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Computational Data Analysis on Global Energy and COVID-19 Pandemic

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Abstract: A global consumption of energy is primarily met by the renewable and non-renewable energy production resources. It is necessary to understand the pattern of global energy consumption in past to refine the overall energy policy for an upcoming demand of the energy market. The consumption of energy and its insights are helpful for grid management and forecasting. This paper presents the consumption of renewable and non-renewable energy resources by different nations and presents the analysis of the impact of COVID19 pandemic over the consumption of Energy. From the detailed analysis in this study, it is evident that all countries are shifting their interest to use renewable sources of energy generation. The global consumption of energy was constantly increasing up to 4% each year for three decades (1990 to 2020). However, during COVID-19 outbreak, energy consumption shows a downward trend in 2020 to -4%, which is twice lower than the decrement of energy consumption observed 2008-2009 economic crisis. The COVID-19 pandemic has seriously affected energy consumption of all countries in the world.

***Highlights-** The main aim of this research was to highlight the impact COVID-19 had on the consumption of energy across the world. Through an extensive analysis on this topic, this research provided the argument that countries should shift the dependency of energy consumption from non-renewable sources to renewable sources so that the negative impact that countries faced during COVID-19 lockdown would not be faced again in any sort of such pandemic again.

***Discussion-** COVID-19 pandemic is one of those historical events that has most affected energy consumption of several countries than that of the Economic crisis 2008-2009. In general, the pandemic has featured the significance of an enhanced energy blend and the need to put resources into environmentally friendly power sources that are less powerless against market changes and supply disturbances. It has additionally highlighted the requirement for stronger and adaptable energy frameworks that can adjust to changing conditions and backing monetary recuperation endeavors.

Index Terms: COVID-19, energy generation, renewable, statistical methods.

1. Introduction

As global warming rises and climate change worsens, it is necessary to use renewable energy sources more frequently and more efficiently. Many nations place a strong emphasis on both the production and consumption of renewable energy sources. This is mainly due to the dependence of countries on different fossil fuels such as coal and gas. Investigations have shown that these fossil fuels present a negative impact on the environment by increasing the

low-level carbon emission footprint. However, on the other hand, renewable energy sources have proved to decrease the carbon emission footprint by a significant margin. By building more renewable power resources, we will protect people and promote local health and sustainable environment. These benefits would even extend to those in rural areas of a country or those who don't live in developed or urban areas at the same time.

Efforts to stop the spread of COVID-19 have had profound impact on the daily life [1] around the world. Different sectors of travel and tourism [2], social connections [3], in-person work and schooling, as well as industrial and commercial operations have been hampered due to the imposed limitation by governments and own self. One of the biggest affects that the pandemic has had on the daily life is the consumption of electricity by both people and in industries in both peak and post pandemic time. To get a thorough understanding of the repercussion of these affects, it is crucial to examine the situation of energy consumption before and during the COVID-19 era. Furthermore, it should be investigated that which form of energy (renewable of non-renewable) were consumed by different countries during and pre- COVID-19 period.

For researchers to get a better grasp on how electricity systems respond to significant shocks, it is required to study in detail, the COVID-19 response as the reactions to the pandemic by both governments as well as people was unprecedented. It is also expected that future shocks would occur in terms of power networks due to the increase in frequency of climate change, extreme weather events and the probability of other infrequent disruptive events like recessions [4] or pandemics. From evaluations it was found that decrease and/or fluctuations in the consumption of electricity, as seen during the COVID-19 pandemic, could affect electricity grid balancing and forecasting [5]. Another factor leading to this research is the examination of how the pandemic limitations and restrictions have affected electricity usage and influenced the potential of the government and policymakers in altering long-standing trends of electricity consumption [6-8]. One of the biggest factors in the changes of power usage changes during the pandemic are due to restriction of mobility and the decision of governments to work from home. During the pandemic lockdown period, the use of electricity fell to Sunday levels with substantial reductions in services and industries. However, this consumption of electricity increased in terms of use by residentials working at home due to the stay-in policies [9]. When the lockdown restrictions were lifted in Italy and Germany in April 2020, the power demand started to recover. Following this pattern, in May, several countries, including India, France, Spain and the UK, eased their own lockdown restrictions. Based on this lifting of restrictions, it was observed that the demands in electricity in the months of June and July, weather corrected, stayed 10% and 5% below than that of the electricity demand observed in the same months of 2019 in most countries, except for India where the recovery was more pronounced. Global energy supply and consumptions is required by different countries for their development, for their economy and their industrialization. This supply and consumption of energy can lead to the preparation of fuel and generation of power and electricity. As global temperatures rise along with an increase in climate change, improving the efficiency and increasing the use of renewable energy sources is extremely critical. The nations that take precedence in the generation and consumption of renewable energy source over non-renewable sources can help impact the environment in a positive manner. Similarly, the effect that the COVID-19 has had on the global energy supply and demand is the leading factor of motivation behind this research. Also, the figures of decrement and fluctuation in demand can be used to accurately represent the effect of such global pandemic in the future. The reflection of this study results can help the energy sector in policy making, grid balancing and forecasting for the future.

1.1. Problem Statement

It is crucial to increase the use of renewable energy sources and increase efficiency as global temperatures rise and climate change intensifies. Many a country are emphasizing in producing and consuming renewable energy resources. This, in turn raises several questions such as, which nations are leading the way, and which require more immediate transformations in terms of making use of renewable energy sources. Which types of renewables are improving the fastest? Which countries use which types of renewables? At the increasing rate of returns on renewables, how long will it take to meet global demands and eliminate non-renewables, or at least, break 50%? As climate was focused on while consuming different forms of energy in some countries, but did the COVID-19 affect the consumption of energy in any way?

1.2. Research and Objectives

This research focuses on highlighting the different energy sources that are available in terms of both renewable and non-renewable that basically help in meeting the global energy demand employed by different countries across the globe. This research also focuses on the impact COVID-19 made on the global energy supply and demand and the effect on the adoption of renewable energy sources to meet the demand in place of usual coal-based energy sources. Through the use of different datasets and computational data analysis, this research presents an analytical report that different countries can make use in future in order to replace their existing energy policies and help them in defining better grid management and forecasting systems.

The objectives of this study are as follows:

RO1. To accumulate the progress of the main renewable energy sectors: Hydro, Wind, Biofuel, Solar PV, and Geothermal and their production and to assess the consumption of non-renewable energy sources all over the world.

RO2.To assess the types of renewable energy sources used among leading countries.

*RO3.*To investigate the energy consumption and growth rate trend in recent years and identify the impact of pandemic on the growth trend.

*RO4.*To identify the impact of COVID pandemic on the energy consumption of different countries.

1.3. Organization of the Article

This article is further divided into 4 sections, section 1 presents a brief introduction along with the problem statement and the research objectives. Section 2 describes the existing literature similar to this problem area, followed by section 3 which elaborates the methodology, dataset, and approach used for this data analysis. Then section 4 enumerates the results of the data analysis followed by section 5 presenting the discussion on the results. Finally, section 6 presents conclusion of this article.

2. Related Work

To explore the impacts of COVID-19, in this research we tracked down examinations on either unambiguous areas or monetary zones or even the worldwide economy. The related studies discussing effect on the adoption of renewable energy sources to meet the demand in place of usual coal-based energy sources, were also focused. In most of the examinations the investigations centered around monetary business sectors and the energy area, while in a few situations, macroeconomic variables were also analyzed. Most of these examinations give helpful ends, and the impacts of the pandemic are supposed to stay at the highest point of scholastic interest for the following time frame. The motivation behind these investigations is to gain the important information to manage comparative cases from here on out, to restrict the adverse consequences and to reset the genuine economy and public activity on target quickly. Existing writing like Global Energy utilization are examined to refine the issue and perform tests. A portion of those articles was summed up in this part.

