Renewable Energy Economics: Understanding the Costs and Capacity of Green Energy in the United States

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ABSTRACT

Although the cost of renewable energy has dramatically decreased in the United States over the past 10 years, many energy experts raise concerns regarding the efficiency of production and capacity to meet demand. This paper evaluates how demand for renewable energy in various sectors has changed over time in relation to cost, and if renewable energy has the capacity to meet growing demand in the future. Despite substantial efforts to maximize the generation of renewable energy, form government contracts with renewable energy companies, and incite investments in research and development for producing clean energy faster, production of renewables will likely not meet its exponentially growing demand. Furthermore, renewable energy is harder to implement in industrial and commercial sectors than traditional energy sources, due to infrastructure constraints. Although demand for energy will continue to increase, the use of natural gas is expected to remain constant, and it is essential that the United States continues expanding its capacity for renewable energy.

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INTRODUCTION

As we continue to battle the climate crisis, discussions about the harms of burning fossil fuels and regarding partially or completely switching to renewable energy—energy from sources that are "inexhaustible in duration but limited in the amount of energy that is available per unit of time" —have increased in prevalence. Unlike fossil fuels, renewable energy sources can be accessed an infinite number of times.[1] However, the amount of energy available for each use is limited. As such, voting for policies that encourage the government to fund research and development into renewable energy efficiency, as well as motivating corporations and individuals to utilize green energy, is essential for reducing the long-term consequences of burning fossil fuels and its impact on climate change.

According to Figure 1 from the U.S. Energy Information Administration, we still primarily burn fossil fuels (petroleum and natural gas) to generate energy. But currently, renewable energy consumption has surpassed that of coal, indicating that we are moving towards a more sustainable future.[1] To better understand how projections of clean energy production relates to the overall demand for energy in various sectors, this paper weighs the effectiveness of solar, hydroelectric, and wind energy sources in meeting growing energy demand.

Global Energy Demand and Renewable Energy Capacity

It's possible that nations that consume more energy per person (such as the U.S. when compared to countries with denser populations like China or India) have more energy draining residential and commercial sectors. This is visualized in Figure 2.[2] We also have to account for each nation's state of development, which influences how many people have access to electricity.

That being said, the U.S also has a greater annual change in renewable energy generation (larger capacity to generate more energy through greener sources).[3] This, however, should not undermine the enormous capacity for implementing renewable energy infrastructure in other nations—there is great potential to do so around the globe. In fact, many countries (especially in the European Union)

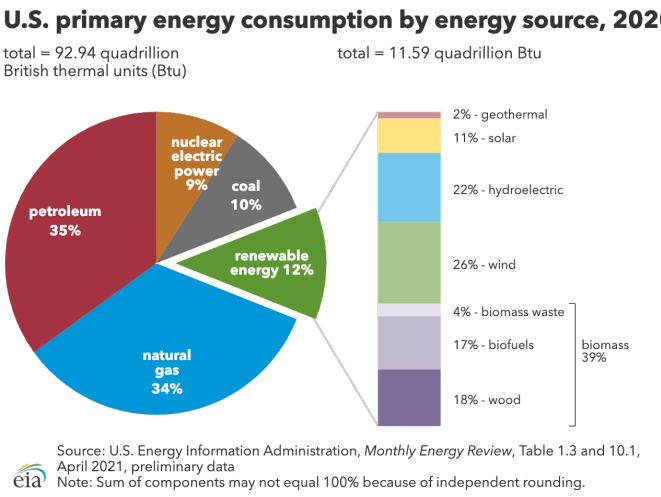

Figure 1: Wind and hydroelectric energy dominate renewable energy consumption, but petrol and natural gas dominate the overall consumption market.

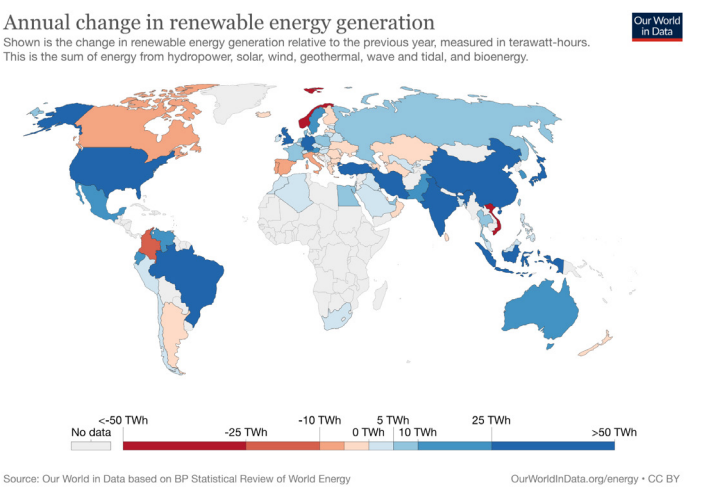

Figure 2: Global renewable energy generation complared to total energy consumption.

