Change in Energy Mix Under COVID-19 Shutdown and Recovery Period in China: A Study of Hunan and Guizhou Province

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ABSTRACT

COVID-19 has brought enormous changes to the world and people's lives. City lockdowns, travel bans and all other restrictions issued by governments have changed people's lives from every aspect. However, its environmental and energy influences are not sufficiently studied. In this study, in order to examine COVID-19's influence on different energy-mixes, two distincts energy-mix provinces in China, Hunan and Guizhou, are examined by focusing separately on the shutdown period and recovery period during the pandemic period. PM 2.5 and renewable energy ratio are used to discover the changes in fossil fuel and renewable energy consumption in these two provinces. Secondary data analysis and literature review are conducted to understand the trends. The study found that for Hunan, industry-concentrated provinces in China, fossil fuel consumption is affected by decreased energy demand in the short term, while in the long term, the reduction is not obvious. For Guizhou less industrial activities, Covid-19 didn't pose a significant effect on its fossil fuel consumption. On the other hand, renewable energy was restricted by its own limitations in terms of providing energy in the recovery period and prospective planning for renewable energy was conducive to energy demand spiking circumstances. A well-rounded combination of energy sources is recommended for the government to maintain a stable energy supply during the pandemic and for future energy-fluctuating circumstances.

KEYWORDS

energy mix, Covid-19, renewable energy, fossil fuel, energy consumption

INTRODUCTION

COVID-19 has heavily influenced people's way of living, and, consequently, people's energy consumption. Containment policies, including working from home, remote learning, locking of international borders, and bans on travel all create a tremendous change in the energy system (Elavarasanet et al. 2020). As a result, we have observed a dramatic worldwide reduction in energy demand, especially on oil and coal (Hoang 2021). Researchers have taken actions to study this new pattern of consumption and how the energy mix could be upgraded to increase resilience to similar unexpected events. Studies were conducted with regional and sectoral focuses. For example, a study in Europe has shown an average of 17% drop in weekly energy consumption during the quarantine policy period. In addition, another research has shown a 30% reduction in national energy consumption in India (Broom 2020). Researchers also found in specific sectors, such as public transportation, there is a dramatic decrease in its energy demand and an increase in the private transportation sector (Cheshmehzangiab 2020). Furthermore, household cooking and entertainment energy demand have increased (Cheshmehzangiab 2020). Although these studies provide us with important information about energy consumption during Covid-19, Eastern Asian countries are less studied holistically and specifically than other parts of the world, which this paper seeks to correct.

Research conducted in Asian countries is uneven and incomprehensive in several ways. First, India and southern Asia countries are being investigated more than other Asian countries. For example, renewable energy and environmental impacts due to Covid-19 in India have been studied extensively (Pradhan et al. 2020 and Shekhar et al. 2021). In contrast, other Asian countries, mostly East Asian countries, are often grouped together to observe overall trends, but not studied individually (Abu-Rayash 2020). Second, although there are studies revolving solely around China, most of them focus on specific sectors rather than a national or provincial level (e.g. transportation sector, restaurant industry, etc.) (Zhang 2021 and Ming et al. 2020). Third, aside from all these, there are few studies about projections of post Covid-19 energy impacts. Researchers generally focus more on the energy change during the pandemic, but less frequently emphasize the period where pandemic gradually fades away. Thus, there is an urgent need not only to conduct research for Asian countries from a more holistic perspective on the total energy

consumption and energy mix, but also to investigate energy consumption during different stages of Covid-19.

China is the center of this study for several reasons. First, it is one of the few Asian countries that could provide us a perspective on three different stages: pre Covid-19, during Covid-19, and post Covid-19. China's highly controlled lockdowns across the whole country led to a 15% drop in the national weekly energy consumption and the drop bounces back at the end of 2020 (Hoang 2021). It is a country that has been through the Covid-19 outbreak and also gradually recovered from it, providing a precious opportunity to study these impacts and present an exemplary strategy to rearrange energy mix in other countries facing similar situations. In addition, China has a wide application of both fossil fuels and renewable energy in different provinces (Dong et al. 2016). This provides an ideal opportunity to observe how different energy types would respond to the fluctuating consumption throughout the pandemic. China shows a dramatic change in energy demand during this special period, with a sharp decrease in the middle of the pandemic period and a sudden overshoot at the later pandemic recovery period, due to economic recovery (García et al. 2021). At the same time, opposing views on the performance of renewable energy and fossil fuels to meet drastic energy demands emerge (Hosseini E. 2020). In order to reconcile these differing views, China is a perfect candidate to be investigated, since the fact that provinces with different energy mixes experienced similar pandemic impact present an opportunity for comparison and contrast to evaluate the performance of varying types of energy resources.

