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EVALUATION OF RENEWABLE ENERGY GROWTH AND ITS ROLE IN CLIMATE CHANGE MITIGATION

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Abstract

Energy systems around the world have developed with an increasing sense of urgency to consider climate change and a continued reliance on fossil fuels. This article analyzed how primary-energy production and consumption shifted over time from 1980 to 2021, by country and region, focusing on the expansion of nuclear, renewable and other non-fossil-energy power sources. Energy indicators were compared on an annual basis by analysing trends, percentage change, compound growth rates, regional shares and country ranking. Total primary energy consumption jumped from 292.94 to 603.32 quadrillion British thermal units (Btus), and combined non-fossil energy consumption increased from 28.28 to 100.87 quadrillion British thermal units (Btus). Its global share increased from 9.65% to 16.72%. Fossil energy use also increased, by 90.38% and still represented over four-fifths of total energy use in 2021. The non-fossil shares were comparatively high in Europe, Central and South America and North America while Africa and the Middle East were more dependent on conventional sources. The results showed that the growth of renewable and other non-fossil energy sources has helped to diversify energy supply but has not yet led to significant fossil fuel substitution. To achieve effective mitigation, therefore, more renewables need to be deployed, fossil fuels need to be phased down or eliminated, the grids need to be modernised, storage needs to be expanded, energy efficiency needs to be improved and technology needs to be made more accessible and available to the world.

Keywords: Renewable Energy, Climate Change Mitigation, Fossil-Fuel Dependence, Energy Transition, Primary-Energy Consumption

1. Introduction

The burning of coal, petroleum and natural gas is still a large contributor of man-made greenhouse-gas emissions, making it extremely important to move away from the current energy system. Governments are under additional pressure to provide secure supplies of energy in the face of the rising demand, industrialisation, urbanisation and population growth, with a drive to minimise the environmental impact. Renewable energy has therefore gained increasingly important importance in global and national mitigation policies and strategies, due to its potential to diversify energy sources, reduce reliance on carbon-intensive energy sources and facilitate long-term decarbonisation. Modelling efforts have demonstrated that a transition to a sustainable electricity system is more likely to be realized via a gradual shift and expansion of renewable energy generation, storage, sector coupling and transmission capacity, instead of a single sudden technological transformation (Bogdanov et al., 2019).

Advances in the cost of solar, wind, battery storage and integration of these power systems have bolstered the economic viability of renewable-energy deployment. Renewable electricity is gaining traction as not just an environmental option, but also a basis for electrifying transportation, heating and industrial processes. In the context of global transition scenarios, efficiency and flexible energy technologies (FET) combined with low cost renewable electricity can be expected to become the key enablers of a sustainable energy system (Bogdanov et al., 2021). Successful technological innovations, enabling policies, foreign investment and infrastructure development have helped the growth of renewable energy in various regions (Guchhait & Sarkar, 2023). However, in the last years, global energy patterns have revealed that fossil fuels still account for most of the energy consumption in the world even as the renewable energy capacity and generation have increased rapidly (Yolcan, 2023).

The climate impacts of the expansion of renewables are linked to whether renewable energy is replacing fossil fuels or is being added to. The additional energy supply from renewables could have a limited role in reducing energy demand if the overall demand for energy is rapidly expanding and conventional energy supply persists. Global carbon dioxide emissions have been linked to investment in renewable-energy technologies, but this link has been weak under certain financial conditions, conditions of institutional capacity, and conditions of development (Appiah-Otoo et al., 2023). The dynamics of the economic growth also complicated the relationship, as in the countries with growing production and consumption, the energy demand is also growing, despite the growth of renewable energy output (Mirziyoyeva & Salahodjaev, 2023). The results of OECD economies have also suggested differential and non-linear impacts of renewables and non-renewables on carbon emissions in both the short and the long term (Şanlı et al., 2023).

The financing capacity has resulted in disparities in renewable-energy transitions across countries. Renewable resources often have a high potential for developing economies, but these often have high capital costs, lack of adequate electrical grid, shortages of electrical storage capacity and poorer investment climates. Better capital markets may increase the availability of long-term financing and boost the contribution of renewable energy consumption towards emission reductions (Ofori-Sasu et al., 2023). Renewable energy has been found to be an important climate solution across the board, with its effectiveness being dependent upon local economic, technological and policy factors (Attanayake et al., 2024). The renewable deployment should go hand-in-hand with purposeful measures to phase down fossil fuels in rapidly growing economies to avoid any erosion in environmental benefits due to increased energy demands (Dalei & Gupta, 2024).

