Addressing the Elephant in the Room: A case for the Swedish renewable electricity generation in the context of COVID-19

Abstract

While many countries are imposing lockdowns and social distancing measures to tackle the nCOV19 that has emerged from the Chinese city of Wuhan, few countries are advocating soft lockdown and Sweden is a pioneer in this movement. This study aims to relate COVID-19 with Sweden's renewable electricity production from three sources as Nuclear, Solar, and Wind energy. As opposed to many studies investigating the direct linkage of COVID-19 and energy development, we present a different approach where we try to validate the empirical linkage between Air quality index (AQI) and electricity production from three types of renewable energy. Results from wavelet coherence analysis reveal that COVID-19 has undermined nuclear energy generation while the pandemic does not have any significant effects on solar electricity generation. The results also find that although both AQI and wind energy production negatively influenced each other in the pre-COVID-19 period, only wind electricity development has a significant negative effect on AQI during the COVID-19 period. In light of our findings, we discuss possible policy actions the country can take to fulfil its renewable development goals.

Keywords: COVID-19, Renewable, AQI, Sweden, Wavelet, Causality, Covid, economic, air quality, renewable

1. Introduction

According to World Health Organization (2020), COVID-19 is an infectious disease from a large family of coronaviruses that may cause illness in animals or humans. In humans, several coronaviruses are known to cause respiratory infections ranging from the common cold to more severe diseases such as Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS). On December 31st, 2019, the first case of COVID-19 was discovered by the Wuhan Municipal Health Commission Chinese in Wuhan City, Hubei province, China. The commission reported a group of pneumonia cases with unspecified aetiology that had a history of exposure to Wuhan's Huanan Seafood Wholesale Market. On January 9th, 2020, the China Center for Disease and Control reported that a novel coronavirus (2019-nCoV) had been detected as the causative agent and the genome sequence was made known to the public (European Centre for Disease Prevention and Control, 2020). Since then, most countries ensured they followed preventive measures and early diagnosis in the host (Manigandan et al., 2020a).

The early symptoms of COVID-19 involve fever, dry cough, fatigue, and myalgia. Other less common symptoms that may affect some patients include aches and pains, nasal congestion, headache, conjunctivitis, sore throat, diarrhoea, loss of taste or smell or a rash on skin or discolouration of fingers or toes. Most people (about 80%) recover from the disease without needing hospital treatment. Around 1 out of every 5 people who get COVID-19 becomes seriously ill and develops difficulty breathing. Although However, anyone can catch COVID-19 and become seriously ill, older people, and those with underlying medical problems like high blood pressure, heart and lung problems, diabetes, or cancer, are at higher risk of developing serious illness (WHO, 2020). Recent study attuned that the pandemic can also be detected without human intervention, but with the help of suitable technology, precisely drones (Manigandan et al., 2020b). The drones will be prepared with the help of a thermal vision camera to recognize body temperature, disinfect the environments, and detect infected persons, therefore, employing the drones to screen the workplaces, shopping centre and training establishment to distinguish to identify the mask through AI are viable without human intervention in less time (Manigandan et al., 2020b).

Corona Virus Disease (COVID-19) is spreading worldwide, and Sweden, like other countries, has been affected. This virus has presented the greatest world health challenges and it has had adverse effects on the world economy. The Swedish economy is an export-dependent economy (Milne, 2020), and it also likely to experience a significant disruption due to the pandemic. According to the National Institute of Economic Research, Swedish GDP is predicted to reduce by 7% while unemployment increases by 10.2% (Ellyatt, 2020). This was evident in the first three months of 2020 when the economy contracted by 0.3% compared to other Eurozone economies. This slowdown in economic activity is accompanied by a reduction in energy demand and an increase in energy costs. Sweden's Framework Agreement on Energy Policy had the target to achieve a 100% share of renewable electricity by 2040 and a net-zero carbon economy by 2045. This is evident from electricity production from renewable sources. Moreover, Sweden demonstrates a bold commitment to achieving its renewable target through investment in a large share of R&D on renewable energy compared to other European countries (IRENA, 2020). A report about the electricity market in Sweden has revealed that renewable electricity capacity is estimated be doubled within the decade increasing from 14.8 gigawatts in 2019 to 30.4 gigawatt in 2030. Also, the report further revealed that the general compound annual growth rate (CAGR) will increase by 6.8%, Solar PV by 16% and wind energy by 8.3% in 2030.

Unfortunately, various environmental impact, which exposes severe harms to the environment, is associated with energy sectors (renewable energy). Some of them are particulate matters, CO_2, NO_x, SO_2, ozone, and water vapour etc. This releases more pollution to the environment thereby reducing the air quality. However, restriction enforced due to the covid-19 pandemic is likely to improve the air quality since there were fewer energy or fuel activities during the lockdown. Backing this point, Manavalan et al. (2020) explore artificial intelligence to predict the air quality changes and accumulation of rainfall during the covid-19 pandemic and revealed that there is a reduction in the concentration of pollutants released from various sources such as CO_2, ozone, particulate matters, and others. Van et al. (2020) also noted that the lockdown placed during the covid-19 pandemic, although effect economic activities, had a significant reduction in CO_2, NO_2 and particulate matters. On the contrary, Syed et al. (2020) investigate the energy consumption rates of residential society during the pandemic. The result noted that the mandatory lockdown forced target residents to consume more energy for their daily activities. This alludes that the air quality of the surrounding is not moderate, thus affecting their health status in this regard.

Although an average Swedish releases carbon emission four times lower than that of an American International Energy Agency reported that Sweden has the second-lowest CO_2 emissions per capita among its member countries and lowest fossil fuel share in primary energy supply (IEA, 2019), but its harmful effects on the health of the environment cannot be neglected. Thus, the sole purpose of this study is to examine the causal relationship between renewable energy production and the air quality of Sweden in the context of COVID-19. The objective is to demonstrate that whether Sweden's more investment in renewable energy could reduce air pollution and thus increase air quality. Furthermore, this study contributed significant research to existing energy and pollution papers in Sweden. (1) we compare both the pre-COVID-19 data and COVID-19 while examining the link between air quality index and renewable energy. (2) we introduced Wavelet power spectrum and wavelet coherence analysis. The wavelet analysis is also useful to handle the daily data as it can very well capture the fluctuations or volatility associated with any high-frequency series.