In this study, to explore the ways different energy mixes confront COVID-19, I observed two provinces in China, Guizhou and Hunan, that consume renewable energy and fossil fuels at very different levels (Jiang 2021) during the COVID-19 and the recovery period, potentially informing guidance on how the energy mix should be improved in the future in order to prepare for similar energy-fluctuating situations. This paper will address the problem of how different energy mixes in China react to Covid-19-related fluctuations, with two specific questions. First, I would like to discover which of the two provinces: Hunan and Guizhou, experienced a more dramatic reduction in fossil fuel consumption during the initial shutdown period. Second, it is interesting to compare Guizhou and Hunan's renewable energy ratio and investigate whether Guizhou increased its renewable energy ratio more than that of Hunan during the COVID-19 recovery period. I conducted a secondary data analysis on the fossil fuel energy consumption during the shutdown period and renewable energy consumption during the recovery period every

month in each province with comparison with the pre-Covid data to answer these questions. For fossil fuels, there is no direct data recorded. Thus, I used a proxy – PM 2.5 level -- as an indicator for the burning of fossil fuels. For renewable energy, China has kept records of renewable energy consumption ratio each month for every province. I hypothesized that for the first question, a more dramatic decrease in fossil fuel consumption will be observed in the province that relies more on fossil fuels (Guizhou) than in the one that has more renewable energy resources (Hunan). Second, I expected that during the COVID-19 recovery period, Guizhou has increased its renewable energy consumption ratio more than Hunan, which has stayed at the same level.

BACKGROUND

Timeframe and study sites description

To address the effect of COVID-19 on energy use in China, it is important to identify the exact timeframe for the shutdown and recovery periods to conduct the study. Firstly, the main focus of my study is the year 2020, since that is when the COVID-19 pandemic began. All the results from the year 2020 will be compared to that of 2019 (pre COVID-19 year). I divided 2020 into two time periods: the shutdown period and the recovery period for different stages of economic growth.

Guizhou is a province surrounded by mountains (Figure 1) and relies on fossil fuel power plants to meet its energy demand.

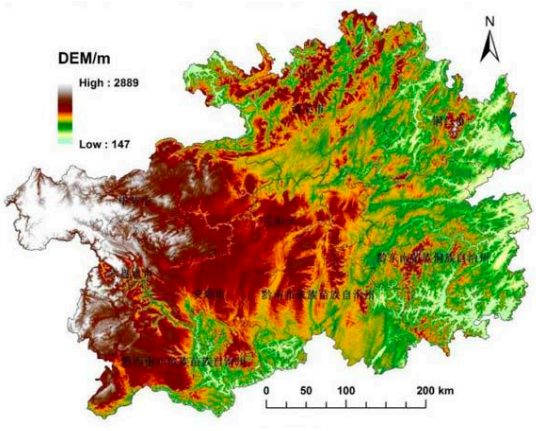

Figure 1. Guizhou Topographic Map (Jiang 2021)

Its reliance on fossil fuels renders it more flexible to cope with fluctuation in energy demand in past years, as fossil fuels are not limited by, such as seasonal fluctuations and other external factors, most of the time around the year (Jiang 2021). Guizhou, although still retains its reliance on fossil fuels (Jiang 2021), started to develop more on its geothermal facilities and gradually increased its renewable energy ratio in recent years. The percentage of fossil fuel and renewable energy consumption is 76% and 24% respectively (Guizhou Energy Department 2020). Within 24% of renewable energy, geothermal is the main renewable energy source– contributing to 75% of the total renewable energy used (Guizhou Energy Department 2020). This type of traditional fossil fuel reliant energy mix contrasts drastically with Hunan's energy mix which relies mainly on renewable energy.

Located near some of the largest rivers in China – Changjiang and Zhujiang (Figure 2), Hunan's main energy source is hydropower (Jiang 2021), with hydropower having an energy production as high as 80% (Jian 2018).

Figure 2. Map of Hunan Province (Travel China Guide, n.d.)