There is also a different correlation between renewable energy and carbon emissions at developed and developing countries. The developed countries have a number of advantages such as well established electricity markets, robust institutions, advanced electricity networks, and access to innovative finance for clean energy while developing countries face a multitude of challenges including energy poverty, industrial growth, and lack of infrastructure. Through comparative evidence, it has been found that the use of renewable energy can lead to emission reduction in both groups, but the magnitude of the effect varies, depending on the structural and developmental conditions (Wang & Khan, 2024). The impacts of renewable deployment do not necessarily lead to the same degree of decarbonisation across countries, as the overall country's energy mix, as well as emissions that are imported, the technical composition and continued reliance on fossil fuels affect the final environmental impact (Huang, 2024).

In light of these trends, measuring the development of renewables should take into account the actual increase in generation capacity as well as the evolution of the energy mix. High proportion of renewables could be an early sign of structural transition, whereas increasing contribution of coal, gas and petroleum could show less-than-complete displacement of fossil fuels. The current study hence focused on the global long-term trends in primary-energy generation and demand from 1980 to 2021, especially regarding the expansion of nuclear, renewable and other energies compared to fossil energies. It measured trends worldwide and across regions, the shifting energy mix of energy shares, and country-level disparities to see if the expansion of non-fossils has significantly lessened fossil-fuel dominance. The study's differentiation between relative diversification and absolute substitution gave more conservative estimates of the growth of renewable energy and its climate-change-mitigation potential. The major objectives of the study:

1. To evaluate global renewable and non-fossil energy growth from 1980 to 2021.
2. To compare changes in renewable and fossil-energy shares across countries and regions.
3. To assess whether non-fossil energy expansion reduced global dependence on fossil fuels.

2. Methodology

2.1 Research Design and Data Coverage

The study was designed as a quantitative longitudinal one to assess the variations in the global energy use and its significance for the mitigation of climate change. Five consumption files, five production files and one monthly energy overview have been analysed. The country-level files contained information on 230 geographical and historical entities from 1980 to 2021, and the monthly file contained information on the United States from January 1973 to November 2022. The annual country panel served as the main analytical data set due to its consistency in observing the various energy types, including coal, natural gas, petroleum, combined nuclear-renewable energy and total primary energy.

2.2 Variables and Measurement

Overall energy-demand was considered as the total primary-energy consumption, and fossil-energy dependence as coal, natural gas and petroleum consumption. The category of combined nuclear, renewable and other-energy was selected as the available non-fossil indicator as renewable energy was not reported separately in the country files. The contribution of the mitigation was estimated by its absolute growth, percentage share of total energy and its correlation with the loss of the fossil energy share. Production variables were kept for comparison while cumulative columns were not included since they included 42 observations a year and lost the temporal variation.

Table 1. Variables and operational measurements

Variable	Measurement	Analytical purpose
Total primary-energy consumption	Quadrillion British thermal units	Overall energy-demand trend
Coal consumption	Quadrillion British thermal units	Fossil-fuel dependence
Natural-gas consumption	Quadrillion British thermal units	Fossil-fuel dependence
Petroleum consumption	Quadrillion British thermal units	Fossil-fuel dependence
Nuclear, renewable, and other-energy consumption	Quadrillion British thermal units and percentage of total energy	Available indicator of non-fossil growth
Fossil-energy share	Coal, natural gas, and petroleum divided by total energy	Relative fossil dependence
Non-fossil energy share	Combined nuclear-renewable energy divided by total energy	Energy-transition and mitigation indicator
Total primary-energy production	Quadrillion British thermal units	Production-consumption comparison

2.3 Data Preparation

The country and continent names were sanitized by stripping leading and trailing spaces and fixed misspelled variable names were standardized in a consistent manner. Annual data for 1980-2021 were re-written in country-years and then disaggregated by country and continent and year. Double dashes and the code "ie" were represented as missing data (not as zeros) in the data set. Negative values in the combined nuclear-renewable series were not eliminated but were recognized as situations where caution should be exercised in reading the values. Historical states and territories (and countries, interpreted as the data set entities) remained in descriptive global totals, but country rankings were not necessarily interpreted as corresponding to sovereign countries.