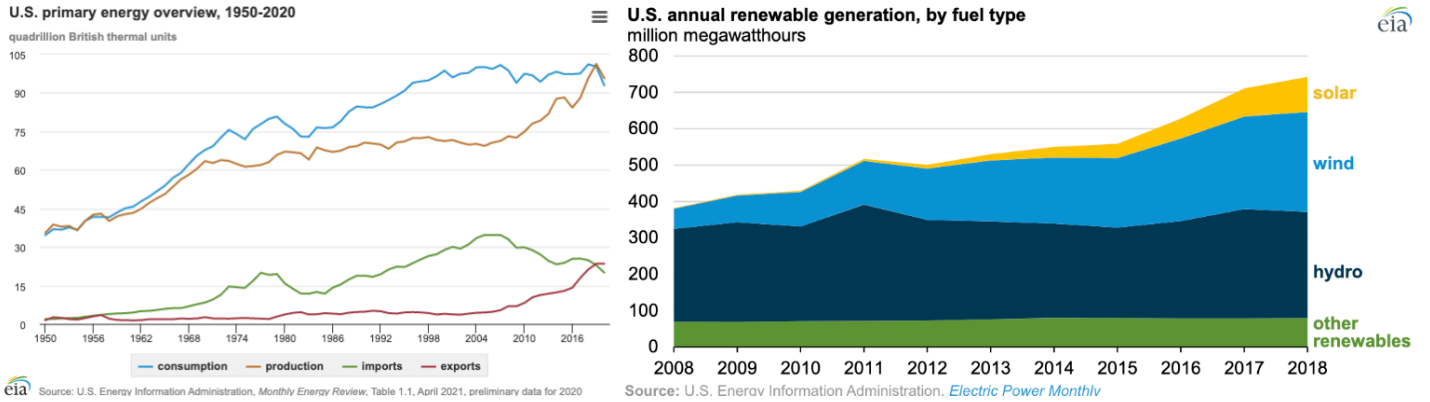

Figure 3: U.S. Energy supply and demand compared with source of renewable energy generation.

have contracts with corporations to expand renewable energy capacity and the "market for corporate power-purchase agreements—long-term deals to supply electricity—[boomed] in 2020."[4] Renewables are expected to "make up to 35% of electricity generation by 2030," mostly from wind and solar sources.[5]

Renewable Energy in the United States

U.S. renewable electricity generation has doubled since 2008, indicating improvements in renewable energy technology and increases in efficiency. The largest improvements are from solar and wind energy sources (Figure 3).[6] Figure 4 further highlights the fact that the electric power sector is the largest consumer of wind, hydropower, and solar power.

We can conclude that the sale of renewable energy is more lucrative than that of fossil fuels because the infrastructure for green energy production costs less than fossil fuel extraction, in most cases, especially when depleting fossil fuel reservoirs force the relocation of mines or drills or presents added challenges to worker safety, labor equipment costs, and liability.[7]

If the costs of implementing green energy continue to decrease and the electric power sector continues obtaining most of its energy from these sources, we can conclude that the consumption of fossil fuels will dramatically decrease.

Oil consumption fell 9.1 million barrels/day (9.3%), a record low since 2011. Most of the demand originated from the U.S. and decreases in demand for oil led to a production decrease of 6.6 million barrels/day. Refinery utilization fell to 74.1%—the lowest level since 1985.[8] Despite this trend, demand for natural gas drastically increased as prices fell to $1.99/mmBtu in the U.S. and the share of gas in primary energy rose to 24.7%.[8] As stated before, solar and wind capacity increased; solar electricity rose by 20%. China, the U.S., and Europe spearheaded the largest renewable growth change, largely due to policies that support investments in renewable energy research and infrastructure.[8] Some examples of such policies include the European Green New Deal, Germany's proposal to reach 50% renewable energy by 2030 and 80% by 2050, and 15 EU nations that reached 18% renewable energy in 2020.[16,17,18] An increase in efficiency and quantity of energy generated from renewable energy, along with government funded implementation and research and development subsidies, lead to a significant decrease in cost, fueling a positive cycle to better implement these technologies and move further away from burn-