The rest of this study is organized as follows: the second section describes the literature review, the third section presents data and methodology, section 4 describes the empirical findings and the final section presents concluding arguments and recommendations.

2. Literature Review

Based on our main objective, we divide the literature into two subsections, one dealing with the AQI and renewable during the pre-COVID-19 period and another one dealing with the aforementioned variables in the COVID-19 period.

2.1 AQI and renewable nexus in Pre-COVID-19 period

In the middle of the 21st century, solar energy development is predicted to experience a substantial growth than any other forms of energy, but this may be severely affected due to man-made particulate pollutants and dust. In this context, different scholars have reported different findings, for instance, Bergin et al. (2017), using China and India as a case study, investigate whether pollution could affect solar energy. The study found that solar energy production decreases by about 7400 MW in China and about 780 MW in India due to atmospheric particulate matter (PM). For the 24 regions examined, an approximate 17 to 25% reduction in solar electricity, due to both ambient PM and PM, was deposited to photovoltaic. In the most similar context, Katzenstein and Apt (2009) were concerned with how renewable energy, such as wind could affect air quality. It was reported from the study that wind energy does not, itself, emit any emissions but its effect on the system of electricity operation could cause a rise in traditional plants' emissions level. Thus, the findings suggested said that wind energy is not sufficient enough to reduce SO_2 and NO_x, rather carbon tax should be implemented simultaneously. Yang et al. (2018) examined how various solar photovoltaic (PV) pathways can affect China's air quality and people's health in particular. Different results based on the deployment of distributed PV were found. The results demonstrated that deploying in the east with inter-provincial transmission has the largest air quality-related health benefits. In particular, they demonstrated that deploying these decreases by 1.2% premature deaths due to air pollution compared to the base case.

In another sense, Li et al. (2017) study how aerosol pollution can decrease the level of solar photovoltaic (PV) electricity generation in China. The result demonstrated interesting findings where an annual average of over 20% reduction in surface solar radiation which is suitable for PV electricity production can be attributed to the aerosol pollution in the atmosphere. The findings suggested that China should improve its air quality to facilitate solar PV generation. This will amount to efficiency that would in turn reduce air pollution. Sweerts et al. (2019) use 100 stations and observational data of radiation for a period of 1960 and 2015 and examined if solar PV generation could be affected by controlling air pollution. The result showed that anthropogenic aerosol emissions and changes in the cloud were responsible for an 11-15% reduction in PV potential. It also found that if reverted to 1960's surface radiation level, a potential 12-13% electricity production increase and US$4.6-6.7 billion of economic benefits in 2030 could be expected. Also, the recent study by Li et al. (2020) investigated the atmospheric concentration of high-level particulate matter (PM) and its significant impact in hampering the development of solar PV capacity. In the paper, total PM impact into were segmented into panel soiling and atmospheric aerosol attenuation. The findings from the result averred that the electricity production efficiency of solar PV, in solar abundant regions, was negatively affected by PM through panel soiling and atmospheric aerosol attenuation. However, in the desert and hugely polluted regions, it was found that reducing this type of air pollution can double the electricity generation efficiency of PV because PM can decrease PV efficiency by over 50%. They recommended that it is extremely necessary to mitigate air pollution in the long run to increase the PV generation capacity for both of these regions.

Furthermore, the benefits of wind energy on air quality are well documented in the empirical literature. The development of this energy does not pollute the air or environment, which is why it is recognized as one of the clean energy technology. Traditional energy sources such as fossil fuels are responsible for air pollution. But wind energy development can curb the rate of nitrogen oxide and sulfur dioxide (Saidur et al., 2011). However, Nordman et al. (2013) holds a very different opinion and has said the benefits of wind energy development on air quality depends on what kind of energy source it is displacing. If a wind farm completely closes or makes a coal electricity plant slow down, the benefits on air quality will be huge. If for example, the plant was emitting pollution at a higher amount, the environmental benefits will also be substantial. However, it should also be noted that any electricity plants (including wind farms) in their construction, maintenance, and demolition stages use electricity and therefore can emit pollution also. Therefore, whether air quality can be improved due to wind energy is not truly a straightforward result. The benefits depend on what kind of energy mixed they have.

2.2. AQI and renewable nexus during COVID-19 period

Naderipour et al. (2020), using Malaysia as a case study, examined the impact of COVID-19 on the environmental consequences and renewable energy generation. As the result, it was observed the restriction on movement enforced in the country contributes to the reduction in air pollution. This in turn closed several recreational and industrial centres which had resulted in a reduction of carbon footprint, CO_2 emissions as well as air pollution. As a result, the maximum sunlight was able to reach the earth, and energy production was also observed to be increased. On the other hand, Jain & Dhadke (2020) assessed the impact of the lockdown on the Indian energy sector and found that electricity demand and consumption reduced as a result of confinement associated to curb the spread of the virus. As a result, the energy demand in India reduced drastically putting an economical strain on the energy sector. Although the cost of energy production remained the same, the low energy consumption leads to low billing rates which in turn resulted in a reduction in the profit margin thus, the energy sector incurring more losses. There is a need to, however, move from the consumption of fossil fuel energy to renewable energy production to ensure the sustainable energy goal and secure future energy demands even amidst uncertainties like the covid19 pandemic.