As a result, Hunan government spends less money and efforts on building fossil fuel power plants. However, seasonal variation during the winter remains a problem for hydropower production.

Some of the geographical and economic backgrounds of these two provinces are also important to mention. First, Hunan has a much higher level of economic activity than that of Guizhou. It could be seen that the average GDP of Hunan in 2020 is 4178 billion, while Guizhou has a GDP of 1783 billion (Hunan Statistical Bureau 2020 and Guizhou Statistical Bureau 2020). As a result, because of high-emission producing industries such as textile and construction, Hunan has historically had higher levels of PM 2.5 compared to Guizhou, even with a greater ratio of renewable energy consumption, and has a greater potential to be affected by lockdown policies under COVID-19. Secondly, Guizhou is surrounded by mountains which makes it very vulnerable to any fluctuation of PM 2.5.. It takes a longer time compared to Hunan, having a more flat topography, to dissipate the effect on air pollution by fossil fuels.

Studies on COVID-19 and SARS

Historical reviews have been conducted for events similar to COVID-19 that had a huge influence on the energy consumption patterns. Studies about SARS and energy consumption in China are the most comparable ones and this comparison proves that COVID-19 is an event that is worth studying in terms of energy consumption. Both happened in China, SARS in 2003 is comparable in the level of infectious capacity with the COVID-19 virus. SARS was listed as a legal in- fectious disease in China on April 20, 2003. Since the end of April, the number of confirmed cases has increased rapidly, and the negative impact of SARS on the transportation industry has been gradually reflected. The passenger flow of all modes of transportation was significantly impacted in May of that year.

The study by Zhang et al. (2021) is the first study that calculated the energy consumption and CO2 emissions during the SARS period and compared it with COVID-19. This study identified and compared transportation energy consumption during the severe outbreak period of SARS and COVID-19. The author concluded that COVID-19 has a much larger impact on transportation energy consumption and CO2 emissions than SARS. There are several reasons for this. First in 2003, China's car ownership was 24 million, while in 2019, China's car ownership

had reached 260 million (Zhang et al. 2021). This huge gap inevitably leads to a difference in energy consumption, which also makes the period under COVID-19 a valuable period study, since both the length and the intensity of the change in energy consumption is large enough to give valuable information and results. Secondly, in 2003, the awareness of SARS and the information spread of the virus were underdeveloped. People were not getting the same level of accurate information at the time as what is happening today. In addition, policy restrictions, like lockdown and traffic control, were not implemented as strict as it is today. Thus, the reduction in traffic energy consumption was not as severe as it was for COVID-19. Lastly, the timing of the outbreak of COVID-19 was very special, since it coincided with the Spring Festival. The Spring Festival season would reduce domestic travel rate and would in turn make the decrease more intense. As a result, accounting for all these factors mentioned above in the study, COVID-19 situates in a very unique position than other similar pandemics in the past history and could be used as a very good indicator and study object for studying energy consumption when experiencing restrictions in economic and transportation activities.

Research framework

Due to the limitations on direct access to fossil fuel data, I used PM 2.5 as a proxy for measuring fossil fuel consumption. I designed measurement methods based on a study conducted by Chen et al. (2018) on the relationship of energy structure and PM 2.5. In that study, the authors showed that countries with a higher level of fossil fuel consumption will have a higher PM 2.5 level. The paper showed that 90% of China's total primary energy came from coal, while for USA and Russia, it's only 55.1% and 16.8% respectively (Chen et al., 2018). Consequently, the USA and Russia have a much lower level of PM 2.5 than that of China. In another study, Yang et al. (2018) explored the evolutionary relationships between global urbanization and PM2.5, concluding that PM2.5 concentrations were low in countries with higher urbanization rate in Europe and America which consume less fossil fuels, and were high in most countries in Southeast Asia, South Asia, Africa, and China that rely on mainly fossil fuel combustion. The two studies both showed a positive correlation between PM 2.5 and fossil fuel consumption. With the fact that burning fossil fuels directly produces PM 2.5 and other particulate matters, I used PM 2.5 concentration as an indicator to test for fossil fuel consumption intensity.

For renewable energy, I used the ratio of renewable energy consumption as a key independent variable. I am using this metric based on previous studies that have used this same ratio by dividing coal consumption by total energy consumption (Dong et al. 2016).