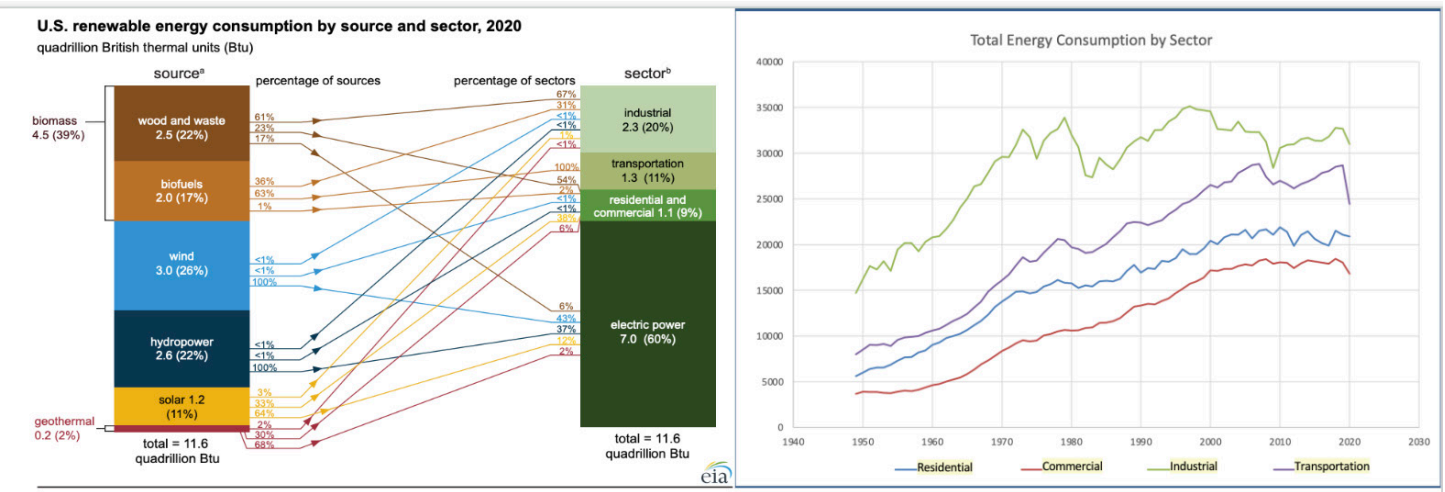

Figure 4: U.S. Energy supply and demand compared with source of renewable energy generation.

ing fossil fuels. Renewable energy continues to cost less and will be a significant part of our future.

My research project aims to analyze how energy demand projections compare with renewable energy production and consumption within each sector, and how this demand may change if costs of developing and using renewable energy continue to decrease. This will help us better understand if renewable energy has the capacity to meet projected demands for energy and if it will continue to be a significant part of energy economics.

METHODOLOGY

Sources

All my datasets come from the United States Energy Information Administration (US EIA), within the U.S. Department of Energy and I mainly studied data from the Energy Consumption by Sector and Type of Energy Consumed by Each Sector. I also used the interactive model feature on their websites for datasets that were too large or had too many sub-files to download, and referenced various articles and data visualizations provided by these government websites or other reliable sources.

Technology

I mainly used the Python libraries Pandas, NumPy, Seaborn, and Matplotlib for my analyses and visualizations after downloading the data and logging it into a Jupyter Notebook. For datasets that were in an Excel file format, I opened the file in Excel and made visualizations using the built-in software.

RESULTS

Demand for Energy

With the data from the Energy Consumption by Sector dataset, I created the Total Energy Consumption by Sector within figure 4 which visualizes how much the demand for energy from various sources has changed from 1949 to 2020. All measurements are in Trillion btus (British Thermal Unit of energy measurement). I would like to mention that we can attribute the dramatic decrease in energy consumption in 2020, especially in the industrial and transportation sector, to the COVID-19 pandemic because of the consequent shutdown of countless offices, businesses, and factories.