Bera et al. (2020) investigated the extent to which the covid19 outbreak affect the renewable energy sector. The result revealed some noticeable effects, such as delays in the supply chain, government tax, and inadequate spending from the government. Hence, the government and policymakers were advised to adjust its renewable energy contract and warranty mechanisms to minimize financial risks. This will help discourage investors from avoiding clean energy investments due to uncertainties like a covid-19 pandemic. The study further stressed the use of land surface temperature maps to demonstrated that lockdown and restrictions on industrial and transport activities, with regards to COVID-19, have substantially reduced CO, NO_2, and SO_2 but increased O_3.

Also, Hosseini (2020) considered an outlook on the global development of renewable and sustainable energy during the covid19 period. He discovered that adopting renewable energy can bring substantial solutions after the pandemic, that is, industries can be revived by ramping up renewable energy technologies while creating new jobs at the same time. Also, a good number of renewable energies provide an approach for the control of energy issues associated with the situation of the pandemic. To return to normal condition and at the same time keeping sustainable energy projects on track in the post covid19 world, the government needs to support renewable investments. This is because the covid19 pandemic has shown that economic uncertainties are capable of harming the transition to a renewable energy regime.

Furthermore, Zhu et al. (2020) explored the fluctuating characteristics of Air quality index in China. He discovered that environmental quality would not be reflected by environmental monitoring and management system without abiding by inherent laws of AQI fluctuations. Thus, adequate control of the weather, GDP, income levels, and, AQI, PM_2, and SO_2 would extremely decrease. The study further buttresses that Implementation of energy transition could amount to synergy required between emission reduction and air quality improvement. Further, the covid19 pandemic and the resultant lockdown measures led to the reduction in transportation activities, thereby leading to less energy use and oil demand. These changes in transport activities and oil & energy demand exert a significant impact on environmental quality. Razzaq et. al. (2020) used quantile on quantile methodology to examine covid-19 pollution nexus in 10 US county. Their findings made a confirmation of the overall dependence that exists between COVID-19 and air pollution. Specifically, the study confirmed that air pollution is the main cause of chronic diseases like covid-19 and it has become imperative for the government to consider asymmetric channels and introduce appropriate policies to control atmospheric pollutions. Sandro (2020), using the EU as a target study, estimates the association between air transport mobility and Covid-19 while considering carbon footprint in pre and post-pandemic periods. The result of the findings showed that air transport mobility was greatly affected by COVID-19 with a reduction in the number of flights which directly reduce the CO_2 emission.

2.3 Research Gap

The overview of the literature outlined above revealed the harmful environmental effects exerted by air quality and environmental pollution in the context of the pandemic. However, the renewable energy and air quality index relationship during the COVID-19 pandemic is also of great importance, and this what this study sought to evaluate in Sweden. Renewable electricity generation has significant benefits in terms of reducing air pollution. Clean energy sources are all considered to be the key technologies to reduce air pollution in Sweden since much of the pollutant gases are emitted by energy production. Therefore, if clean and sustainable energy can be generated, premature deaths from AQI can also be easily avoided. In this pursuit, the study documents the causal effect of renewable and AQI while controlling for the covid-19 pandemic period.

3. Data and methodology

3.1 Data description

To see the causal effect between air quality and renewable electricity production, we have collected data from two sources. We have collected daily hourly data of renewable electricity generation from Svenska kraftnät, the Swedish transmission network for electricity's statistics database, and then took the end of day settled data. Air quality data has been collected from the World air quality index (WAQI). The data is split between the COVID-19 period and pre COVID-19 period. For example, pre-COVID-19 data ranges from October 2019 to January 2020 and the COVID-19 period involves data from February 2020 to July 2020. We have specifically chosen the February as starting date for COVID-19 because Sweden encountered its first confirmed case at the very beginning of this month.

Descriptive statistics for all the variables are presented in Table 1.

[Place for Table 1]

3.2 Methodology

In this current investigation, we apply both wavelet electricity spectrum and wavelet coherence analysis which are quite suitable for handling the daily data. The wavelet analysis takes both the frequency and time dimension into account simultaneously, which is a helpful device in the econometric examination since contemplates are broadly led by either time arrangement investigation or dependent on recurrence area. Also, utilizing time-sensitive customary causality tests and fixed boundaries causes mistaken outcomes when there are auxiliary breaks in time arrangement. At this juncture, determining where structural breaks occur in the modelling technique is quite remarkable. In this unique situation, the Fourier change is created by utilizing an alternate recurrence area approach. In this methodology, disregarding the data in the time area and zeroing in on the recurrence space represents a basic issue.

Also, the wavelet analysis combines the two widely used separated techniques under a unified frame of time and frequency dimension. At the end of the day, the persistent wavelet coherence approach permits the current investigation to look at how the renewable energy production and air pollution got affected in the presence of COVID-19 in Sweden is connected at various frequencies and how their relationship fluctuates after some time since the wavelet examination has taken both the recurrence and time measurement into account all the while. In any case, it merits referencing that the quantity of studies in the monetary and condition writing utilizing the persistent wavelet coherence is significantly low contrasted with different fields, for example, engineering fields. All things considered, the ceaseless wavelet electricity range and coherence approaches have gotten more common as of late since the methodology takes into account acquiring profoundly important data about the connection of the monetary, money related, and condition time arrangement factors which cannot be seen by different strategies applied.

