies of each category, exploring their significance, water-use impact, and role in meeting the nation's energy demands.

A. Renewable Energy Sources

Renewable energy sources are characterized by their ability to replenish themselves naturally over time. These sustainable options play a crucial role in reducing greenhouse gas emissions and mitigating climate change. Some key renewable sources are as follows:

1) Solar Energy: Solar power harnesses energy from the sun via the photoelectric effect. As sunlight strikes these cells, it generates electricity. Solar panels are increasingly common on rooftops, in solar farms, and even integrated into building designs operating without the need for water-intensive cooling systems.

2) Geothermal Energy: Geothermal energy taps into the Earth's internal heat. By utilizing steam or hot water from underground reservoirs, geothermal power plants produce electricity. This source is particularly abundant in regions with active volcanoes or geothermal hotspots.

3) Hydroelectric Power: Hydroelectric power relies on the force of flowing water—rivers, dams, and waterfalls—to turn turbines and generate electricity. Large-scale hydroelectric projects provide a stable and renewable energy supply.

4) Wind Power: Wind turbines convert wind energy into electrical power. Wind farms, both onshore and offshore, contribute significantly to the renewable energy mix. Their blades capture kinetic energy from the wind, driving generators housed inside the turbines.

B. Non-Renewable Energy Sources

Non-renewable energy sources, while essential for meeting current energy demands, have finite reserves. Once depleted, they cannot be replenished. Some key non-renewable sources are as follows::

1) Coal: Coal-fired power plants have historically been a dominant energy source. However, coal combustion releases greenhouse gases and pollutants, contributing to air pollution, climate change and high water usage.

2) Petroleum: Petroleum fuels our transportation sector and serves as a raw material for various industries. Yet, its extraction, refining, and combustion pose environmental challenges, including oil spills and emissions.

3) Natural Gas: Natural gas, abundant in shale formations, is a versatile fuel used for electricity generation, heating, and industrial processes. While cleaner than coal, it still emits carbon dioxide during combustion.

4) Nuclear Energy: Nuclear power plants rely on controlled nuclear reactions to produce heat, which then drives steam turbines. Although nuclear energy is low in greenhouse gas emissions, managing nuclear waste remains a critical concern.

C. Thermoelectric Power Plants and Water Usage

Non-renewable sources, especially coal, petroleum, natural gas, and nuclear, are commonly used in thermoelectric power plants. These plants operate by heating water to produce steam, which drives turbines connected to generators. However, water plays a crucial role in cooling these systems, enhancing their efficiency. Consequently, thermoelectric power plants consume substantial amounts of water, impacting local ecosystems and water availability. In contrast, renewable sources directly convert natural energy (such as sunlight or wind) into electricity, eliminating the need for external cooling.

D. Biomass

Biomass is derived from organic materials like wood and agricultural waste and offers a dual advantage in energy production. It is renewable, sourced from continually replenished organic matter, ensuring long-term sustainability. Additionally, biomass serves as a viable fuel for thermoelectric power plants, generating electricity through combustion and steam production. Unlike fossil fuels, biomass combustion is part of the natural carbon cycle, making it environmentally preferable. Due to the cooling requirements of thermoelectric plants, biomass tends has a higher water intensity compared to other renewable sources.

II. Methods

A. Data Preparation

We sourced the data for our analysis from the United States Energy Information Administration (EIA), which provides comprehensive information on water consumption across various energy sources. We excluded data preceding 2000 from the original dataset, focusing solely on the years 2000 to 2020. Subsequently, we transferred the dataset to Google Sheets for analysis.

B. Energy Consumption Analysis

We utilized the built-in tools within Google Sheets to generate a stacked bar graph illustrating energy consumption breakdown by various sources from 2000 to 2020. Additionally, we created pie charts for the years 2015 and 2020, showcasing energy consumption distribution among different sources (Figures 2, 3). Further segmentation of energy sources into renewable and non-renewable categories was conducted, with pie charts generated for 2015 and 2020 (Figures 4, 5).

C. Water Use Calculation

We computed water usage by the US power sector in 2020 based on the average water intensity of 11857 gallons per megawatt-hour (gal/MWh) [1]. This calculation involved aggregating energy consumption figures for each energy source and converting them from British thermal units (Btu) to megawatt-hours (MWh). We then multiplied the total energy consumption for by the average water intensity.

Similarly, we determined water usage by natural gas in 2020 using an average water intensity of 2793 gal/MWh. We converted the energy consumption from natural gas to MWh from Btu and multiplied it by the water intensity.