METHODS

Data collection

First, daily PM 2.5 data is extracted from the website: *PM 2.5 past record*. It is a website that records the PM 2.5 level in every province in China on a daily basis. It is an official and reliable source, since it gains data directly from each province's weather bureau.

Second, the renewable energy data is from *China Statistical Yearbook from China's Statistics Bureau* (Jiang 2021). It is the most authoritative data documentation in China which includes data about monthly renewable energy consumption and total energy consumption every year in each province. The data of 2020 was published in 2021 January.

Third, as mentioned, GDP data is used to identify the start of shutdown period and recovery period. Although briefly explained in the introduction part – GDP starts to have a positive increase starting from July – specific data should be included to present to the readers in order to prove my separation between these two periods is reasonable. This data is collected from the *China Statistical Yearbook* from China's Statistics Bureau (Jiang 2021).

Method design: descriptive analysis

I conducted a secondary data analysis on fossil fuel energy consumption during the shutdown period and renewable energy consumption during the recovery period in each province. I compared the data of 2020 with the baseline year – 2019 – in order to determine any change in the consumption each month. By this comparison, the influence of seasonal fluctuation could be eliminated as it is only comparing the same month of the two years with each other. I divided 2020 into two time periods: the shutdown period and the recovery period according to different stages of economic growth. I used GDP as an indicator to evaluate economic activities. According to Hunan Statistical Bureau (2020) and Guizhou Statistical Bureau (2020)'s data on GDP, both

Hunan and Guizhou experienced a negative increase in GDP for the first two quarters of 2020 and started to recover after the second quarter which is from the start of July. Thus, the start of July is the line that separates the shutdown and the recovery period.

For fossil fuels consumption, there is no direct data recorded. Thus, I used a proxy – PM 2.5. PM 2.5s are tiny particles suspended in the air and are inhalable by human bodies, causing potential air-related disease, such as respiratory system infection (Anenberg et al. 2019). Fossil fuel combustion is a major source of PM 2.5 and PM 2.5 could be used as a great indicator for fossil fuel consumption (Anenberg et al. 2019). By using PM 2.5, I could detect the change in fossil fuel combustion by extracting data of daily PM 2.5 in each province. A line graph tracking the PM 2.5 difference in each province throughout the shutdown period is made in order to describe the change in fossil fuel consumption as lockdown policies proceed. In addition, a box graph is made to observe the distribution of the shutdown period data from each province.

For renewable energy, China keeps records for cumulative renewable energy consumption and total energy consumption each month for every province. I didn't use solely the renewable energy consumption, but instead a renewable energy to total energy consumption ratio in order to make a fairer comparison between the energy mix of the two provinces, since Hunan and Guizhou are two provinces of different size and populations. In order to describe the trend, a line graph is made to record the change in monthly renewable energy consumption ratio with respect to time elapse during the recovery period.

Method design: statistical analysis

The statistical analysis mainly focuses on fossil fuel consumption during the shutdown period, since the data for renewable energy is only a 6-months data and is not large enough for a statistical analysis.

First, daily PM2.5 data from 2019 January to June (the shutdown period) is subtracted from the daily data from 2020 in order to exclude seasonal variations. After this, PM 2.5 difference data from Hunan and Guizhou is used for a two sample t-test. Besides, the same two sample t-tests are conducted on PM 2.5 difference ratio data. The ratio data set is calculated by dividing the PM 2.5 difference value over the 2019 PM 2.5 data.

RESULTS

Descriptive analysis results – PM2.5

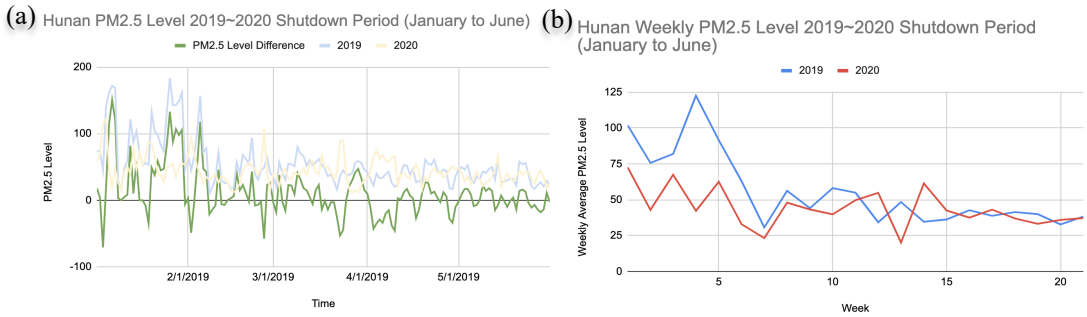

Figure 3a. Hunan PM2.5 level 2019-2020 shutdown period (January to June)
Figure 3b. Hunan weekly PM2.5 sevel 2019~2020 shutdown period (January to June)