We use the wavelet equation developed by Goupillaud, Grossmann, and Morlet (1984) as follows, $\psi(t) = \pi^{-\frac{1}{4}} e^{-i\omega_0 t} e^{-\frac{1}{2}t^2}$, p(t), t=1, 2, 3….., T, where ψ is applied on limited observations by Kirikkaleli et al. (2020). The simple equation of the continuous wavelet is shown below in equation two. The continuous wavelet is constructed from ψ as a function of k and f have given time series data p(t) as follows:

$$W_p(k,f) = \int_{-\infty}^{\infty} p(t) \frac{1}{\sqrt{f}} \psi\left(\frac{\overline{t-k}}{f}\right) dt, \quad (1)$$

Whereas k and f show time and frequency, respectively. "The main role of the k is to define a wavelet's particular location in time by exchanging the wavelet while f controls the distended wavelet for localizing various frequencies" (Kirikkaleli and Sowah, 2020). Equation 2 presents the modified p(t) with the ψ coefficient.

$$p(t) = \frac{1}{C_\psi} \int_0^\infty \left[\int_{-\infty}^{\infty} \left| W_p(a,b) \right|^2 da \right] \frac{db}{b^2}. \tag{2}$$

This current study employed the wavelet electricity spectrum (WPS) to gather data about the vulnerability of air pollution on renewable energy production. Therefore, WPS allows us to capture the vulnerable periods and frequencies of the time series variables.

$$WPS_p(k,f) = \left| W_p(k,f) \right|^2. \tag{3}$$

As referenced, the upside of the wavelet coherence approach against the customary relationship and causality tests is that the methodology draws out any connection or causality effect between air pollution and renewable production in consolidated time-recurrence-based causalities. As Kirikkaleli (2020) stated, the squared wavelet coherence equation is constructed, as shown below:

$$R^2(k,f) = \frac{\left| C\left(f^{-1} W_{pq}(k,f)\right) \right|^2}{C\left(f^{-1} \left|W_p(k,f)\right|^2\right) C\left(f^{-1} \left|W_q(k,f)\right|^2\right)} \tag{4}$$

Meanwhile, C shows time and the smoothing process over time, with $0 \leq R^2(k,f) \leq 1$. Whenever $R^2(k,f)$ approach the value of one indicates a correlation among the time series variables. In the figures, correlated areas are surrounded by a black line and depicted in red color. However, whenever the value gets close to zero, this indicates no correlation between the time series variables and is pictured by blue color. Obtaining $R^2(k,f)$ does not give us a chance to discuss the relationship's sign. To deal with this, Torrence and Compo (1998) postulated a means by which we can detect "the wavelet coherence differences through indications of deferrals in the wavering of two-time series. The equation of the wavelet coherence difference phase is constructed as follows:

$$\phi_{pq}(k,f) = tan^{-1}\left(\frac{L\left\{C\left(f^{-1}W_{pq}(k,f)\right)\right\}}{O\left\{C\left(f^{-1}W_{pq}(k,f)\right)\right\}}\right), \tag{5}$$

Where, L and O denote an imaginary operator and a real part operator, respectively.

4. Empirical Findings

The present study aims to capture the effect of Air pollution on renewable production and vice versa in Sweden while taking into account the effects of COVID-19. Here, we consider the short run to be 0 to 4 days, medium run to be 4 to 8 days, long run to be 8- 32 and 32 onwards to be the very long run.

Based on the aim of capturing the co-movement between air pollution and renewable production, we employ the wavelet coherence approach which allows capturing both the short-term and long-term causalities among the time series variables but as an initial step, the wavelet electricity spectrum approach is employed in the present study to identify the behaviour of the air quality index, nuclear electricity generation, solar energy production and wind electricity production variables in the present study.

A wavelet electricity spectrum for the time series variables - is represented in Figure 4-11. Figures 4-7 represent the pre-COVID-19 period. Before the Covid-19 period, while AQI exhibits high electricity (high variation) between 20/10/2019 and 25/12/2019, a high variation occurs for (i) Nuclear electricity generation from 10/09/2019 to 20/12/2020 in the long-run; (ii) Solar energy production from 10/09/2019 to 25/09/2019 in the short-term, (iii) Wind electricity production from 20/10/2019 to 31/01/2020 at different frequencies.

[Place for Figure 4]

[Place for Figure 5]

[Place for Figure 6]

[Place for Figure 7]

The outcome of the wavelet electricity spectrum for the times series variables during the COVID-19 period is reported in Figure 8-11, while AQI exhibits high electricity (high variation) between 25/02/2020 and 04/04/2020 in the short-term and medium-term, a high variation occurs for (i) Nuclear electricity generation in the short-term and medium-term at different periods; (ii) Solar energy production from 25/02/2020 to 01/05/2020, (iii) Wind electricity production in the short term at different periods.

[Place for Figure 8]

[Place for Figure 9]

[Place for Figure 10]

[Place for Figure 11]

As a main empirical approach, the present study employs a continuous wavelet electricity spectrum to capture both long-term and short-term dependency between air pollution and renewable electricity production before and during COVID-19 periods. Figure 12 and 15 report wavelet coherence between nuclear electricity generation and AQI for the periods before Covid-19 and during Covid-19, respectively. From figure 12, we find a mixed result depending on the time-frequency. In the short run, arrows are left up meaning that they have negative co-movement with nuclear is leading. Since here arrows are left up, it also indicates that nuclear is having a negative causal effect on AQI in the short run. However, AQI is having a leading effect on nuclear electricity generation in the medium run. In both the short run and medium run, AQI and nuclear electricity generation are negatively related to each other. That means that nuclear electricity generation can help curb out air pollution in the short run and reduction in air pollution increases nuclear electricity production in the medium run.

But In the very long run, two variables are in phase, indicating that they are moving in the same direction where AQI is leading. Here, arrows are right up meaning that before the COVID-19 period, AQI is leading (AQI has a positive causal effect on nuclear electricity generation). Now looking at figure 15, a significant dependency that was observed during the pre-COVID-19 period between these two variables seems to fade away when COVID-19 hit the country. Therefore, we can rightfully conclude that COVID-19 disrupted the linkage of nuclear energy development and air pollution. This is supported by a report from IEA (2020) which said that COVID-19 has been undermining nuclear electricity's role in the transition towards a clean energy system.