2.4 Analytical Procedure

Analysis was conducted on annual totals, percentage changes, compound annual growth rates, the percentage of various energy sources, continental trends, and country rankings. The fossil-energy consumption was simply the sum of consumption from coal, natural gas and petroleum, and the non-fossil share was the consumption of combined nuclear-renewable divided by total primary-energy consumption. Growth rates were calculated for the period 1980-2021, and intermediate benchmark years were used to ensure that structural changes were observed. Production quantities were checked against consumption quantities as a consistency check. Results were summarized in tables, plotted as time-trend graphs, compared by region, and ranked by country, without making any conclusions about actual reductions in emissions, but rather about energy-transition evidence.

3. Results

3.1 Growth in Global Primary-Energy Use

However, global primary-energy consumption grew from 292.94 quadrillion BTU in 1980 to 603.32 quadrillion BTU in 2021, growing by 105.95%. Production of the rest of the world was the same; it increased from 296.34 to 606.82 quadrillion British thermal units. In 2021, petroleum was the top single consumption source at 186.71 quadrillion British thermal units (Btu), followed by coal at 166.72 and natural gas at 150.35. The parallel growth of production and consumption showed that the overall energy system had more than doubled, but not seen a contraction in conventional energy consumption.

Table 2. Changes in global primary-energy consumption, 1980–2021

Energy source	1980	2021	Growth (%)	Compound annual growth rate (%)
Coal	78.69	166.72	111.86	1.85
Natural gas	53.87	150.35	179.12	2.54
Petroleum	132.06	186.71	41.38	0.85
Nuclear, renewables, and other	28.28	100.87	256.70	3.15
Total fossil energy	264.62	503.78	90.38	1.58
Total primary energy	292.94	603.32	105.95	1.78

Note: Energy values were measured in quadrillion British thermal units.

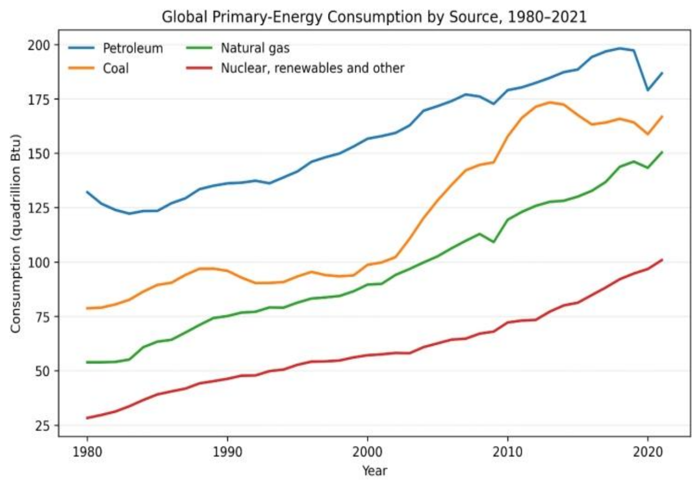

Figure 1. Global trends in primary-energy consumption by source, 1980–2021

3.2 Expansion of Nuclear, Renewable, and Other Energy

In 1980, the combined nuclear, renewable and other-energy consumption was 28.28 quadrillion British thermal units (Btu), while the consumption in 2021 was 100.87 quadrillion Btu. This sector achieved 256.70% CAGR and 3.15% growth which was higher than other fuels like coal, natural gas, petroleum, and total energy. It contributed to 9.65% of the global primary-energy consumption, which increased to 16.72%. Asia and Oceania had the highest growth numbers and the shares in Europe and Central and South America in 2021 were higher. These results showed significant non-fossil growth, but the total category did not allow for an individual assessment of renewable energy.