The effects of urbanization are investigated on disaggregated energy consumption while controlling for other demographic and economic factors [10]. The study differs from existing empirical studies in its approach and findings. The results reveal the significant impact of demographic factors on energy consumption, particularly non-renewable energy consumption. The paper contributes to the ongoing discussion on the urbanization-energy use relationship. The data from OECD countries for the period of 1980 to 2011 used for this study. The variables used in the study include total population, GDP per capita, industrialization, share of service sector in GDP, population density, urbanization, and renewable and non-renewable energy consumption. Similarly, in [11] the determinants of CO2 emissions in OECD countries from 1980 to 2011 were investigated using the STIRPAT model. The results suggest that nonrenewable energy consumption increases CO2 emissions, while renewable energy consumption decreases them, and there is an Environmental Kuznets Curve between urbanization and CO2 emissions. Another study presents the similar findings, which was conducted on renewable and non-renewable energy consumption in Pakistan using data from 1970 to 2016 [12]. The results suggest that renewable energy consumption has an insignificant impact on CO2 emissions, while natural gas and coal are the main contributors to pollution in Pakistan.

Peng et al. [13] applied a nonlinearity autoregressive convey slack model to inspect the raw petroleum cost change while they likewise utilize an occasion concentrate on a model to look at what changed in the sorts of occasions mean for raw petroleum cost vacillations. In their work to consolidate unrefined petroleum cost change with what causes it, a state-space model is applied and proof of solid relationship between occasion shocks and occasion types was found. Bouri et al. [14] applied a heterogeneous autoregressive acknowledged unpredictability model to look at the prescient power for oil-market instability utilizing a vulnerability file considering the everyday paper news for the pandemic time frame. They observed that by fusing such data in their model, figure precision improves fundamentally.

The non-renewable energy resources have been in discussion for researchers' community. In [15], the author looks at the relationship of the worldwide oil market with the USA energy securities exchange utilizing their suggested instability records. The primary focus of this research is the presence of a long-run connection among oil and securities exchange suggested instability records. Along these lines, [16] concentrated on the unique relationship between stock vulnerability file and the spot oil cost vacillations for the USA, Hong Kong, China, and Japan to see if raw petroleum can be utilized as a supporting instrument. As per the applied wavelet cognizance examination, raw petroleum can't uphold supporting on a long-term period, yet it very well may be a supporting method in a condition of frenzy, similar to the pandemic time frame.

The consequences of COVID outbreak were highlighted in multiple ways, such as energy efficiency in [17] outlined a method for improving energy efficiency and conserving energy. They looked at COVID-19's implications for the energy sector and also investigated the impact of new practices imposed by the epidemic on energy demand and consumption. They discovered that demand in energy had decreased, but the intensity had changed. This was because to combat COVID-19 extra energy used was not inconsequential in the recovery of energy demand, and there were also disparities in recovery between various regions. Similarly, an approach to expanding energy effectiveness and energy saving is given by [18]. They analyzed the difficulties of COVID-19 for the energy sector. Specifically, they researched new practices implemented by the pandemic and the manner in which they impacted energy interest and utilization. They observed that energy demand has declined, however it showed clear changes as the additional energy used to

battle COVID-19 was not immaterial for the recuperation of the interest in energy, while contrasts in recuperation can likewise be found between various districts. However, COVID-19's implications for sustainable energy advancements were examined in [19], where the authors investigated the COVID-19's gamble transmission to metals and energy markets, as well as the COVID-19's crucial negative instability transmission to gold, palladium, and Brent oil markets. COVID-19 isn't sent to the modern metal market, as these results show, but COVID-19 causes an increase in oil market instability.

The impact that COVID has had on the energy, economy and the environment have summarized by Priya et al. [20]. One of the biggest issues that the authors have shown is the fluctuations of oil price in the post-COVID era. The fluctuations would be caused due to the reduction of use of coal, natural gas and other such energy generation methods. With the decline of use, the price of such energy generation resources would also naturally fall which would in turn prove to be a negative turn for global economies. Because of these issues, countries would face a difficult time in the transition to clean and renewable energy. Though the issue of clean energy for countries would not be on a long-term basis, it would still pose a concerning picture based on cost reduction, carbon neutrality and improved efficiency on a short-term period as it would cause a sudden growth in the demand of renewable energy sources. However, as per the authors, there are some positive aspects of post-COVID which include the positive effect on the environment as well as the repairing of the ecology and the overall environment of our world.

Tian et al. [21], in their study have provided a comprehensive review of the energy transition before and after the COVID era. As per the authors, before the COVID era, the world was mostly dependent on fossil fuels, however this trend was changing around 2015, where the world started moving towards renewable energy sources. This caused a dramatic loss of fossil fuel prices and this downward trend continued into the pandemic era. Because of this situation, the need as well as the demand for a faster conversion to green energy before another such pandemic is ever increasing. Because of this, there have been several organizations as well as countries that have put forward strategies for the conversion to green energy, however most of these strategies incorporate the use of fossil fuels. As such, the authors in their paper have put forth a roadmap, considering the different opportunities of clean energy, that details the energy transition in the post-pandemic era which would constitute of strengthening the cooperation of the international community as well the broadening of the instruments of green financing.

Aruga et al. [22] have discussed the relationship between the consumption of energy and COVID-19 cases in India different regions. The authors analyzed the situation of energy consumption before lockdown and after the end of lockdown in India. Using the model of Autoregressive Distributed Lag (ARLD), the authors research presented a long-standing relationship between the rise of COVID-19 cases and the consumption of energy. For their research, the authors presented two hypotheses, the first stating that the lockdown during COVID presented a positive light to the consumption of energy and whether this positive outcome differed from region to region. The second hypothesis made was based on those regions with higher level of income and compared to lower income level regions in the case for the recovery of the energy consumption in the pre-crisis. From their review, the authors concluded that both hypotheses were correct and as per this, the conclusion made was that the consumption of increased during lockdown and as well as after the lockdown relaxation. Based on the results of their review, that authors presented that not all regions of India were able to recover from the loss of energy consumption. The Eastern and Northeastern regions were among the poorest regions in India and had a difficult time in recovering energy consumption which in turn requires the need of introduction of policies and reforms.

In their paper, Jia et al. [23] have tried to measure the impact the COVID-19 and the international slump in oil prices had on China economy in 2020. The authors in their research have considered not only the consumer side but the supplier side too in order to determine the correct impact the year 2020 had on China. Though both COVID-19 and decline of international oil prices had a massive impact on China, the research found that there were some different results as initially considered. Using a computable general equilibrium (CGE) model, the authors found that in China, initially, the decline in international oil prices had a major negative impact on its economy. Though the consumer side were not much affected with this as the domestic crude oil was normally used by residents, but the supplier side suffered a lot in this regard as there was higher production cost with low prices. With the arrival of COVID soon after, the entire economy of China took a double impact which significantly stunted the economy as the supplier end were in lockdown and were thus unable to maintain the production of crude oil. Though the government tried to accommodate the residents as well as the producers so that the economic downturn would not negatively impact them however, they are partially successful as the issue of oil price and COVID also had a negative impact on the carbon emissions with the increase in consumption crude oil and the producers to increase the production of oil to meet the demand. The authors concluded that in order for China to progress post-COVID, it is necessary for the government to shorten the price gap between fossil energy and renewable energy and introduce more environmental policies.