Figure 3a shows Hunan's daily PM2.5 level during the shutdown period. A bigger fluctuation could be seen from January to March and this fluctuation gradually becomes smaller after March. The green line marks the PM2.5 difference between the year 2019 and 2020. As the major fluctuation is above 0, it could be substantiated that PM2.5 level has an overall decrease compared to that of 2019. Since daily fluctuations are complex when viewing the overall trend, weekly average PM2.5 level is calculated to simplify the data description process, as shown in figure 3b. Figure 3b shows that during 2019, there's a big downward trend during the 4-6th week. On the other hand, 2020 has less fluctuation and no significant trends overall. Fossil fuel consumption level maintains a roughly similar level.

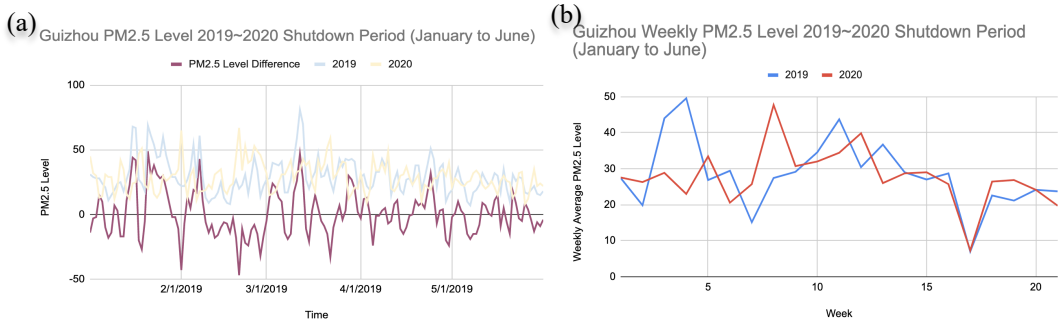

Figure 4a. Guizhou PM2.5 level 2019-2020 shutdown period (January to June)
Figure 4b. Guizhou weekly PM2.5 sevel 2019~2020 shutdown period (January to June)

I did not observe significant trends in both 4a and 4b.

Descriptive analysis results – renewable energy

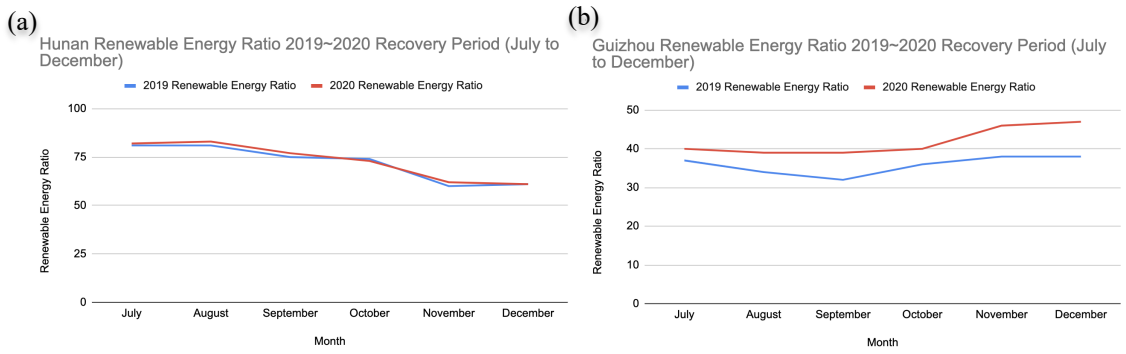

Figure 5a. Hunan energy ratio 2019-2020 recovery period (July to December)
Figure 5b. Guizhou energy ratio 2019-2020 recovery period (July to December)

In figure 5a, I find no distinct pattern on Hunan's renewable energy ratio. The seasonal decreasing pattern is maintained. There is an overall decrease in hydropower consumption after October due to decrease in flow in Changjiang and Zhujiang rivers during the winter season in both years.