Now let us turn to the wavelet coherence between solar energy production and AQI. Figure 13 illustrates their relationship for the pre-COVID-19 period whereas figure 16 depicts it for the COVID-19 period. From figure 13, we see that there is no significant relationship between AQI and solar electricity production in the short run. In November 2019, we find that arrows are left upward meaning that solar energy generation leads to a reduction in air pollution. This is evident from the figure of AQI also where we see that in November 2019, we find that AQI is lower than the previous month. However, in January 2020, we find arrows to be right downward (Solar is leading AQI) indicating a positive co-movement. Across December 2019, in the long run, arrows are left downward (AQI is leading Nuclear electricity generation) depicting an anti-phase relationship. This indicates that AQI has a negative causal effect on solar electricity generation in the long run. So before the COVID-19 period, high AQI was hampering solar electricity generation in Sweden.

During the COVID-19 period in figure 16, a significant correlation can be found only in the long run and very long run periods between solar electricity generation and AQI. We find the arrows to be left downward, meaning that they have an anti-phase relationship and AQI is leading. So an increase in AQI negatively affected Sweden's electricity production from solar. Since we find this to be the case for both the pre-COVID-19 and COVID-19 period, we can infer that COVID-19 induced reduction in air pollution did not contribute much to the electricity production from solar energy.

Finally, we look at the relationship between wind electricity production and AQI. Here figure 14 demonstrates the pre-COVID-19 period relationship between the aforementioned variables. In the long run, we find that AQI has a leading effect meaning that AQI affects wind electricity generation. In the very long run of December 2019, wind electricity production is leading with both having an anti-phase relationship with each other but by the time another year came, AQI again seemed to lead wind energy generation. This is an indication that in December 2019 and January 2020 when COVID-19 was detected first in Wuhan province of China, both AQI and wind energy production negatively influenced each other.

Now let us look at figure 17 where we demonstrate a relationship between wind energy production and AQI in the COVID period. We find no strong co-movement between these two variables either in the short run or medium run. However, a significant anti-phase relationship can be observed between the variables from April to June 2020 where wind electricity generation is leading throughout. So in April, May, and June months, we find that wind energy has a negative influence on AQI, which means that due to the level of wind energy generated, air quality level decreased in these three months in Sweden. This can be well attributed to the fact that Sweden's stringency index was well above 60 in these periods. Sweden started implementing harsh lockdown in these periods because of its rise in the total number of confirmed COVID cases and deaths as can be seen again from figure 2. In these periods, we provide strong evidence that wind electricity generation significantly contributed to a decline in AQI. This result is consistent with Greene and Morrissey (2013) who found that wind electricity development can have significant reductions in SO_2 and NO_X. They also reported notable benefits in terms of health as well as economy because of wind electricity development.

[Place for Figure 12]

[Place for Figure 13]

[Place for Figure 14]

[Place for Figure 15]

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[Place for Figure 17]

5. Conclusion

This study sheds light on the issue of renewable energy development in Sweden in the COVID-19 context. There is currently an ample amount of evidence on how renewable energy has been hampered due to COVID-19 induced lockdown and restrictions, but not enough evidence on how COVID-19 induced reduction in air pollution has contributed towards the development of renewable energy. Although COVID-19 does seem to present a hopeless scenario for renewables as the budgets are currently diverted from developing clean energy towards handling the COVID-19 situation, we tried to see whether COVID-19 has a silver lining in terms of the effect of AQI on renewable energy and vice versa.

The study adopted the Wavelet electricity spectrum as well as wavelet coherence approach for investigating the aforementioned link. Our findings can be summarized as follows: (1) Nuclear electricity generation and AQI had a strong causal effect on each other during the Pre-COVID-19 period but these effects faded away once COVID-19 hit the country. (2) Solar energy production was negatively influenced by air pollution in the long run for both COVID-19 and pre COVID-19 periods. (3) The pre-COVID-19 period demonstrated a strong negative causal linkage between wind electricity and air pollution. But in the COVID-19 period, only a unidirectional causality from wind energy development to AQI was discovered.

Based on the above findings, we can conclude that COVID-19 disrupted the linkage of nuclear electricity with air quality but it did not influence the linkage between solar and AQI. In the case of wind, AQI's positive/negative effect on this clean energy was not found, demonstrating that COVID-19 again disrupted the aforementioned linkage but less than that of the disruption between nuclear and air pollution. The above results demonstrate that both nuclear and wind energy production can be effectively hampered due to extreme events and thus the government should be mindful while producing them. Therefore, it is recommended that Sweden must balance its renewable energy sources and invest simultaneously in all renewables that are feasible for the country since events like COVID-19 can disrupt the electricity production capacity of renewable power at any time.

The majority of the cases we have examined show that an increase in the level of air pollution can significantly lower the production of renewable electricity in Sweden. Therefore, although the AQI of Sweden is lower than other counties, it must still invest in controlling air pollution if it wants to increase its renewable production. As Sweden wishes to become a 100% renewable country by 2040, it is of the highest necessity for this country to implement measures that can control AQI.

Paulsson and Mathis (2020) have recently said that the COVID-19 pandemic could not stop Sweden from wind plant development. However, it should be also noted that the maintenance and construction of renewable plants can induce air pollution and can negatively affect renewable energy production (Nordman et al., 2013). Therefore, measures should be in place to control air pollution that emerges during the construction and maintenance phase of renewables.

We have also found in most of the cases that renewables have a strong negative effect on air pollution. This means that if renewables can be developed fully, they are sufficient enough to improve the air quality in Sweden. Renewable energy development has certain benefits in terms of economic growth, employment generation, and reduction in carbon emissions but our analysis shows that the production of renewable electricity can help Sweden save thousands of premature deaths occurring in the country every year and also reduce the disability diseases associated with the air pollution.

Future research can delve into these issues further by looking at how Sweden's renewable energy production during COVID-19 can be compared to other Scandinavian countries, using a variety of other techniques to handle the daily data.