Over the past 70 years, demand for energy has exponentially increased in each sector—and it will continue to do so before plateauing at a high consumption amount. Since we primarily rely on natural gas and petroleum for electricity, if we fail to generate enough energy to meet demand from renewable sources, we will be forced to continue burning these "dirty" fuels and harming our planet. The limited supply and increasing costs of procuring "dirty" fuels also puts our economy at risk. Even minor disturbances in this supply chain could result in disastrous energy crises and recessions, since the health and stability of many industries relies on steady energy costs and production.

DISCUSSION

Costs of Energy

According to Our World in Data, "wind was 22% [and] solar [was] 223% more expensive than coal." Figure 5 best visualizes the changes in costs of various sources of energy from 2009 to 2019. The most dramatic decrease is in solar photovoltaic power by 89% followed by onshore wind by 70%.[9] Although the cost of renewable energy has decreased, the overall costs of energy have increased between 2010-2020 by 1.61 cents/kilowatt hour for residential consumers, 0.4 cents/kilowatt-hour for commercial consumers, yet decreased by 0.1 cents/kilowatt-hour for industrial consumers, and 0.66 cents/kilowatt-hour for transportation consumers, as shown in figure 6.[10] The overall staggering decrease in fossil fuel consumption for electricity generation, as shown in figure 5 could also influence the changes in price for each of these sectors.

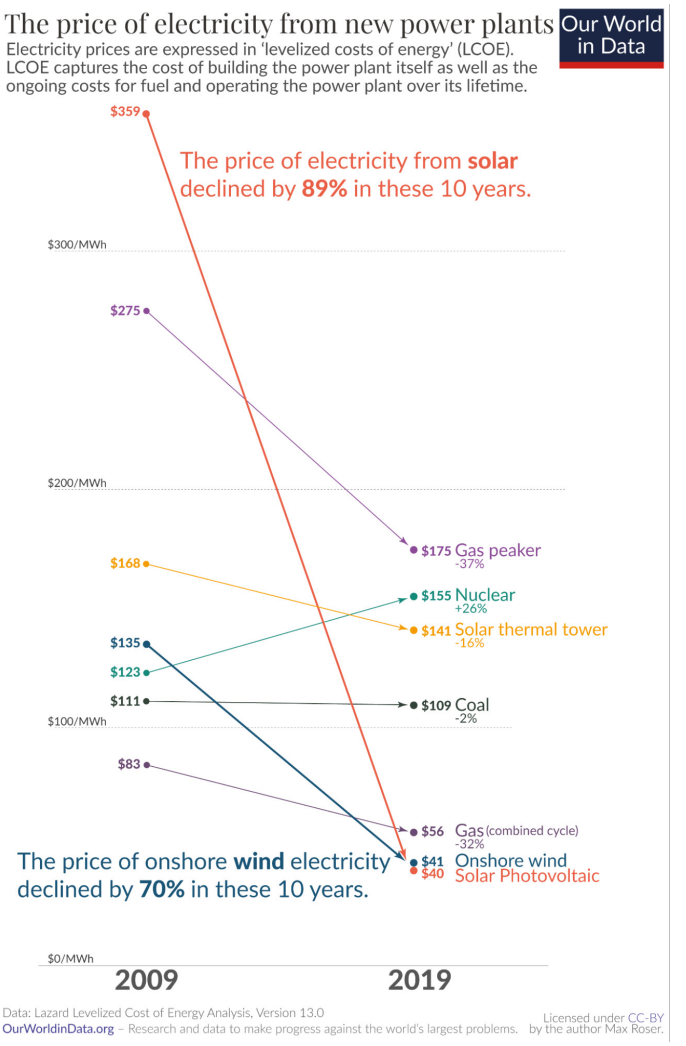

Figure 5: Visualizations of changes in costs for various energy sources.