For coal, we calculated water usage in 2020 using an average water intensity of 21406 gal/MWh. We converted the total energy consumption attributable to coal to MWh from Btu and multiplied it by the water intensity.

In a 2014 study, Arent et al. [2] found that transitioning to 80% renewable energy sources could reduce water withdrawals by 50%. By 2020, renewable energy sources contributed 19.0% of the total energy supply, with projections suggesting a rise to 42% by 2050 [3]. To calculate the percentage reduction in water withdrawals from 2020 to 2050, we utilized the linear relationship identified in the study to determine the respective percentages for both years based on the contribution of renewable sources. We then found the difference between these percentages to ascertain the percent reduction, which we subsequently applied to the water consumption level in 2020 to estimate consumption in 2050.

III. Results

A. Energy Consumption over Time

The energy consumption over the past 20 years has remained fairly constant, with the most significant drop occurring in 2009, as illustrated by the bar graph in figure 1 showing consumption from 2000 to 2020.

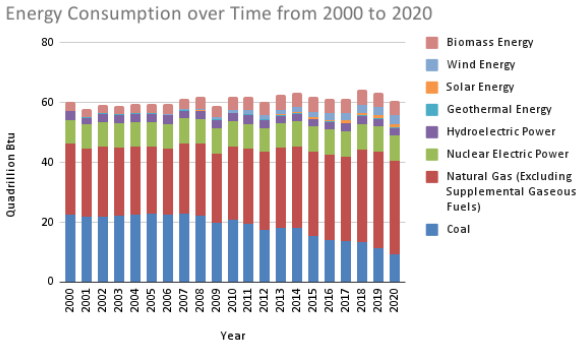

Fig. 1. Stacked Bar Graph Showing Consumption from 2000 to 2020 showing displacement of coal by natural gas after 2007 and steady increase in renewables

1) Energy Consumption by Source: Figure 2 elaborates on the energy consumption recorded in 2015. Natural gas emerges as the largest contributor, followed by coal, both of which are non-renewable sources. In contrast, renewable energy sources make the smallest contribution, with biomass energy being the most prominent, and solar energy being the least.

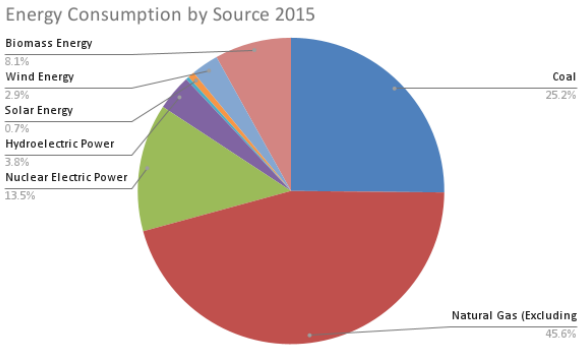

Fig. 2. Pie Chart Showing the Energy Consumption by Source in 2015 with total as 61.8 quadrillion BTU

Figure 3 illustrates the energy consumption recorded in 2020, by energy source. Natural gas continues to

hold a significant share, but there has been a notable shift. Coal's contribution has decreased substantially from 25.2% in 2015 to 15.2% in 2020 possibly due to hydraulic fracturing of natural gas. Conversely, renewable energy sources have seen an increase in their share, with solar energy, for instance, rising from 0.7% in 2015 to 2.0% in 2020, a relative tripling.

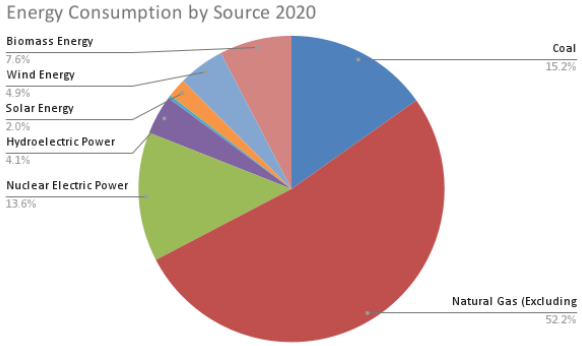

Fig. 3. Pie Chart Showing the Energy Consumption by Source in 2020 with total as 60.47 quadrillion BTU

2) Renewable Energy Sources: Figure 4 illustrates the breakdown of energy consumption from renewable sources in the year 2015. It reveals a significant contribution from biomass energy and hydroelectric power, with geothermal and solar energy trailing behind.