In figure 5b, there is an overall increase in renewable energy consumption ratio in 2020 compared to that in the year 2019, especially during November and December, when the economy was recovering. In addition, these months coincide with holidays and winter seasons, when there is an increasing demand for energy both in residential and industrial sectors. This increase can also be attributed to the development of renewable energy in the previous years in Guizhou, which will be explained in the discussion section. Since the data points for renewable energy are too small, no statistical tests and analysis were made.

Statistical analysis results - PM2.5

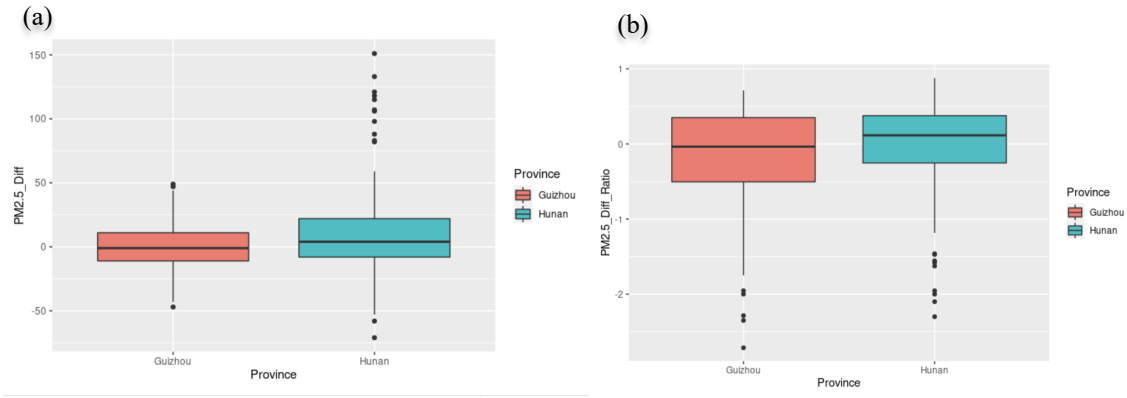

Figure 6a. PM2.5 level difference in Guizhou and Hunan
Figure 6b. PM2.5 level difference ratio in Guizhou and Hunan

Figure 6a and 6b are two box plots showing the distribution of the daily PM 2.5 level difference data and difference ratio data. The medians of PM2.5 difference between Guizhou and Hunan are relatively similar (Figure 5a). However, Hunan has a wider distribution of data, showing a bigger PM2.5 fluctuation between the two years (Figure 5b). Figure 5b shows a similar data distribution of PM2.5 difference ratio in the two provinces.

Both T-tests have statistically significant P-value: 0.002 and 0.035 respectively for PM 2.5 difference and difference ratio data. It confirms that Guizhou and Hunan present a very distinct PM2.5 trend before and during COVID-19.

DISCUSSION

Results from PM2.5 and renewable energy ratio give insights on how fossil fuels and renewable energy are used during the shutdown and recovery periods. In order to explore the ways different energy mixes confront COVID-19, important trends in the results section are worth to be discussed, potentially informing guidance on how the energy mix should be improved in the future in order to prepare for similar energy-fluctuating situations. Main discussions revolving around the results include Hunan is not heavily affected in the longer term by COVID-19 situation in terms of fossil fuels, and Guizhou's prospective planning in renewable energy is essential for energy supply during energy demand spiking periods, the recovery period.