Iqbal et al. [24], in their study have provided a comprehensive look in the outbreak of COVID, and its impact on both energy consumption and CO_2 emission. For their research, the authors have taken Pakistan as their primary location of research. As per the authors, like every other country, Pakistan also faced an economic crisis during the pandemic which was evident from the adverse effect on the consumption and demand of energy, CO2 emissions, fuel consumption, and declination of supply. The authors for their study to provide a definitive link between the pandemic, CO_2 emission and energy consumption conducted a quantitative study where the data was gathered from different online sources. For the model of their study, the authors made use of ARDL and panel unit root test. The results of the model were then verified through the use of panel quantile regression. From their study, the authors reported with

conclusive evidence that COVID had a significantly negative impact on the CO_2 emissions and consumption of energy. The authors also provided their insight that several policies need to be developed by the government of Pakistan to tackle such situation as well as initiate the introduction of renewable energy sources in the country.

It can be seen from the above discussed recent research works, it has been proven by different authors that with the fluctuating oil prices in the whole world which already had a negative impact on the energy consumptions, the arrival of the COVID pandemic had an extremely negative effect on the entire world in terms of both the economy and the consumption of energy. Even though, China was the first country to initiate a lockdown in view of the increasing cases of COVID, it still suffered a blow in terms of economy decline and consumption of energy. Though China recovered more quickly in comparison to other countries such as South Korea [25], Indonesia [26], Poland [27], it still faced several economic and energy challenges as it is more evident in research such as [28][29][30]. In view of this, majority of the research works have encouraged the transition of fossil fuels towards renewable energy and some of the research works have also pushed for countries to introduce reforms and policies that could provide for a cleaner world with lower CO_2 emissions.

3. Methodology

Energy consumption is the amount of energy or power used. In the dataset used in this research, there were four organizations considered, OECD, BRICS, CIS and Middle East. Also considered was the dataset containing energy consumption data from 6 continents. Each country in the world is in some organization like OECD, BRICS, CIS and Middle East. For example, BRICS is an organization that gathers data from countries like Brazil, Russia, India, Chine and South-Africa. The energy generation and consumption w.r.t to these regions are focused on this study. The data about types of energy is also collected to gain insight about the incline towards renewable energy over the years. The step of this research starts from defining the research question move towards data analysis and visualization, as depicted in Fig 1.

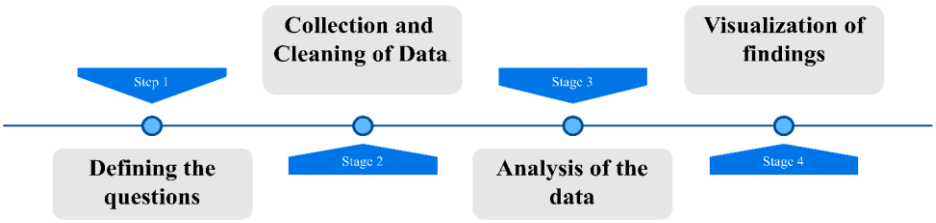


Fig. 1. Research methodology

3.1. Defining Research Questions

The research objectives, mentioned in Section I(B) have been transformed into research questions (as shown in Table I) to perform this study in a systematic way.

Table 1. Research Questions

Sr#	Research Question
RQ1	What is the current progress of the main renewable energy sectors: Hydro, Wind, Biofuel, Solar PV, and Geothermal and their production?
RQ2	Which type of renewable energy sources are preferred to be used among leading countries and how they impact the energy consumption and economy?
RQ3	What is the change rate of world energy consumption and growth rate trend during the period of 1990 to 2020?
RQ4	How COVID-19 impact the Energy Consumption of different countries?

3.2. Data Collection and Cleaning

Multiple datasets (provided in Appendix) used for this study, outline the quantity of terawatt hours (TWh) produced through various sources of energy [31], comparing both renewable and non-renewable sources, while also highlighting the use of renewable energy sources of the top 20 countries. The Renewables Power Generation dataset includes a 1997-2017 timeline that outlines the progress of the main renewable energy sectors: Hydro, Wind, Biofuel, Solar PV, and Geothermal. Additionally, the Top 20 Countries Power Generation dataset includes the national data for each of the renewable categories as outlined above. The last 2 datasets include the global TWh generated from renewable and non-renewable sources. The datasets which contain the global consumption figures on national and continental/international group levels, help to provide context about the quantity of energy required, change in demand of energy over time, and the level of transition from non-renewable to renewable energy use.

3.3. Data exploration and Analysis

The data is divided w.r.t each year from 1990 to 2021. The countries and continent wise data contained the year wise energy consumption for the processing. This data is arranged in .csv file for plotting the trend among different countries computationally. The main parameters for assessing the growth of global energy consumption in this research are consumption in TWh, years and different regions of all over globe (OECD, CIS, Middle East, BRICS). The rate of change in consumption is calculated on the basis of years. Furthermore, the correlation of the consumption was computed among these different regions.

For assessing the type of consumption (renewable or non-renewable) all over the world, the separate data is compiled for renewable and non-renewable energy consumption globally w.r.t years. The renewable and non-renewable energy resources are defined in different types (Coal, Natural Gas, Nuclear, Oil, Waste, Hydro, Biofuel, Solar PV, Geo-thermal) and the consumption of these resources is compiled over the years.

3.4. Data Visualization

The implementation of this analysis is carried out using python. The libraries used for the data analysis and visualization include Pandas, Statsmodels, Matplotlib, Seaborn, SciPy, NumPy, and Sklearn. The data is processed and then visualized using these libraries to answer the research questions (discussed in Table 1), in order to achieve the objectives of this research study.

4. Results

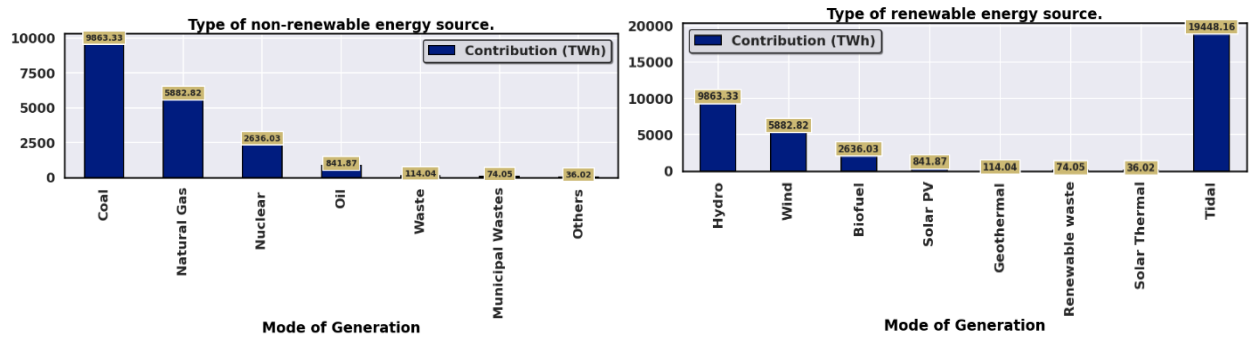
Every year, the world's energy consumption rises as the population across the world increases. But over the past 20 years, there have been two jarring shifts, one around the time of the economic crisis in 2009 and the other around 2020 (COVID-19 pandemic). This study analyzed all the shifts in the history and conducted data computation for the consumption of energy over different continents and countries. The result for all countries varies and the detailed analysis of their consumption is provided in the following subsections.