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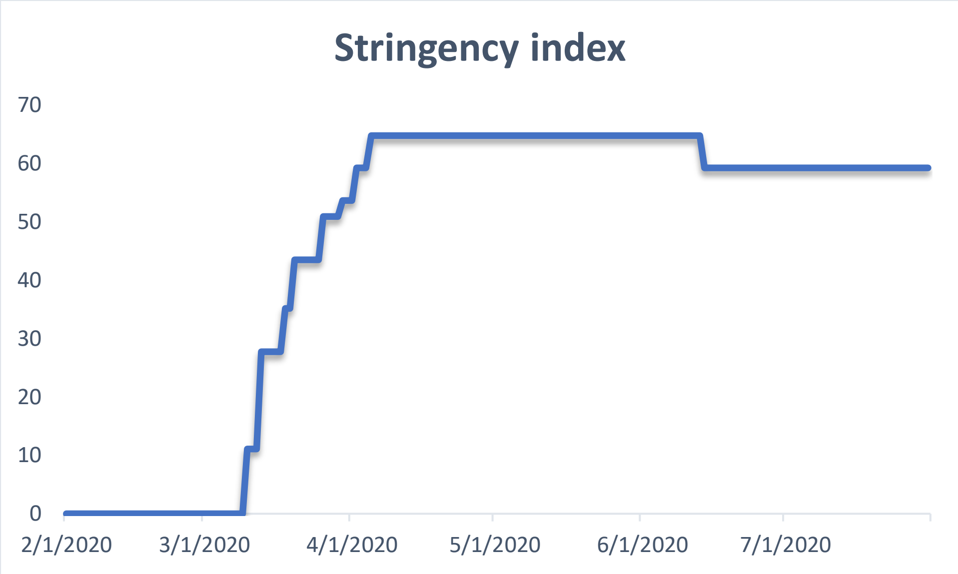
Table 1. Data and Descriptive Statistics

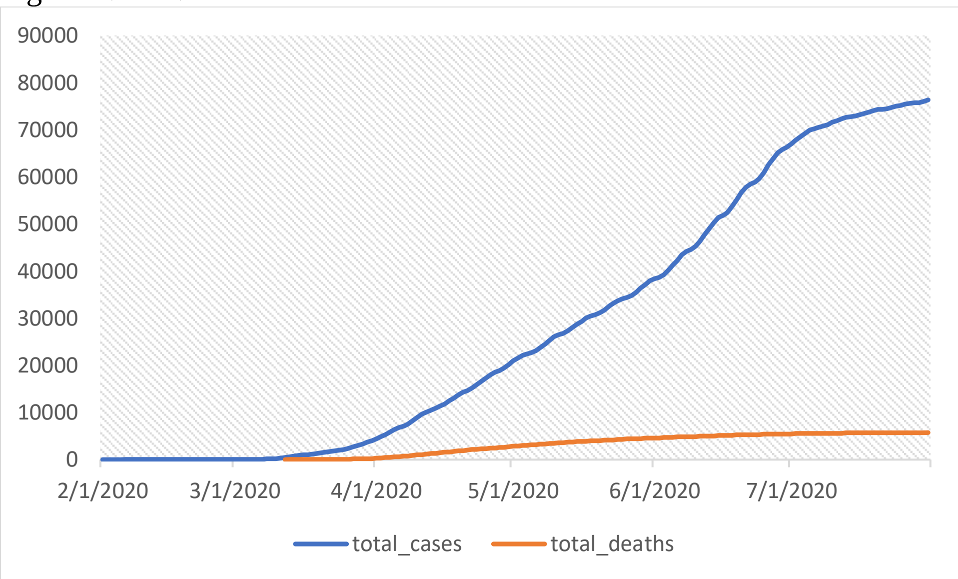
Variable	Air Quality Index	Nuclear electricity generation (kWh)	Solar electricity production (kWh)	Wind electricity production (kWh)
Period		Before Covid-19		
Mean	27.60196	7359812.	175.5614	3055325.
Median	23.50000	7585850.	173.6760	2502367.
Maximum	75.00000	8217900.	770.0510	7484503.
Minimum	13.00000	5673570.	63.87600	163506.3
Std. Dev.	11.76419	789936.4	89.61143	1881603.
Skewness	1.512223	-0.904624	2.794649	0.674759
Kurtosis	4.864041	2.449061	16.08422	2.496792
Jarque-Bera	80.46474	22.80284	1290.536	13.22442
Probability	0.000000	0.000011	0.000000	0.001344
Period		During Covid-19		
Mean	29.23901	5433374.	341.3031	3340371.
Median	28.90000	5394200.	264.3610	3013028.
Maximum	62.00000	7783110.	1517.951	7809435.
Minimum	15.90000	3029800.	165.0110	229439.9
Std. Dev.	7.918861	1278889.	249.5501	1781873.
Skewness	1.197688	0.408841	2.985043	0.531783
Kurtosis	5.813573	2.335907	11.58397	2.436192
Jarque-Bera	103.5430	8.414643	829.0586	10.98866
Probability	0.000000	0.014886	0.000000	0.004110

Figure 1: Stringency index for Sweden



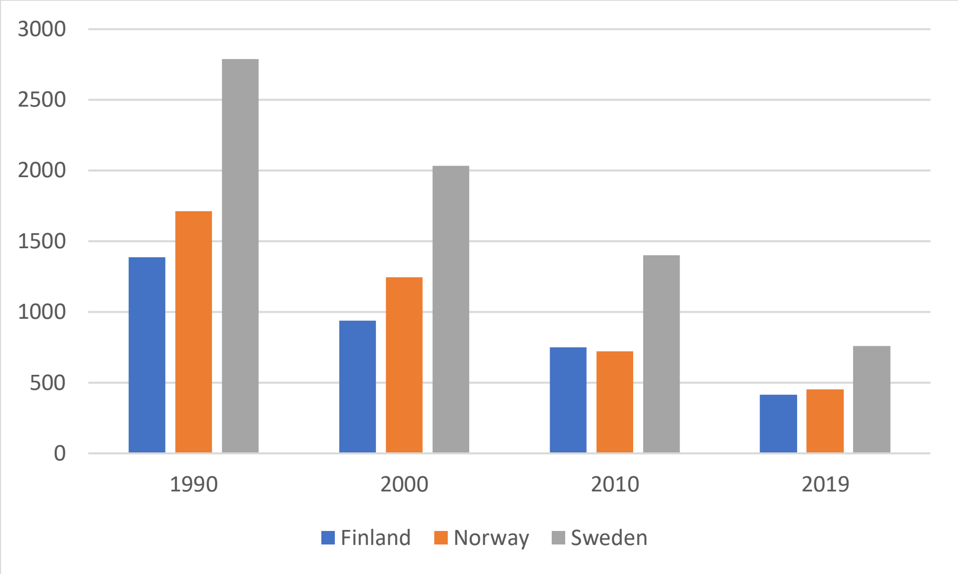
Source: Oxford COVID-19 Government Response Tracker (OxCGRT)