Table 3. Regional shares of nuclear, renewable, and other-energy consumption

Region	**Share in 1980 (%)**	**Share in 2021 (%)**	**Change in percentage points**
Africa	9.46	8.94	−0.52
Asia and Oceania	7.28	13.65	6.37
Central and South America	19.90	29.47	9.57
Eurasia	5.20	12.51	7.31
Europe	10.15	27.23	17.08
Middle East	1.70	1.31	−0.39

North America	12.37	21.63	9.26

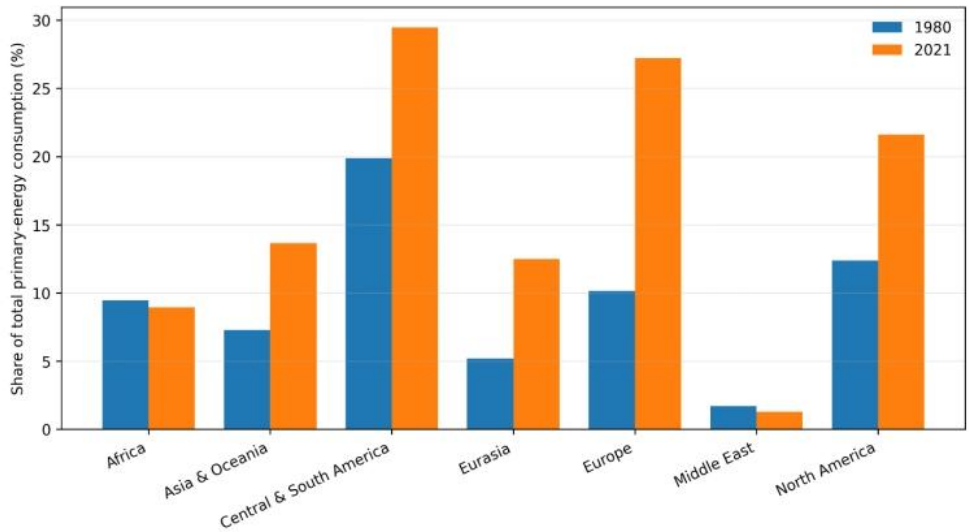

Figure 2. Regional comparison of nuclear, renewable, and other-energy shares in total primary-energy consumption, 1980 and 2021

3.3 Fossil-Energy Dependence and Mitigation Implications

The consumption of fossil energy has increased from 264.62 in 1980 to 503.78 in 2021, which represents a growth of 90.38%. However, its contribution to primary energy has dropped from 90.33% to 83.50% and the share of both nuclear and renewables has increased by 7.07 percentage points. The pattern showed a relative diversification, but not any displacement of fossil fuels. The greatest fossil-source growth was achieved for natural gas (179.12%), coal (111.86%) and petroleum (41.38%). Thus, non-fossil growth had been helping to enhance the energy mix, but not to offset the ongoing growth in global fossil-energy consumption.

3.4 Country-Level Energy-Transition Patterns

In 2021, the largest share of nuclear and renewables energy use was in China (24.72 quadrillion British thermal units), followed by the United States (20.30 quadrillion). The next ten largest entities were France, Brazil, Canada, Russia, India, Germany, Japan and South Korea. The shares of Norway and Sweden were higher: Both countries had more than 65% of their consumption consumed by relative shares, while Finland, Switzerland and France had more than 48% of their consumption consumed by relative shares of entities that use at least one quadrillion British thermal unit. Even with such big absolute volumes, their combined share was 14.97% (China) and 11.06% (India). It was revealed that scale and energy-mix transformation were two different aspects of the progress on mitigation.

Table 4. Leading entities by combined nuclear, renewable, and other-energy consumption in 2021

Rank	Entity	Consumption (quadrillion Btu)	Share of total energy (%)
1	China	24.72	14.97
2	United States	20.30	20.73
3	France	4.70	48.30
4	Brazil	4.69	38.79
5	Canada	4.64	32.71
6	Russia	4.19	12.25
7	India	3.53	11.06
8	Germany	2.69	21.55
9	Japan	2.43	13.42
10	South Korea	1.86	14.62

Source for all tables: Calculated from the uploaded energy datasets.

4. Discussion

The results indicated that primary energy use globally grew by over twice from 1980 to 2021 and that the growth in energy use from the nuclear, renewables, and other-energy group was greater than for all fossil-energy use. Its share rose to 16.72% from 9.65%, marking a progressive shift towards diversifying the energy mix. But the relative transition did not result in a real reduction in the use of fossil energy. Consumption of coal, natural gas and petroleum oil increased by more than 90%, and they continue to provide more than 4/5 of global primary energy in 2021. So non-fossil growth did not supplant fossil fuels, but helped to slow the dominance of fossil fuels. There were variations by region, with non-fossils higher in Europe, Central and South America and North America, compared to Africa and the Middle East. It was also found that large absolute amounts of energy consumption were not a good indicator of an energy mix transformation, as China and

India consumed energy from non-fossil energy sources, but had relatively low shares of non-fossil energy.