4.1 Analysis on RQ1

Globally, coal produces most non-renewable energy in comparison to Natural Gas, Nuclear, Oil, etc. However, Tidal produces more renewable energy than Hydro, Wind, Biofuel, etc. [31]. The mode of generation of non-renewable energy is represent in a tabular form through Table 2. While Fig. 1 represents both, mode of generation of renewable and non-renewable energy sources through Fig. 2. It can be seen from Fig. 1 that the renewable energy source of Tidal energy performs better in comparison to coal based non-renewable energy. It should also be noted that 90% of the power generated by renewable sources comes from solar, wind, tidal and geothermal sources and not from biofuels, according to the data from 1990 to 2017. The New York State Department of Environmental Conservation is considering several bills to make fossil fuels cleaner, while also removing existing subsidies for coal and other polluting fuels. The “Clean Coal Initiative” is proposed to make coal cleaner and eventually make the technology more affordable for utilities. Coal proponents suggest that clean coal technology already exists and will work in new coal plants. The idea is that coal plant will generate more clean power with natural gas and a much cleaner carbon emission. This cleaner coal technology, proponents say, will allow for more use of carbon neutral (negative carbon emissions) energy sources.

Table 2. Mode of Generation of non-renewable and renewable energy sources and their contribution in 2017

Non-renewable energy sources		Renewable energy sources	
Mode of Generation	Contribution (TWh)	Mode of Generation	Contribution (TWh)
Coal	9863.33	Hydro	9863.33
Natural Gas	5882.82	Wind	5882.82
Nuclear	2636.03	Biofuel	2636.03
Oil	841.87	Solar PV	841.87
Waste	114.04	Geothermal	114.04
		Renewable waste	74.05
		Solar Thermal	36.02
		Tidal	19448.16



(a) (b)

Fig. 2. Total Energy generation from renewable (a) and nonrenewable energy sources (b) generation in TWh

In short, 19448.16 TWh are produced from Tidal only which is more than the energy produced by all non-renewable energy resources. While coal is producing more than half of the entire energy production from non-renewable sources.

Countries have been focusing on renewable energy sources for around five to ten years now, from wind and solar on their roads. However, as the wind-powered economy hits a peak and electricity demand drop, the demand for energy from renewable sources will have to increase substantially for countries to meet their long-term financial goal. As seen from Fig. 3, Solar PV and Biofuel demand has grown exponentially over the years while an abrupt change is present in Hydro (between 2010-2017). Solar PV, on the other hand has improved on an exceptionally fast rate over the decade. That is an indication of countries emphasis on renewable energy sources and the sudden growing trend towards Solar PV and Biofuel. To be summarized we can state that the trend of energy generation from renewable sources is increased over the years as shown in Fig. 4

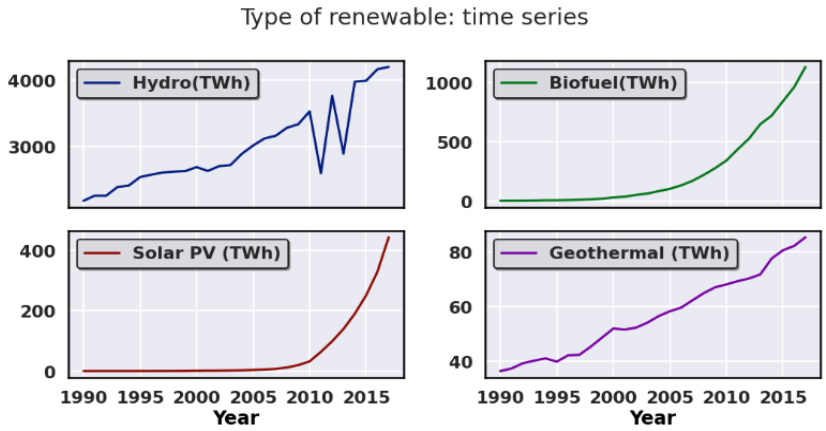


Fig. 3. Time series growth of renewable energy sources.

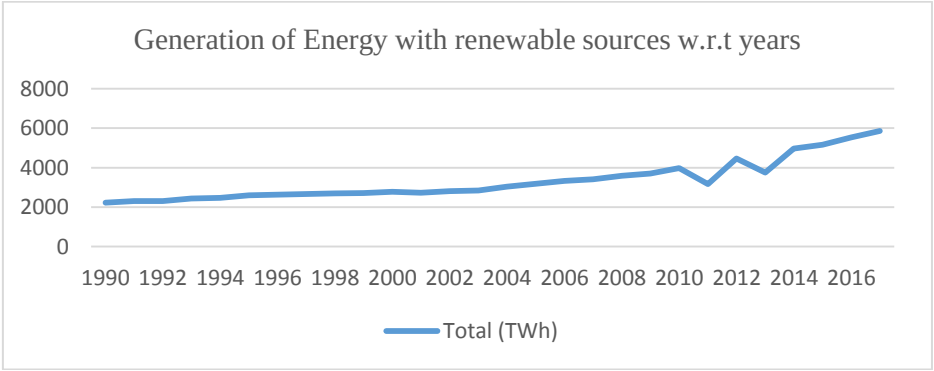


Fig. 4. Time series growth of renewable energy sources.

4.2 Analysis on RQ2

The Top 20 countries use four types of renewable energy sources. In terms of *Hydro,* three countries, Brazil, China and Canada, outperform in power generation, while the other 17 countries in the top 20 do not exceed 359.17 TWh (as presented in Table 3). For *Biofuel*, two countries, China, and USA, outperform in generation of power, however the other countries do not exceed 123.77 TWh. For *Solar PV*, it has been observed that none of the top 20 countries can exceed 80 TWh till 2017. For Geothermal, two countries, USA and Indonesia, outperforms in the generation of power but 18 countries in top 20 cannot exceed 7.93 TWh.

China performs well in Hydro, Biofuel and Solar sources but plays poorly in Geothermal. Whereas USA performs well in Hydro, Biofuel, Solar PV and very well in Geothermal. Indonesia, on the other hand, is the second country with good performance in Geothermal behind USA. The ranking of 5 best countries according to the type of renewable energy is presented in the Table 4.

Table 3. Top 20 countries in renewable energy generation with the total energy generated by the country.

Country	Hydro (TWh)	Biofuel (TWh)	Solar PV (TWh)	Geo-thermal (TWh)	Total (TWh)
China	1189.84	295.0200	79.43	0.1250	1819.9400
USA	315.62	277.9100	58.95	18.9600	758.6190
Brazil	370.90	42.3700	52.25	0.0000	466.3500
Canada	383.48	29.6500	7.12	0.0000	424.0900
India	141.80	51.0600	43.76	0.0000	262.6500
Germany	24.17	111.5900	45.10	0.1600	227.1800
Russia	187.13	0.1400	0.08	0.4300	188.3300
Japan	90.67	7.6300	19.01	2.4400	187.3490
France	70.13	28.5000	5.87	0.1300	114.8200
Italy	50.92	17.4900	16.85	6.0800	113.9900
UK	7.96	57.1100	32.08	0.0000	110.0700
Spain	36.74	50.8100	5.48	0.0000	100.5400
Turkey	59.74	19.8800	2.63	6.9000	96.6200
Mexico	32.52	13.0700	1.88	5.3600	56.0200
Australia	16.02	15.1700	3.51	0.0000	44.6200
Indonesia	18.63	0.0006	0.23	12.7600	41.6406
Thailand	9.52	1.1000	15.38	0.0001	30.5401
South Korea	7.28	2.4600	6.82	0.0000	25.3200
Iran	15.05	0.3000	0.02	0.0000	15.4500
Taiwan	8.87	1.7300	0.11	0.0000	12.4000

Table 4. Best countries in renewable energy production

Rank	Hydro (TWh)	Biofuel (TWh)	Geothermal (TWh)	Solar PV (TWh)
1	China	China	USA	Germany
2	Canada	USA	Indonesia	India
3	Russia	Brazil	Turkey	UK
4	Indonesia	Germany	Mexico	Brazil
5	Turkey	India	Italy	Thailand

The gap of renewable power generation between China and rest of the world is too large (as depicted by Fig 5.). China produces more renewable energy than any other country since it respects the carbon tax and wants to reduce pollution rates. Considering this, it should not be forgotten that the demand for energy consumption is very high in China while it being the leading economic power in the world. This is the reason that China is leading the energy generation in terms of renewable sources of energy (see Fig 5).