Figure 2: COVID-19 total confirmed cases and deaths in Sweden

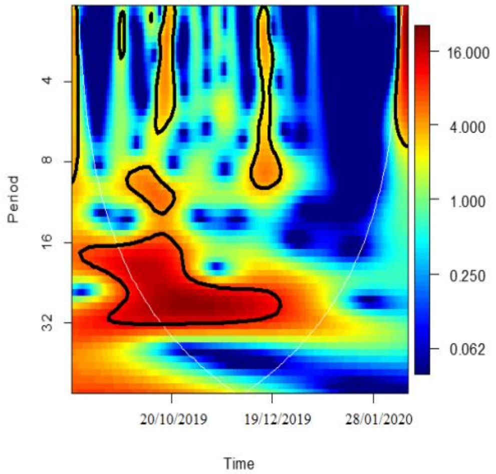
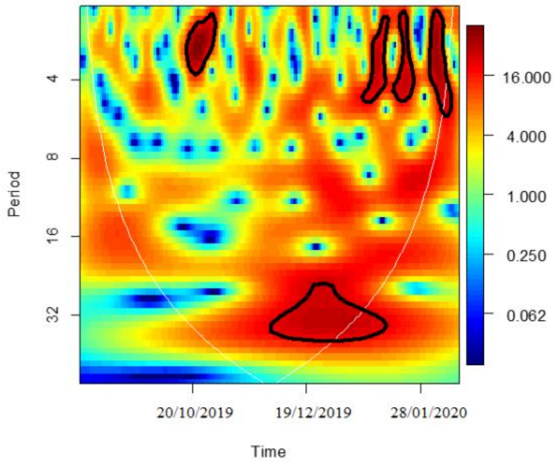


Source: Center for Systems Science and Engineering (CSSE), *Johns Hopkins University (JHU)*

Figure 3: Number of deaths attributable to AQI in selected countries



Source: Vos et al. (2020). Global burden of Disease Study.

Figure 4. Wavelet Power Spectrum for Nuclear power generation (kWh) (B-C) 	**Figure 6. Wavelet Power Spectrum for Wind power production (kWh) (B-C)** 
Figure 5. Wavelet Power Spectrum for Solar energy production (kWh) (B-C)	**Figure 7. Wavelet Power Spectrum for AQI (B-C)**

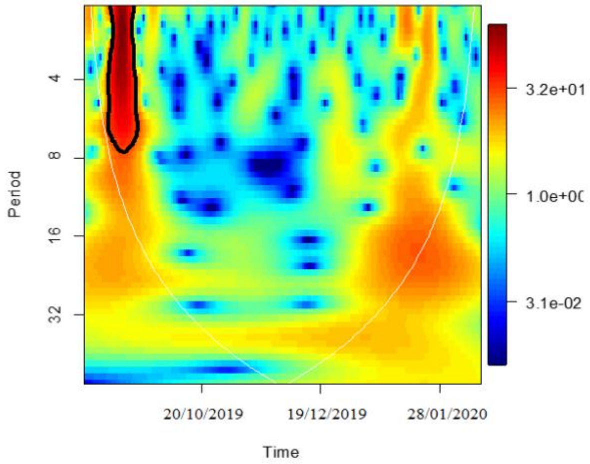


Figure 8. Wavelet Power Spectrum for Nuclear power generation (kWh) (D-C)

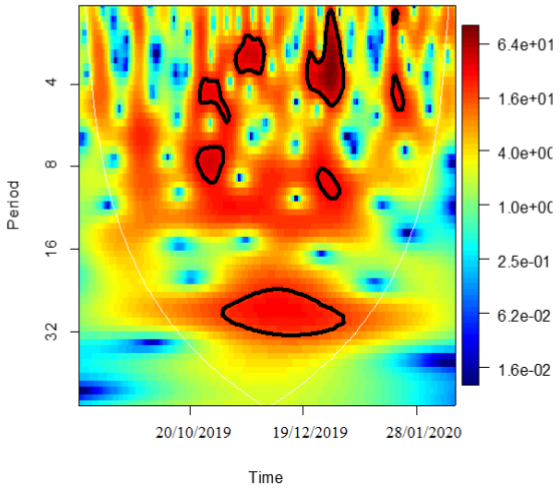


Figure 10. Wavelet Power Spectrum for Wind power production (kWh) (D-C)

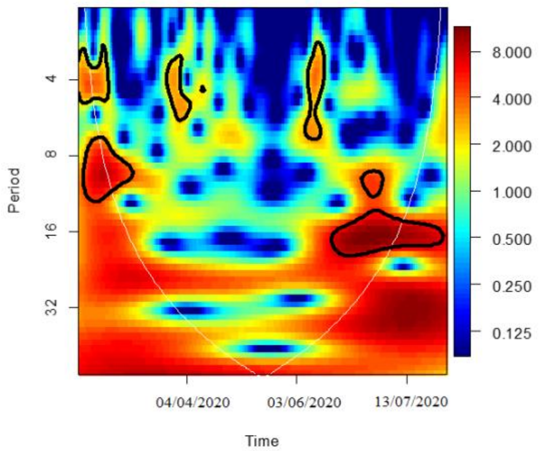


Figure 9. Wavelet Power Spectrum for Solar energy production (kWh) (D-C)