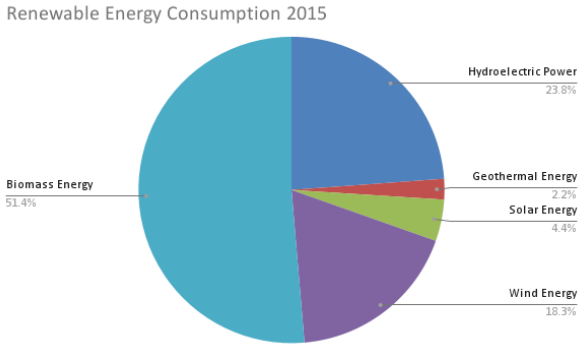

Fig. 4. Pie Chart Showing the Renewable Energy Consumption in 2015 with total as 9.737 quadrillion BTU

Figure 5 depicts the distribution of energy consumption from renewable sources in the year 2020. It indicates a decrease in the percentage contribution from biomass and hydroelectric power compared to previous years. However, there is an evident increase in the contribution from solar and wind energy, despite these sources still being among the overall least significant contributors.

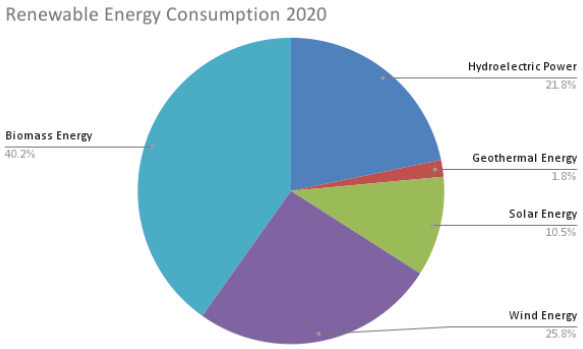

Fig. 5. Pie Chart Showing Renewable Energy Consumption in 2020 with total as 11.5 quadrillion BTU

B. Water Use

Table I presents the water usage data in gallons for the entire US Power Sector in 2020, along with the specific figures for Natural Gas and Coal. Additionally, the table provides projected water usage estimates for 2050, derived from the methodologies outlined in the methods section.

TABLE I
WATER USE IN GALLONS IN 2020 AND PROJECTED USE IN 2050

	Energy (MWh x 10^9)	Water (gal x10^{12})
2020 US Power Sector	17.7	210.2
2020 Natural Gas	9.20	57.6
2020 Coal	2.70	25.8
2050 Projected Total	-	179

IV. DISCUSSION

In 2015, the average water intensity for energy production was 14928 gal/MWh. However, by 2020, this figure notably decreased to 11857 gal/MWh. This reduction can be primarily attributed to the decline in reliance on coal, which in 2015 accounted for 25.2% of energy production at an average water usage of 21406 gal/MWh. This value is substantially higher than the overall average across all sources and significantly exceeds the water intensity of natural gas, which stood at 2793 gal/MWh.

Moreover, the increased adoption of renewable energy sources such as solar and wind has played a significant role in driving down average water usage. These renewable sources require considerably less water compared to traditional fossil fuels. The widespread transition towards renewable energy and the corresponding decrease in dependence on coal have thus contributed significantly to the overall reduction in average water usage for energy production. It is evident from projections that

with renewable energy sources poised to represent 42% of all energy sources in 2050, there is an anticipated 15% decrease in water usage compared to 2020 levels when renewables comprised 19% of total energy sources.

V. Conclusion

Transitioning to an energy mix dominated by renewable sources typically leads to a reduction in overall water usage. However, this transition faces practical challenges, particularly due to the varying efficiency and high setup costs associated with renewable sources like solar and wind energy. Consequently, the continued reliance on non-renewable sources such as coal persists, despite their high water consumption. Nevertheless, there has been a decreasing dependence on coal, considering its significant water usage. This decrease underscores the importance of ongoing efforts to promote renewable energy adoption while addressing the associated challenges to achieve a more sustainable and water-efficient energy future.

References

[1] "Thermoelectric cooling water data," *U.S. Energy Information Administration*, 2020. https://www.eia.gov/electricity/data/water/

[2] D. Arent, J. Pless, T. Mai, R. Wiser, M. Hand, S. Baldwin, G. Heath, J. Macknick, M. Bazilian, A. Schlosser, and P. Denholm, "Implications of high renewable electricity penetration in the U.S. for water use, greenhouse gas emissions, land-use, and materials supply," *Appl. Energy*, vol. 123, pp. 368–377, 2014, doi: https://doi.org/10.1016/j.apenergy.2013.12.022.

[3] K. Dubin, "EIA projects renewables share of U.S. electricity generation mix will double by 2050," 2021. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=46676

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