Analysis and Visualization of Global Renewable Energy Trends

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***Abstract*—**To counteract global climate change and achieve sustainable development, a shift to renewable energy is needed. To visualize the trends, challenges and advancements in the adoption of renewable energy, this research, entitled "Analysis and Visualization of Global Renewable Energy Trends," analyses data on renewable energy worldwide. We analyze yearly percentage changes in consumption and production over the last 20 years using a comprehensive dataset that includes biofuel, coal, fossil fuel, gas, hydro, low carbon, nuclear, solar, oil, and wind. We depict the increasing significance of renewable energy in the global energy landscape using a variety of intricate visualizations, including choropleth maps, bar charts, line charts, and stacked bar charts. Our data shows a significant rise in coal and oil output, as well as constant increases in fossil fuel and biofuel use. Furthermore, a geographical study highlights the varying rates of renewable energy adoption across nations and continents. This paper provides vital insights into the worldwide transition to renewable energy, emphasizing major trends and problems that governments, industry stakeholders, and researchers must address to ensure continued success in sustainable energy development.

I. INTRODUCTION

The global energy landscape is undergoing profound transformation as a result of the urgent need to combat climate change and achieve sustainable development goals. For many years, fossil fuels such as coal, oil, and gas dominated the energy industry, boosting economic expansion but producing substantial environmental issues such as greenhouse gas emissions and air pollution. Transitioning to renewable energy sources is critical for reducing these effects and ensuring a sustainable future.

Renewable energy sources, including solar, wind, hydro, and biofuels, provide a cleaner and more sustainable alternative to fossil fuels. These energy sources not only cut carbon emissions, but they also provide economic advantages such as growth in employment, energy security, and technological innovation. The rising affordability and efficiency of renewable technologies, together with supporting legislative frameworks, have hastened global adoption of renewable energy. However, the shift to renewable energy presents significant problems. High initial investment costs, infrastructure constraints, and political and market impediments may stunt development. Furthermore, adoption rates vary greatly among areas and nations, depending on local legislation, economic conditions, and resource availability.

Using a comprehensive dataset covering biofuel, coal, fossil fuel, gas, hydro, low carbon, nuclear, solar, oil, and wind, this study investigates the annual percentage changes in consumption and production from 2000 to 2022. Through intricate visualizations such as stacked bar charts, bar charts, line charts, and choropleth maps, the study highlights major patterns and fluctuations in the global energy balance. The main objectives are to analyze these annual changes, compare growth rates of renewable and non-renewable energy, visualize the transition to renewable energy across different regions, and identify key trends to inform policy and decision-making.

II. DATASET

The dataset utilized in this report encompasses a comprehensive array of energy-related metrics sourced from 'Our World in Data'. It includes data spanning multiple dimensions such as energy consumption, annual changes, annual percentage changes, electricity generation, and the share of primary energy consumption derived from biofuel, coal, gas, oil, wind, solar, hydro, low carbon, and nuclear sources. Additionally, the dataset provides insights into production metrics for coal, oil, and gas, as well as greenhouse gas emissions stemming from electricity generation.

Dataset variables

Column name	**Description**	**Units**
cons_change_pct	Annual percentage change in power consumption	%
cons_change_twh	Annual change in power consumption	terawatt-hours
consumption	Primary energy consumption from power	terawatt-hours
elec_per_capita	Electricity generation from power per person	kilowatt-hours
electricity	Electricity generation from energy source	terawatt-hours
energy_per_capita	Power consumption per capita	terawatt-hours
share_elec	Share of electricity generated	%
share_energy	Share of primary energy consumption that comes from energy source	%

Table 1. Type of attributes in the dataset

Moreover, the dataset is enriched with demographic and economic indicators, including data on population and GDP, alongside temporal and geographical categorizations, ensuring a robust foundation for detailed analysis and visualization of global energy trends and dynamics. This comprehensive dataset serves as a pivotal resource for informing strategic decision-making and policy formulation aimed at advancing sustainable energy practices worldwide.

III. PROCEDURE

We commenced our study by importing a comprehensive dataset sourced from 'Our World in Data', focusing on key energy metrics critical for understanding global energy trends. Through rigorous preprocessing steps, we meticulously cleaned the dataset by removing duplicates and null values, ensuring data integrity. Subsequently, we filtered the dataset to include only data spanning from 2000 to 2021, a timeframe essential for conducting meaningful visualizations and analysis.

Our analysis was centred around plotting trends in various energy sources across different regions, spanning from 1970 to 2021. This approach provided us with a longitudinal perspective, enabling the identification of significant patterns and shifts in global energy consumption and production dynamics over decades.

Three major case studies formed the cornerstone of our project:

European Case Studies: We focused on prominent European countries including the United Kingdom, France, Germany, Italy, and Spain. This analysis aimed to explore regional energy consumption patterns, policy impacts, and technological advancements within the European Union.