Fossil fuel consumption during shutdown period

Results from daily PM2.5 data shows that Hunan has a lower level of PM2.5 level in the first two months of the COVID-19 outbreak compared to that of 2020. This trend is largely due to lockdown policies and cease of industrial production that is extremely energy-consuming. However, this positive difference got smaller after the first 6-7 weeks. It infers that the consumption goes back to normal level. As people adjusted their living styles, residential energy consumption went up. Residential energy consumption goes up. Fossil fuel consumption is only negatively affected by COVID-19 lockdown and restriction policies in the short term. In comparison, Guizhou had no specific trend. This may be due to the fact of Guizhou's lag in economic development and inactive industries. On the other hand, Hunan is more urbanized and has a higher population density which results in much more energy demand. According to Hunan Statistical Bureau (2020) and Guizhou Statistical Bureau (2020), Hunan's GDP in 2020 is 4.18 trillion yuan which is 2.3 times higher than that of Guizhou (1.78 trillion yuan). Furthermore, Hunan's industrial activity accounts for 30% of its GDP (Hunan Bureau of Statistics 2021) while Guizhou only accounts for 20% (Guiyang Bureau of Industry and Information Technology 2022). With a more dense population, Hunan also has a heavier carbon emission in the transportation sector. Both T-tests confirm that Guizhou and Hunan present a very distinct PM2.5 trend. It could be inferred that for provinces that are not industry-concentrated like Guizhou, fossil fuel consumption doesn't fluctuate much. This conclusion could also be substantiated by another research paper (Ravindra et al. 2021) It mentioned that for economically underdeveloped areas, mobility restriction due to COVID-19 makes it more difficult for these areas to access energy. Thus, although Guizhou relies mainly on fossil fuels, the energy fluctuation is not as sensitive as that of Hunan. This deviates from my hypothesis that I expect a more dramatic decrease in fossil fuel consumption will be observed in the province that relies more on fossil fuels (Guizhou) than in the one that has more renewable energy resources (Hunan). The hypothesis didn't account for the fact of different economic development and baseline energy demand.

Renewable energy consumption during recovery period

In terms of renewable energy, the results suggest that since Hunan relies mainly on hydropower, renewable energy consumption is largely affected by the seasonal variation rather

than COVID-19. Even though there is a spiking demand for energy during the recovery period, hydropower didn't make up much of this demand. Thus, power cutoff was administered in Hunan in order to compensate for public energy consumption, e.g. hospitals and other essential facilities (Xi, 2020). Guizhou, on the other hand, presents an increasing renewable energy ratio consumption during the recovery period. This increase is benefited by Guizhou government's prospective planning of renewable energy development, which is essential for energy-fluctuating circumstances, like COVID-19. Guizhou, although still retains its main reliance on fossil fuels, started to develop more on its geothermal facilities and increased its renewable energy ratio these years (Jiang 2021). Especially during November and December, holidays are approaching and winter season also adds on the pressure to the energy supply. This conclusion perfectly proves my hypothesis that during the COVID-19 recovery period, Guizhou has increased its renewable energy consumption ratio more than Hunan, whose ratio has stayed at the same level.

Referring back to the central research question of this research, it could be concluded from my research that during COVID-19 shutdown period, Guizhou, whose energy-mix that is not heavily industry-emphasized, wasn't affected by the pandemic heavily. Hunan, whose energy-mix that is industry-emphasized, was only impacted negatively in the short term, and it bounced back to normal energy distribution after people started to adjust their lives accordingly. During COVID-19 recovery period when energy demand skyrockets, renewable energy usage is heavily affected by its own limitations (e.g. seasonal variation). For renewable energy that is not affected by season (e.g. geothermal), it is largely exploited during the recovery period in order to meet the energy demand.

Limitations and future directions

Lastly, there are drawbacks and improvements that should be mentioned in this study. First, there is limited data for renewable energy for this study. Monthly data set is too small for any statistical analysis. Second, it is doubtful that PM2.5 could give a direct and accurate measurement of fossil fuel consumption, since it is heavily dependent on other physical factors such as weather and topology. More rigorous studies should be conducted if accurate fossil fuels data is available in the future. Third, there should be more analysis and literature review on relevant policies and economic development status before conducting the research in order to thoroughly understand

the trends found. Further studies could also break energy consumption by different sectors and dive into the trend of each sector under COVID-19 to gain a more comprehensive understanding of the energy structure and its changes. Fourth, the scope of future studies could also include data from 2021 and 2022 to get a better understanding of the relationship between the whole pandemic period and energy consumption. More provinces in China could also be studied for a national-level comparison.

Conclusion

In a nutshell, this study presents two different energy consumption trends in China in the pandemic period in 2020. Fossil fuel consumption presents an important source of energy for industries and it is not heavily affected in the longer term by COVID-19 situation for industrial-dependent provinces. Fossil fuel still appears to be a reliable source of energy. On the other hand, renewable energy prospective planning is essential and conducive for energy supply during energy demand spiking periods. It is important to value the limitations of different renewable energy by selecting them carefully. A combination of different energy sources is recommended in order to mutually complement each other's drawbacks for a stable energy supply.

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