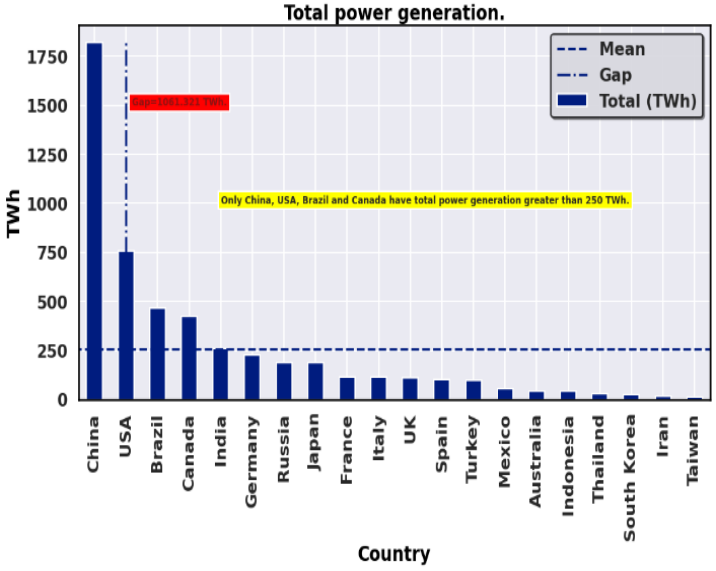


Fig. 5. Total Energy Power generation of different countries

It can be learned from this analysis that; no country in the world could have exceeded 80 TWh of power generation from Solar PV. China has reached till 79.43 TWh, so we can expect that it can be improved in future. Also, some countries have only basic renewable energy sources such as Hydro, Geothermal, Biofuel with no presence of Solar PV. However, even those countries with Solar PV don't have access to basic electricity grids, such as grid operators. They also have no access to the electrical grid, their water cycle is poor, and they depend on the need to clean up after themselves, which means they do not have the financial resources necessary to power their generators. When developing cities, it is very important to understand the need to install energy grid power. In reality, Solar PV is used in a variety of countries, each with its own infrastructure and electricity distribution system that is required to run the power grid.

4.3 Analysis on RQ3

Two changes in the growing trend of energy consumption occurred in three-decade period; one is the economic crises of 2008-2009 and the other was the time when pandemic hit the whole world. The time between these two rapid changes is 11 years (see Fig. 6). The rate of change of the global energy consumption ranged between 0 and 4% during the years 1990 - 2008, and 2010 - 2019. Only in the year 2009 and 2020 was a negative value noted (as given in Fig 7.). The Economic crisis in 2008–2009 was to blame for the extremely high oil prices. The occurrence of COVID-19 in 2020 significantly reduced global energy use due to locked-down, and stoppage of industries.

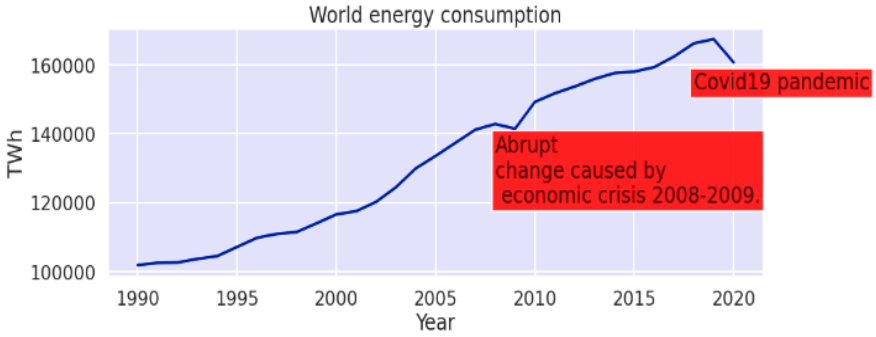


Fig. 6. The world energy consumption during 1990 to 2020.

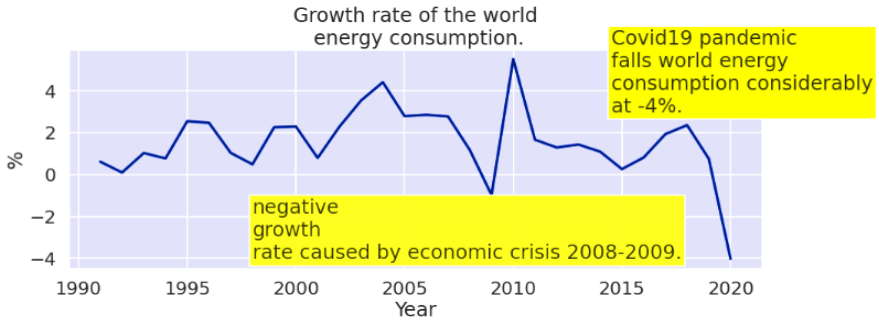


Fig. 7. The growth rate (b) of world energy consumption during 1990 to 2020.

The 2008-2009 worldwide financial emergency fundamentally affected worldwide energy utilization, as it prompted a sharp decrease in monetary movement and energy interest in numerous nations. The emergency was set off by the breakdown of the real estate market in the US, which prompted a broad credit crunch and a sharp decrease in customer certainty. Because of the emergency, numerous organizations and production lines all over the planet had to close or diminish their tasks, prompting a huge drop in energy interest. Specifically, interest for oil and gas, which are key drivers of the worldwide energy market, was extraordinarily impacted by the monetary slump.

One of the main effects of the emergency on worldwide energy utilization was a sharp drop in oil costs. As interest for oil fell, the cost of raw petroleum plunged, with costs dropping from around $140 per barrel in mid-2008 to under $40 per barrel by mid-2009. This decrease in oil costs affected the remainder of the energy market, as it prompted a drop in costs for flammable gas and other energy products. In spite of the drop in energy utilization during the emergency, the drawn-out influence on worldwide energy patterns was generally restricted. Energy utilization returned rapidly as the worldwide economy recuperated, and interest for oil and other energy sources kept on filling in the years that followed. Nonetheless, the emergency featured the significance of energy effectiveness and environmentally friendly power sources, as legislatures and organizations all over the planet searched for ways of decreasing their reliance on petroleum derivatives and further develop their energy security.

The Coronavirus pandemic essentially affects worldwide energy utilization, as lockdowns and different measures to contain the spread of the infection have prompted huge changes in the examples of energy interest and supply. One of the most observable effects of the pandemic on energy utilization has been a sharp drop popular for oil, as movement limitations and a lull in monetary action have prompted a decrease in the utilization of transportation energizes. This, thusly, has prompted a decrease in ozone harming substance discharges, as the copying of petroleum derivatives is a significant supporter of environmental change. Nevertheless, the decrease in oil interest, the pandemic has likewise prompted a drop in power interest in numerous nations, as organizations and plants have shut or diminished tasks, and individuals have invested more energy at home. Nonetheless, the effect of the pandemic on power utilization has changed relying upon the locale, for certain nations encountering an expansion sought after because of additional individuals telecommuting and utilizing more machines.