Developing Countries Case Studies: Our investigation extended to developing nations such as India, Brazil, Argentina, South Africa, China, Indonesia, Mexico, and Nigeria. This comprehensive analysis delved into the unique challenges and opportunities these countries face in their energy transitions, considering factors like economic growth, infrastructure development, and sustainability initiatives.

United States Case Studies: We conducted detailed examinations of energy trends and policies in the United States, focusing on consumption patterns, renewable energy integration, and environmental impacts. This analysis provided insights into one of the world's largest energy consumers and its transition towards cleaner energy sources.

Additionally, we conducted a worldwide analysis of energy trends to identify global patterns, regional disparities, and emerging trends in renewable and non-renewable energy adoption. By leveraging sophisticated visualizations such as stacked bar charts, bar charts, line charts, and geographic maps, we gained valuable insights into the evolving landscape of global energy consumption and production.

Our approach not only facilitated a comprehensive understanding of current energy dynamics but also highlighted key insights crucial for informing policy decisions, supporting sustainable development goals, and advancing global efforts towards a more resilient and sustainable energy future.

IV. RESULTS

The analysis of global energy consumption trends from 2000 to 2021 reveals significant shifts in the energy landscape. Fig. 1 illustrates the Share of Renewable Energy across the Globe, driven by both developing and industrialized nations. During this period, renewable energy sources, including solar and wind, have shown exponential growth, contributing to a notable reduction in the share of fossil fuels such as coal and oil in the global energy mix.

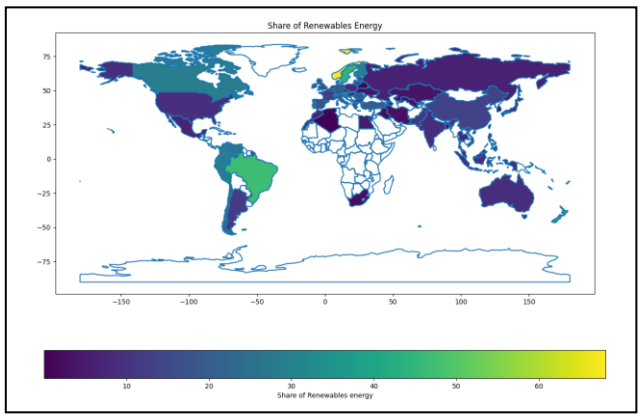

Fig. 1. Share of Renewable Energy across the Globe

Regional Case Studies

A. European Case Studies

Focused investigations into energy consumption patterns across major European countries—United Kingdom, France, Germany, Italy, and Spain—reveal diverse levels of renewable energy adoption and underscore the policy impacts on their respective energy landscapes. Fig. 2 visually depicts a consistent reduction in greenhouse gas emissions across these regions, reflecting Europe's steadfast commitment to attaining carbon neutrality by 2050. This trend underscores significant strides towards sustainable energy practices and highlights the effectiveness of regional policies aimed at mitigating climate change impacts.

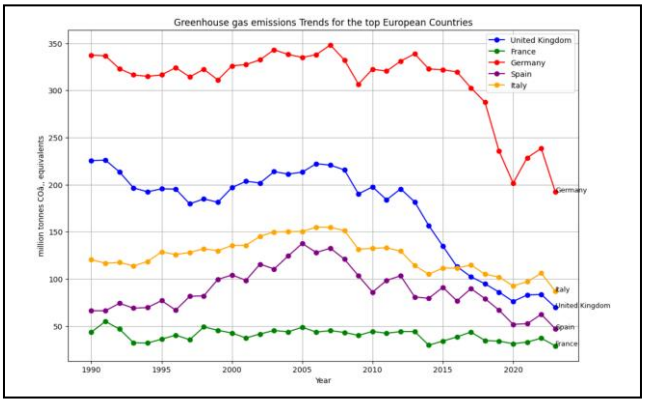

Fig. 2. Greenhouse gas emissions for European countries (1990-2023)

B. Developing Countries Case Studies

In developing nations like India, Brazil, China, and Nigeria, energy consumption trends mirror rapid economic expansion alongside challenges posed by urbanization. Fig. 3 illustrates a growing dependency on coal in countries such as India, China, Indonesia, and South Africa, despite substantial investments in renewable energy infrastructure. Conversely,

Nigeria, Mexico, and Argentina primarily rely on natural gas, yet they have made notable strides in hydroelectric power generation, capitalizing on their abundant natural resources to promote sustainable energy solutions. These contrasting trends highlight the diverse energy strategies and challenges faced by developing countries striving to balance economic growth with environmental sustainability.