Implementations of Renewable Energy

A 100% shift to renewable energy can be an unrealistic goal because lots of existing infrastructure, especially in the commercial and industry sector, was built to consume fossil fuels. For example, New York's ambitious goal to reach 100% Clean Energy by 2040 is facing challenges as their "grid must grow to supply 75% more power" and "has just nine years to more than double the share of electricity it uses that is generated from wind, sun, and water to 70 percent, from less than 30 percent today".[11] We can hope for more dramatic shifts in the residential sector because it is easier to build new greener homes and remodel older ones, especially when there is an incentive to do so—if it increases

(From Chapter 5.) Consumption of Fossil Fuels

	For Electricity Generation				For Useful Thermal Output			
Year	Coal (Thousand Tons)	Petroleum (Thousand Barrels)	Natural Gas (Millions of Cubic Feet)	Other Gas (Millions of BTU)	Coal (Thousand Tons)	Petroleum (Thousand Barrels)	Natural Gas (Millions of Cubic Feet)	Other Gas (Millions of BTU)
2010	979,684	65,071	7,680,185	90,058	21,727	10,161	821,775	172,081
2011	934,938	52,387	7,883,865	91,290	21,532	9,223	839,681	191,138
2012	825,734	40,977	9,484,710	103,353	19,333	9,828	886,103	199,121
2013	860,729	47,492	8,596,299	115,303	18,350	10,886	882,385	189,902
2014	853,634	53,593	8,544,387	110,010	18,107	9,513	865,146	194,088
2015	739,594	49,145	10,016,576	105,997	16,632	8,864	935,098	183,596
2016	677,371	43,671	10,170,110	73,785	16,586	7,770	1,151,866	221,835
2017	663,911	39,144	9,508,062	70,721	14,667	6,899	1,168,544	227,981
2018	636,213	46,727	10,833,043	78,757	13,813	7,261	1,205,962	274,612
2019	537,620	34,454	11,601,600	71,854	12,397	6,357	1,196,025	209,000
2020	435,351	33,391	11,916,248	69,609	10,402	5,629	1,292,624	199,076

(From Table 2.4.) Average Price
(Cents per Kilowatthour)

Year	Residential	Commercial	Industrial	Transportation	Other	Total
2010	11.54	10.19	6.77	10.56	N/A	9.83
2011	11.72	10.24	6.82	10.46	N/A	9.90
2012	11.88	10.09	6.67	10.21	N/A	9.84
2013	12.13	10.26	6.89	10.55	N/A	10.07
2014	12.52	10.74	7.10	10.45	N/A	10.44
2015	12.65	10.64	6.91	10.09	N/A	10.41
2016	12.55	10.43	6.76	9.63	N/A	10.27
2017	12.89	10.66	6.88	9.68	N/A	10.48
2018	12.87	10.67	6.92	9.70	N/A	10.53
2019	13.01	10.68	6.81	9.66	N/A	10.54
2020	13.15	10.59	6.67	9.90	N/A	10.59

(From Tables 10.1. and 10.2.) Energy Efficiency

	Incremental Annual Savings		Incremental Costs		Life Cycle Savings		Life Cycle Costs	
Year	Energy (MWh)	Peak Demand (MW)	Incentives (thousand dollars)	Other (thousand dollars)	Energy (MWh)	Peak Demand (MW)	Incentives (thousand dollars)	Other (thousand dollars)
2013	24,653,124	11,078	2,871,654	1,944,597	249,940,645	10,956	6,028,810	3,994,889
2014	26,466,020	6,453	3,410,854	2,209,098	301,956,123	8,040	4,007,452	3,120,898
2015	26,129,489	5,952	3,448,286	2,283,300	296,346,403	7,096	4,255,368	3,710,453
2016	27,500,224	5,658	3,570,950	2,522,854	354,347,692	7,050	4,126,758	3,432,717
2017	29,899,028	6,071	3,664,407	2,297,957	374,826,892	5,951	4,849,803	3,162,995
2018	28,415,037	6,309	3,484,767	2,165,981	359,446,175	6,075	4,177,905	4,179,320
2019	28,562,529	7,135	3,657,477	2,288,028	355,216,512	6,931	4,351,926	3,655,607
2020	28,167,459	6,287	3,152,372	2,112,261	367,829,206	6,003	3,561,148	3,349,318

Figure 6: Consumption of fossil fuels, average price of electricity per kilowatt-hour, savings from increased energy efficiency.