4.4 Analysis on RQ4:

As has already mentioned (in Research Methodology section), practically every nation belongs to an organization like the OECD, BRICS, CIS, or Middle. Organizations that consume the most energy include the OECD and the BRICS, according to Fig. 8. This might be because, BRICS accounts for 40% of the world's population with two most populous countries i.e., China and India. Similarly, OCED have 38 countries including Australia, Canada, USA and UK, hence the trend of growth in energy consumption is self-explanatory. The other two organization consist of Middle East and Commonwealth Independent States, which are not much dense in population. BRICS and Middle East are similar that means Middle East and BRICS have same energy consumption (China buys Oil from Saudi Arabia, Turkey buys gas of Gazprom from Russia). OECD and CIS are opposite in energy consumption (as presented by the correlation of these organizations in Table 5). The details of this correlation can be plotted to visualize the proportionality of energy consumption. These visualizations are explained in Fig 9. One more noticeable thing is all the organization remained in negative growth during COVID-19 that is -7.02%, -5.49%, -1.23% and -0.15% for OCED, CIS, Middle East, BRICS respectively. However, in 2008-2009 economic crises it was not the same, then OCED and CIS declined to -4.43% and -7.64% respectively, but Middle-East and BRICS had positive 3.06% and 4.01% growth rate. Thus, it can be inferred that the COVID-19 impacted the energy consumption more than the economic crises of 2008.

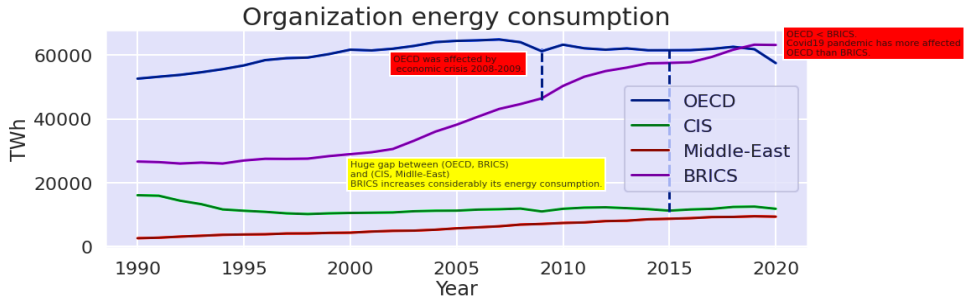


Fig. 8. Energy Consumption by Organizations (OECD, CIS, Middle East, and BRICS)

Table 5. Correlation between organizations from 1990 to 2020

Correlation	OCED	CIS	Middle East	BRICS
OECD	1.000000	-0.605396	0.579156	0.488856
CIS	-0.605396	1.000000	-0.181752	-0.036594
Middle East	0.579156	-0.181752	1.000000	0.986791
BRICS	0.488856	-0.036594	0.986791	1.000000

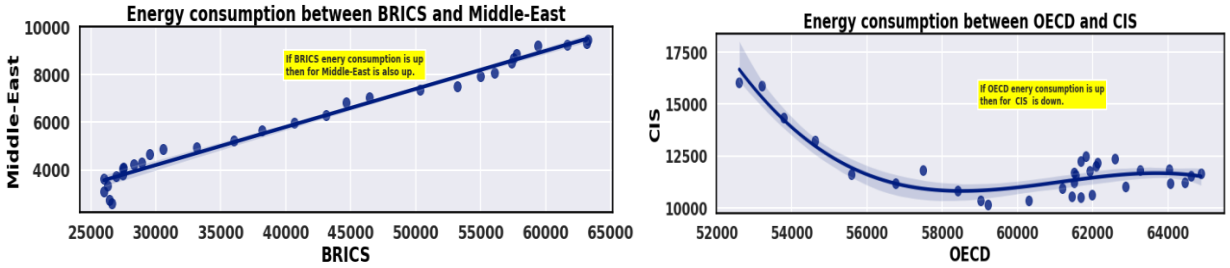


Fig. 9 The proportionality of energy consumption between Middle East and BRICS in (a) which is directly proportional; and OCED and CIS in (b) that is inversely proportional.

If the countries are classified with their region and continents, then 6 continents are to be considered for the detailed analysis. The COVID-19 pandemic significantly influenced energy usage across all six continents. However, Asia's trend in energy consumption is incomparable to that of Africa, Latin America, and the Pacific, as the rate of change in the growing trend of Asia is minor than other continents (see Fig. 10, 11 and 12). Asia's China lost just -0.47% of its energy consumption compared to Europe's -6.74% and North America's -7.48% losses. Europe's trend in energy consumption appears to be similar to those of North America, the Pacific, and Latin America. Africa has lesser generation of energy w.r.t to the population of Africa, and this has seen the decline in COVID-19 era too.

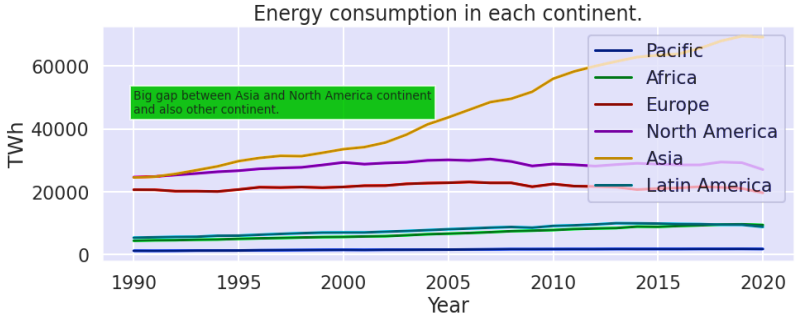


Fig. 10. Energy Consumption by Continents

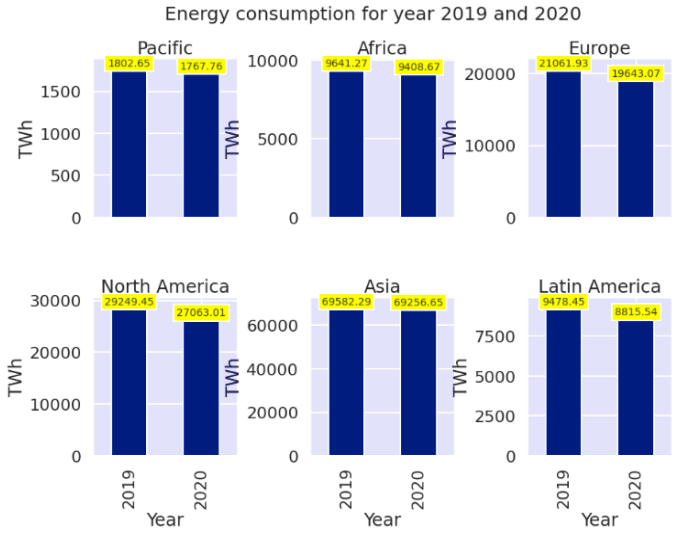


Fig. 11. The decrement in energy consumption for years 2019 and 2020

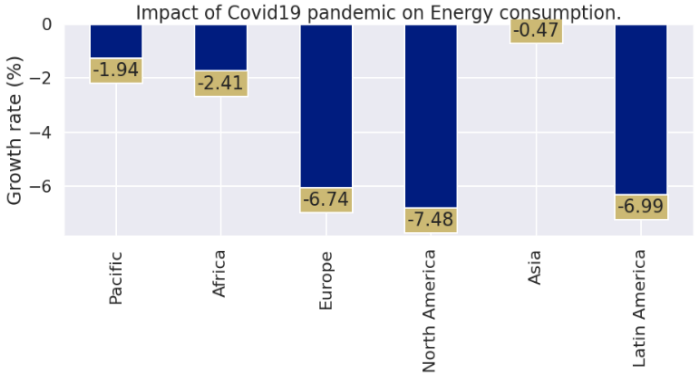


Fig. 12. Impact of COVID-19 pandemic on consumption of energy by continents w.r.t percentage of negative growth rate.