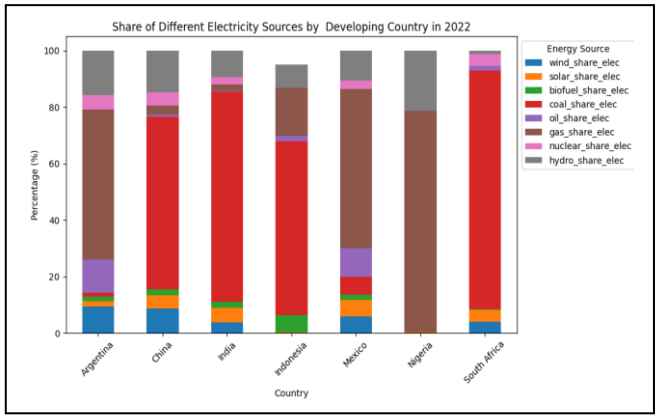

Fig. 3. Share of Electricity Sources by Developing Countries in 2022

C. *United States Case Studies*

The United States demonstrates a diverse energy portfolio marked by a gradual reduction in coal and oil consumption since the turn of the 21st century, alongside significant growth in natural gas and renewable energy production (Fig. 4). State-level analyses highlight California's leadership in adopting solar energy and Texas' prominence in wind power generation, showcasing regional disparities in energy policy and resource utilization strategies. These trends underscore the country's evolving energy landscape and the varying approaches states employ to meet energy demands while advancing towards sustainable energy solutions.

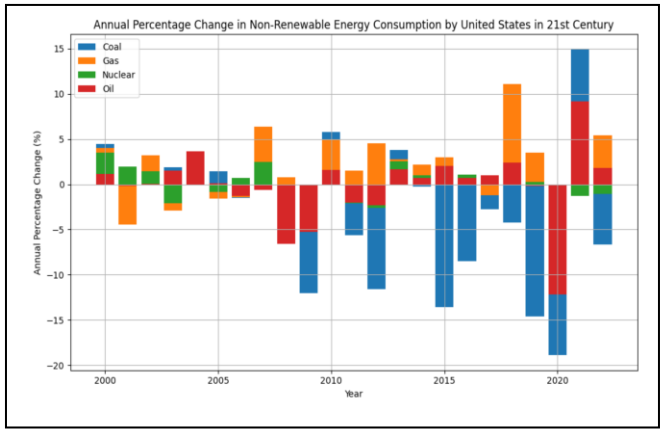

Fig. 4. Annual Percentage Change in Non-Renewable Energy Consumption by United States

A comprehensive global analysis reveals that the pace of energy transition varies significantly worldwide, shaped by a complex interplay of economic factors, policy frameworks, and technological advancements. Developed regions exhibit promising trends towards integrating renewable energy sources into their energy mix, driven by robust policy support, technological innovation, and increasing environmental awareness. In contrast, developing nations encounter unique challenges as they strive to balance rapid economic growth with the imperative of environmental sustainability. This analysis underscores the importance of tailored strategies and collaborative efforts on a global scale to accelerate the transition towards a more sustainable energy future for all nations.

V. CONCLUSION

Our project has provided a comprehensive analysis of global energy trends, highlighting significant insights into the evolving landscape of energy consumption and production from 2000 to 2021. The findings underscore a marked transition towards renewable energy sources across developed regions, driven by robust policy frameworks and technological advancements. This shift reflects a growing commitment to mitigating climate change and achieving sustainable development goals.

Conversely, developing nations face distinct challenges in balancing economic growth with environmental sustainability. Despite these challenges, countries like India, Brazil, and Nigeria have made notable strides in renewable energy adoption, leveraging their natural resources to expand hydroelectric power generation while grappling with ongoing reliance on coal and oil. The regional dynamics underscore the critical role of localized policy initiatives and resource utilization strategies in shaping national energy portfolios.

Overall, our study emphasizes the uneven pace of global energy transition, influenced by diverse economic contexts and policy landscapes. Moving forward, addressing these disparities will require tailored strategies, international cooperation, and continued innovation to accelerate the adoption of sustainable energy solutions worldwide. By harnessing these insights, policymakers and stakeholders can effectively navigate the complexities of energy transition, fostering a more resilient and environmentally sustainable future for all nations.

VI. FUTURE WORK

Looking ahead, there are several promising avenues for further research and action to advance our understanding and support sustainable energy development globally. Enhancing data granularity with more detailed temporal and spatial resolutions will allow for deeper insights into regional variations and the localized impacts of energy policies and technological advancements. Longitudinal studies beyond 2021 could provide valuable insights into the long-term effectiveness of renewable energy initiatives and their impacts on global energy transitions. Comparative analyses of energy policies across different regions would help identify best practices and lessons learned, supporting more effective policy interventions worldwide. Integrating socioeconomic factors such as income levels and urbanization rates into energy transition models would provide a more comprehensive understanding of the drivers and barriers to renewable energy adoption. Addressing these areas of future work will be crucial in navigating the complexities of energy transition and advancing towards a sustainable and resilient energy future for all.

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