The patterns were in line with research that found a key mechanism for decarbonisation globally is the expansion of renewables, but that efficiency, electrification and structural changes are also key. (Gielen et al., 2019). Decomposition evidence confirmed that the change in renewable energy was influenced by demand, technology and economic structure in the case of absolute growth and genuine substitution (Dietzenbacher et al., 2020). It was found that the relationships between renewable consumption and emissions as well as between financial development and emissions differed by region, which corroborated with evidence that there are differences across countries between relationships among renewable consumption, emissions, and financial development (Khan et al., 2020). The simultaneous growth of conventional and non-conventional energy as reported would also mimic the situation of the emerging economies where economic growth had led to rising energy demand despite the growth of renewables (Le & Sarkodie, 2020). The higher non-fossil shares in a few of the regions were matched by comparative evidence that there was inter-regional variation in the mitigation contribution of renewable energy (Jia et al., 2021). Patterns at the country level also agreed with evidence that when renewable energy deployment was scaled up to a meaningful level, emissions reductions were possible in the largest energy-consuming economies (Huang et al., 2021). The lack of full fossil displacement led to the results obtained in the thresholds, in which greater gains from the emissions reduction did not occur unless the renewable consumption had reached a “sufficient” threshold (Chen et al., 2022). The continued reliance on fossil fuels was the other plentiful indicator that renewable energy would not be able to substitute fossil fuels without the inclusion of conservation, efficiency, storage, and policy to support these goals (Holechek et al., 2022).

Findings had significant policy and planning implications. Governments required to take a step beyond these absolute measures of renewable progress and to evaluate if renewable growth in energy use actually displaced fossil fuels in final demand, decreased the carbon intensity of energy use, and reduced fossil fuel shares. Low non-fossil shares in regions needed greater investments in access to cheap, clean energy, in cross-border interconnections, storage and grid expansion. Substitutions in energy mixes had to be fast for large economy energy consumers due to the fact that small proportional changes in their energy mixes had the potential to impact global results. Policy packages should also have to include measures for deploying renewables, promoting energy efficiency, demand management, transport electrification, decarbonisation of industry and retiring carbon-intensive infrastructure. Regional strategies should therefore take into consideration the availability of resources, income, technology and institutional capacity, and energy-security priorities, and should not be based on a single transition model.

There were a number of factors that limited interpretation. The main non-fossil variable was not just renewables, but included nuclear energy and other sources, which made it impossible to separate out the independent contribution of renewables. There was no carbon dioxide or GHG emissions and so no direct measurement of climate-change mitigation was performed instead it was extrapolated from change in energy-mix. The data also contained historical data for states and territories, missing-value codes, negative observations and minor inconsistencies between component and total consumption series. Global values may mask inequalities at the national level and differences across technologies and emissions imported. Comparisons in description were not able to prove a causal relationship between the nonfossil growth and the improvement in the environment. Future studies should discard renewable technologies from the nuclear technology and incorporate country-level emissions and economic controls, and use panel methods to determine whether higher shares of renewable technologies led to a decrease in carbon emissions in various development scenarios.

5. Conclusion

The growth of energy consumption was significantly outpaced by an even greater increase in the contribution to global energy from nuclear output, renewable and other energy sources, and total primary energy output between 1980 and 2021. Its share increased from 9.65% to 16.72%, reflecting the slow shift towards diversifying the world energy mix. But fossil-energy use has grown by more than 90% as well and fossil fuels are still more than four-fifths of total primary-energy use in 2021. This relative reduction in the importance of fossil fuels was further reduced by growth in renewable and other non-fossil fuels, which did not lead to an absolute decline in fossil fuels consumption. Differences were also noticeable regionally, with the non-fossil segment being over-represented in Europe, Central and South America compared to Africa and the Middle East. At the country level, it was also found that high absolute consumption doesn't indicate a high level of transformation of energy structure. Renewable electricity growth needs to be complemented by fossil fuel phase down, energy efficiency, electrification, storage development, grid modernization, and enabling investment policies to enable effective mitigation of climate change. It also revealed the importance of looking at energy transition both in absolute and proportional measures. Further studies should take a closer look at renewable energy and distinguish it from nuclear power, and also include direct carbon-emission measurements to better assess the mitigation impacts in various regions and development settings.

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