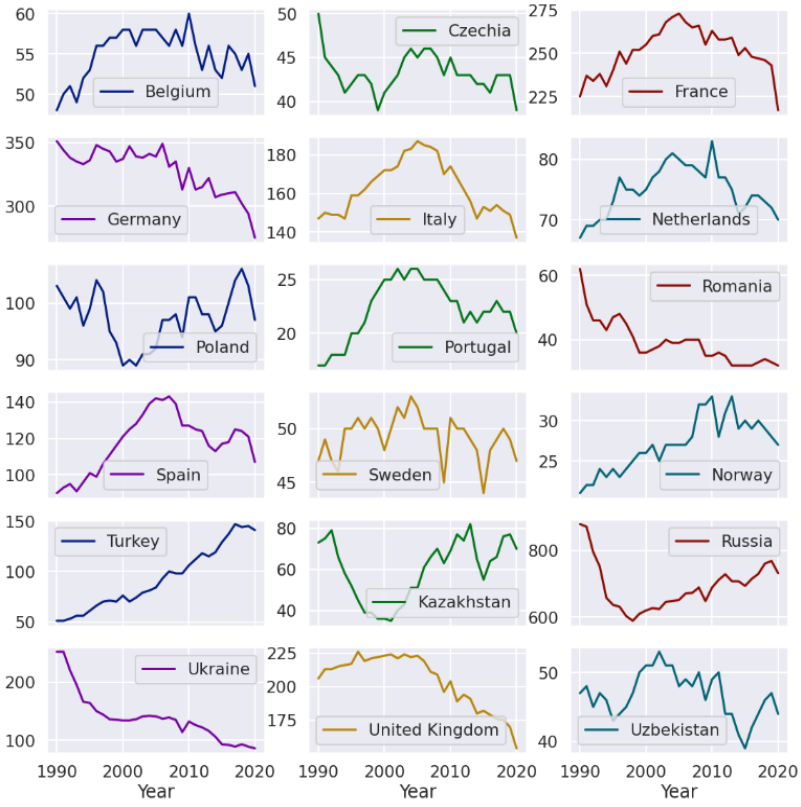


Fig. 13 Energy consumption w.r.t countries in Europe from 1990 to 2020

If the data of the countries of these continents are individually considered and visualized, then it can be interpreted that most countries in European union have shown a negative slope in terms of energy consumption as shown in Fig. 13. However, Russia, Turkey, Germany France and Italy had a better show in terms of consumption of energy (see the end of the curves of the counties graphs in Fig. 13). On the other hand, in Asia only Japan has a negative slope. However, other countries, starting from China followed by India, Kuwait, South Korea and Iran are slightly affected. Energy consumption of all Asian countries slightly got lowered due to COVID-19 pandemic (see Fig. 14), mainly because the denser population of the continent and the use of power in households differed than other nations.

Like Europe, the countries in North and Latin America showed a negative slope in the growth of energy consumption. However, Brazil, Chile, and Columbia were not intensely affected from the lockdown (as presented in Fig. 15). On the other hand, Australia and New Zealand from Oceania showed better performance in terms of negative impact but the African countries especially South Africa saw a decline in energy consumption. Nigeria was the only country in South Africa that was slightly affected during COVID-19 outbreak (see Fig. 16).

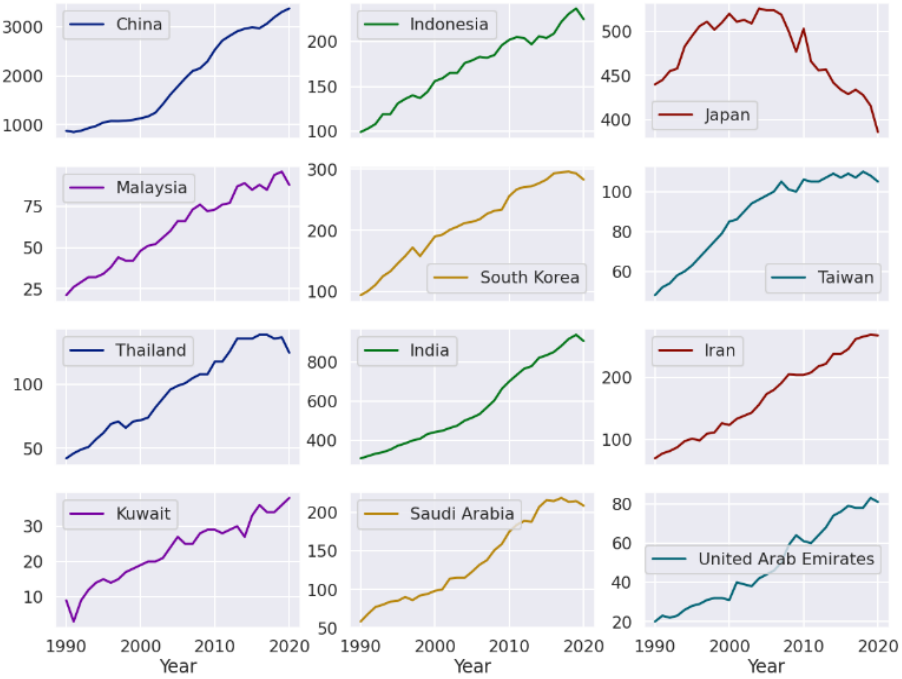


Fig. 14. Energy Consumption w.r.t countries in Asia from 1990 to 2020

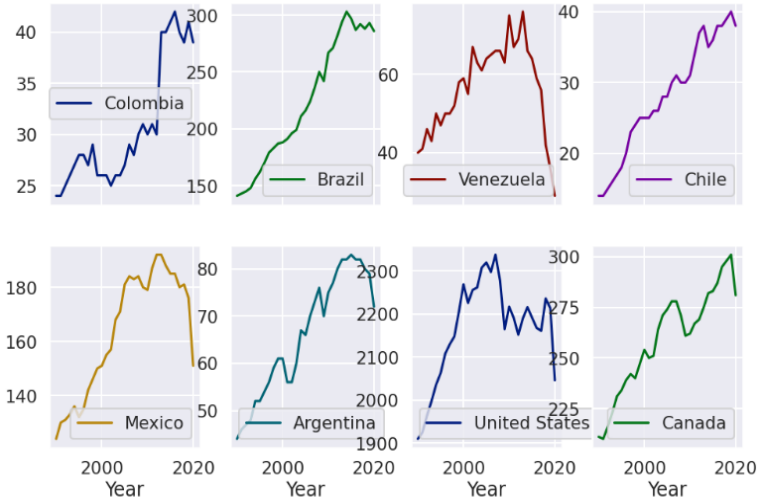


Fig. 15. Energy Consumption w.r.t countries in Latin and North America from 1990 to 2020