property value. Figure 6 further supports this notion because it shows the total decrease in energy used in newer homes; the primary energy source is not natural gas.[12] Since homes can more easily adapt to renewable energy, it is possible that the slight increase in costs resulted from the initial costs of incorporating renewable energy infrastructure at the beginning of the decade. Again, costs for doing so have now dramatically decreased, making it easier for future homeowners to make the switch. Although it does not specify what sources create the "Electricity" category, we can eliminate one of the largest dirty fuel sources, natural gas, because Figure 7 Average cost of gas in the US per week since 1990 (adjusted for inflation) it is in a different category. Additionally, governments have subsidized the costs of installing renewable energy infrastructure in the residential sector to encourage movements towards a greener economy.[13] We can also hope for larger shifts in the transportation sector; companies like Tesla, Ford, Toyota, and Chevrolet have brought electric vehicles to the forefront, and existing strict emission regulation policies have incentivized the sales of such vehicles for consumers and sellers through emission subsidy programs. Since the number of consumers is projected to increase, as shown in figure 6, any progress towards renewable energy implementation in any sector is better than nothing.[10]

Despite these efforts, the average price of gas per gallon per week since January 1st, 1990 has dramatically decreased, as visualized in figure 7. Maintaining low gas prices is essential for a healthy economy as it allows consumers to have more "disposable income [which would not] weigh on discretionary spending," Such low prices, however, could reduce incentives for consumers to switch to electric or hybrid vehicles.[14] Although this may motivate electric power companies and clean energy suppliers to double-down on research and development investments to further reduce the costs of electricity—countering the low gas prices to remain a player in an extremely market with exponential demand—the overall convenience for consumers' continued reliance on gas may slow progress towards a greener future. Again, the energy industry responds as governments and car manufacturers offer even more EV savings and emphasize the fact that low maintenance and operations cost could save "consumers up to an extra $7,000" of which "$800-$1,000 are from fuel costs alone".[15]

CONCLUSION

Demand for energy is projected to increase in every sector, most notably in the total electric industry. As efficiency for renewable energy increases, most of the generated energy will be allocated to this sector. Again, costs for sustainable energy must continue to decrease and remain significantly cheaper than fossil fuels to provide the total electric industry sector an incentive to invest in this energy. We can conclude that the use of natural gas will largely remain constant while the use of renewable energy will increase, especially in the residential sector. The use of coal is projected to decrease; since we are still burning natural gas for most of our energy, we will still be damaging our environment. As such, renewable energy has tremendous potential and will decrease our use of certain fossil fuels, but it may fail to diminish the burning of natural gas by a notable amount. To ensure that we can develop renewable energy technology that can meet the ever-increasing demand and prevent dependency on natural gas, we must continue to fund research in the materials sciences, energy sector, and energy economics.

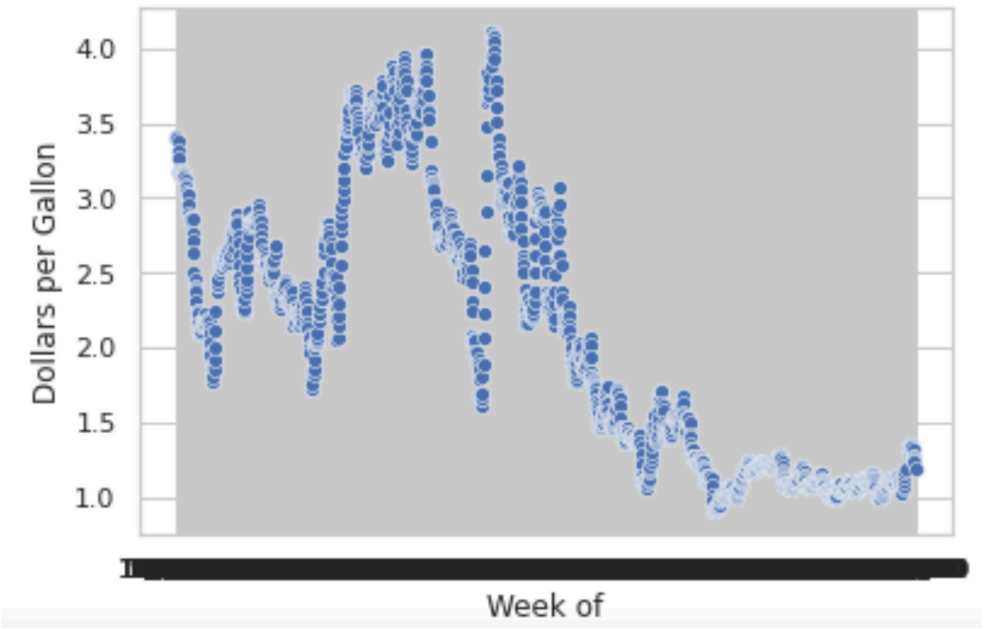

Figure 7: Average cost of gas in the US per week since 1990 (adjusted for inflation).

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REFERENCES

1. U.S. Energy Information Administration. (2022, January). Renewable energy explained. Retrieved from U.S. Energy Information Administration - Independent Statistics & Analysis: https://www.eia.gov/energyexplained/renewable-sources/
2. Our World in Data. (2019, December). Primary Energy Consumption. Retrieved from Our World in Data - Energy Data Explorer : https://ourworldindata.org/explorers/energy?facet=none&country=USA~GBR~CHN~OWID_WRL~IND~BRA~ZAF&Total+or+Breakdown=-Total&Energy+or+Electricity=Pri mary+energy&Metric=Annual+consumption.
3. Our World in Data. (2019, December). Primary Energy Consumption. Retrieved from Our World in Data - Energy Data Explorer : https://ourworldindata.org/explorers/energy?facet=none&country=USA~GBR~CHN~OWID_WRL~IND~BRA~ZAF&Total+or+Breakdown=-Total&Energy+or+Electricity=Pri mary+energy&Metric=Annual+consumption.
4. The Economist Group. (2021). The use of renewable energy is accelerating. Retrieved from The Economist: https://www.economist.com/graphic-detail/2021/05/11/the-use-of-renewable energy-is-accelerating
5. Center for Climate and Energy Solutions. (2022). Renewable Energy. Retrieved from Center for Climate and Energy Solutions - Technology Solutions: https://www.c2es.org/content/renewableenergy/#:~:text=Renewables%20made%20up%2019.8%20percent,come%20from%20wind%20and%20solar
6. U.S. Energy Information Administration. (2019, March 19). U.S. renewable electricity generation has doubled since 2008. Retrieved from U.S. Energy Information Administration - Independent Statistics & Analysis: https://www.eia.gov/todayinenergy/detail.php?id=38752
7. U.S. Energy Information Administration. (2020, December). U.S. renewable energy consumption by source and sector. Retrieved from Independent Statistics & Analysis: https://www.eia.gov/totalenergy/data/monthly/pdf/flow/renewable_energy_2020.pdf British Petroleum. (2021). Statistical Review of World Energy. Retrieved from BP Energy Economics: https://www.bp.com/en/global/corporate/energy-economics/statistical review-of-world-energy.html
8. Our World in Data. (2020, December 1). Why did renewables become so cheap so fast? Retrieved from Our World in Data: https://ourworldindata.org/cheap-renewables-growth U.S. Energy Information Administration. (2020). Summary Statistics for the United States 2010-2020. Retrieved from U.S. Energy Information Administration - Data and Figures: https://www.eia.gov/electricity/annual/html/epa_01_02.html
9. Anne Barnard, G. A. (2021, November 21). New York: Can New York Really Get to 100% Clean Energy by 2040. Retrieved from The New York Times: https://www.nytimes.com/2021/11/29/nyregion/hochul-electrical-grid-climate change.html
10. U.S. Energy Information Administration. (2018, May).

Residential Energy Consumption Survey (RECS). Retrieved from U.S. Energy Information Administration - Independent Statistics & Analysis: https://www.eia.gov/consumption/residential/data/2015/hc/php/hc1.3.php
11. California Distributed Generation Statistics. (2022). California Solar Initiative. Retrieved from California Distributed Generation Statistics - Statistics and Charts: https://www.californiadgstats.ca.gov/charts/
12. Emma Goldberg, C. M. (2021, November 20). Family Unvisited, Travel a No-Go: The Hard Costs of High Gas Prices. Retrieved from The New York Times: https://www.nytimes.com/2021/11/20/business/high-gas-prices.html
13. Preston, B. (2020, October 8). EVs Offer Big Savings Over Traditional Gas-Powered Cars. Retrieved from Consumer Reports: https://www.consumerreports.org/hybrids-evs/evs offer-big-savings-over-traditional-gas-powered-cars/
14. International Energy Agency (IEA) (2020), Germany 2020, IEA, Paris https://www.iea.org/reports/germany-2020
15. International Trade Administration (ITA) (2020, October 10) Italy - Country Commercial Guide. Retrieved from https://www.trade.gov/country-commercial-guides/italy-renewable-energy#:~:text=Italy%20ranks%20third%20in%20Europe,versus%20a%2017%25%20target).
16. European Commission (2022) A European Green New Deal. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en