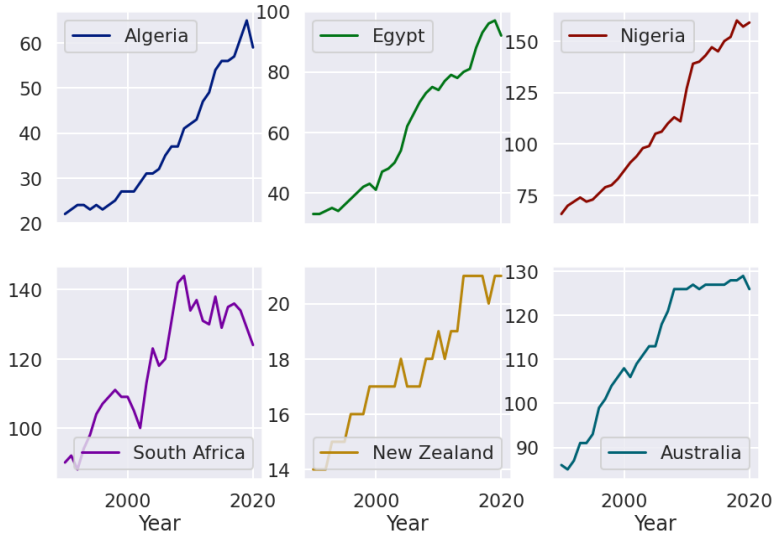


Fig. 16. Energy Consumption w.r.t countries in Oceania and Africa from 1990 to 2020

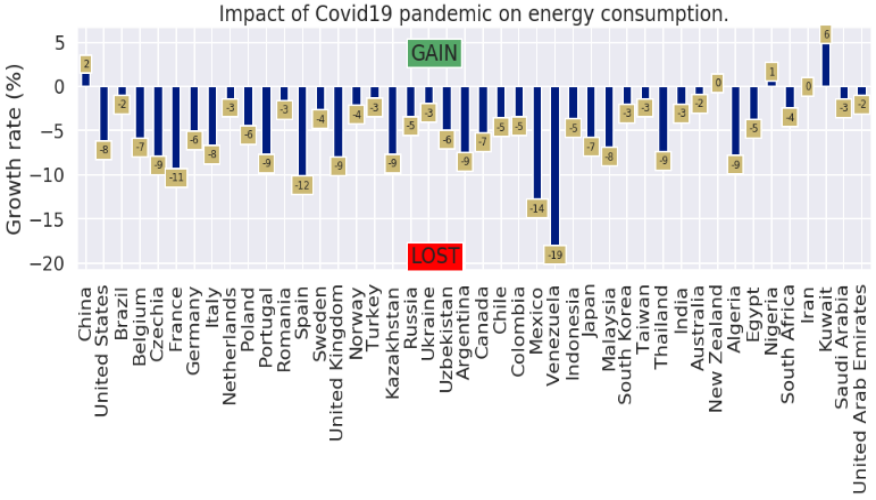


Fig. 17. Impact of COVID-19 on Energy Consumption (during 2020) of different countries

To summarize it can be inferred that there exists two group of countries according to the energy consumption curve. The first group is the countries having bell-shaped and exponential shaped energy consumption curve, for example, European countries and Latin America countries. These countries' energy consumption was highly affected during COVID-19, even more than economic crises in 2008-2009. The second group are the countries having oblique energy consumption curve e.g., Asian and some African countries. These countries were only slightly affected by the epidemic. If the growth rate of energy consumption is numerically considered for these countries, then it is clearly seen that almost every country has negative impact of COVID-19 pandemic over the growth of energy consumption. However, 3 countries showed positive change rate of power consumption which were China, Nigeria and Kuwait (as presented in Fig. 17). Only one country of the BRICS (i.e., China) outperforms but all countries in OECD shows a downward trend.

5. Discussion

All countries in the world need to consume power for its development. That is why, energy consumption is very important. COVID-19 pandemic is one of those historical events that has most affected energy consumption of several countries than that of the Economic crisis 2008-2009. In general, the pandemic has featured the significance of an enhanced energy blend and the need to put resources into environmentally friendly power sources that are less powerless against market changes and supply disturbances. It has additionally highlighted the requirement for stronger and adaptable energy frameworks that can adjust to changing conditions and backing monetary recuperation endeavors.

Some countries generate energy using renewable sources such as with Hydro, Biofuel and Solar PV but only USA and Indonesia produce energy using Geothermal sources. Any country in the world can exceed 80 TWh energy consumption through Solar PV production, as China has already reached to 79+TWh.

This work discloses that the crisis and pandemic of COVID-19 had a considerable impact on energy consumption of the world. Energy consumption between 1990 and 2020 varied between 0 and 4% but it was destabilized by economic crisis 2008-2009 and COVID-19 pandemic. During this destabilization the energy consumption growth becomes negative globally. All the countries with locked down and minimum industrial consumption, shown a negative trend in the growth of energy consumption. However, China, Kuwait and Nigeria had stable energy consumption even during COVID19. The question that we must ask now, is What will be the impact of COVID-19 pandemic and its variants on energy consumption for year 2022 and 2023?

6. Conclusion

This paper encompasses the generation of energy from both renewable and non-renewable sources by the leading countries in world for the period of three decades. This analysis can be useful for the policy makers and the researchers of different countries to get an insight of the energy consumption patterns and demands of energy in different regions.

To be summarized, the energy consumption for some countries in the world is exceedingly high than other countries. For example, China consumes more energy, 1.67 times than the USA, 2 times that of Canada, and 5 times that of the rest of the world. Moreover, not only developed countries but also several developing countries use renewable energy like Hydro, Biofuel, etc. From the data analysis, it is evident that, the energy consumption grew constantly between 0 and 4% for last three decades, however it met two phenomena's: the economic crisis of 2008-2009 (the loss of the world energy consumption at -0.98%) and the COVID pandemic (decreased the world energy consumption at -4%). The energy consumption of the Pacific, Latin America and Africa countries got significantly lowered. However, Asia continent countries sustained the energy consumption growth as before, despite the presence of the COVID-19 pandemic.

Conflicts of Interest

The authors have no conflict of interest.

Funding Statement

This experimental study did not receive specific funding but was performed as part of the employment of the author, from University of Roehampton, London, UK.

Appendix A

Dataset Used: Global Energy Consumption & Renewable Generation
https://www.kaggle.com/datasets/jamesvandenberg/renewable-power-generation

Appendix B

Table A. The Energy generated from renewable sources over the years.

Year	Hydro (TWh)	Biofuel (TWh)	Solar PV (TWh)	Geothermal (TWh)	Total (TWh)
1990	2191.67	3.88	0.09	36.42	2232.06
1991	2268.63	4.19	0.1	37.39	2310.31
1992	2267.16	4.63	0.12	39.3	2311.21
1993	2397.67	5.61	0.15	40.23	2443.66
1994	2419.73	7.31	0.17	41.05	2468.26
1995	2545.96	7.95	0.19	39.89	2593.99
1996	2583.18	9.45	0.22	42.18	2635.03
1997	2614.54	12.08	0.27	42.38	2669.27
1998	2628.63	16.07	0.35	45.35	2690.4
1999	2636.26	21.52	0.61	48.66	2707.05
2000	2695.85	31.34	0.99	51.98	2780.16
2001	2638.2	38.45	1.32	51.57	2729.54
2002	2711.12	52.85	1.58	52.29	2817.84
2003	2726.33	64.23	2.01	54.09	2846.66
2004	2894.22	84.43	2.66	56.5	3037.81
2005	3019.5	103.92	3.92	58.28	3185.62
2006	3124.34	133.05	5.52	59.61	3322.52
2007	3165.71	170.83	7.47	62.29	3406.3
2008	3285.59	221.05	11.92	64.91	3583.47
2009	3338.82	277.44	20.04	67.03	3703.33
2010	3530.72	341.38	32.22	68.1	3972.42
2011	2603.78	436.01	63.76	69.29	3172.84
2012	3765.96	525.04	99.03	70.27	4460.3
2013	2898.28	646.36	139.64	71.74	3756.02
2014	3976.01	718.07	190.25	77.52	4961.85
2015	3989.28	838.31	250.75	80.56	5158.9
2016	4162.26	958.15	329.14	82.18	5531.73
2017	4197.29	1127.31	443.55	85.34	5853.49

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