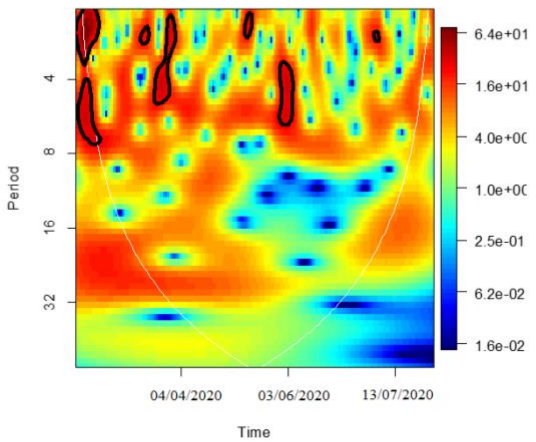
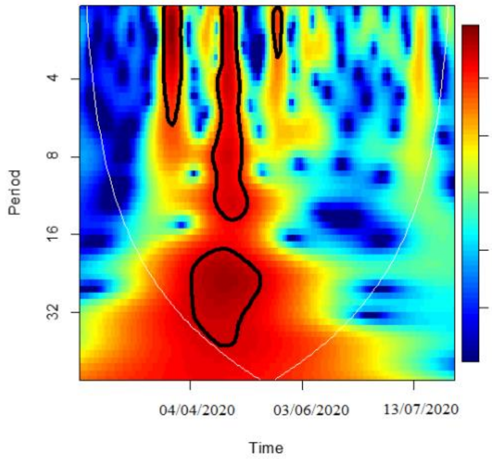


Figure 11. Wavelet Power Spectrum for AQI (D-C)



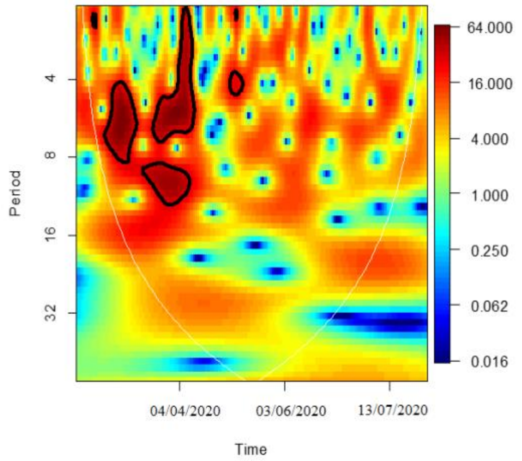


Figure 12. Wavelet Coherence between Nuclear power generation (kWh) and AQI (B-C)	Figure 14. Wavelet Coherence between Wind power production (kWh) and AQI (B-C)

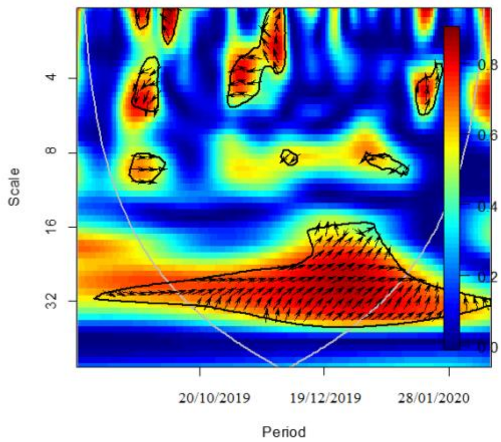
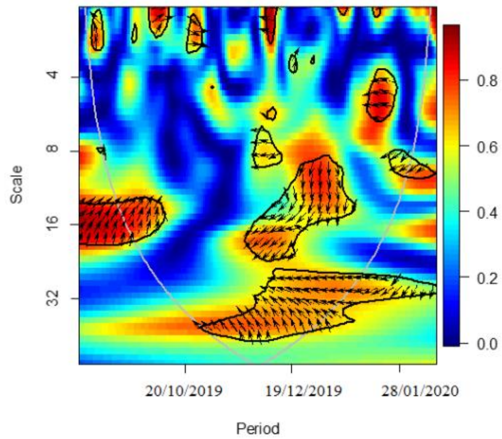

	

Figure 13. Wavelet Coherence between Solar energy production (kWh) and AQI (B-C)	

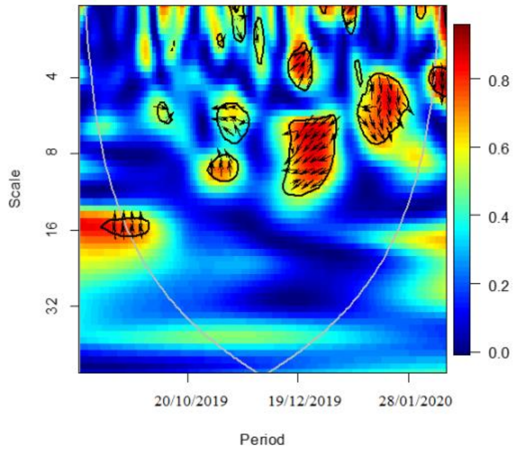


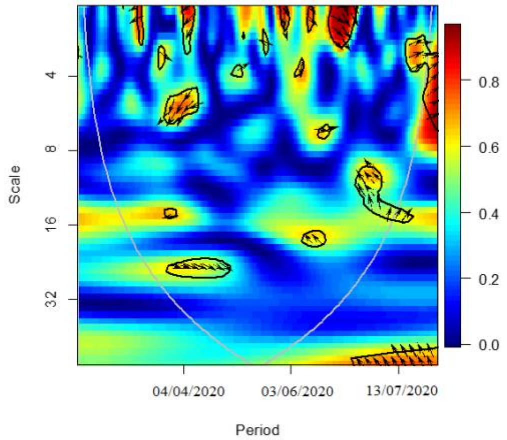
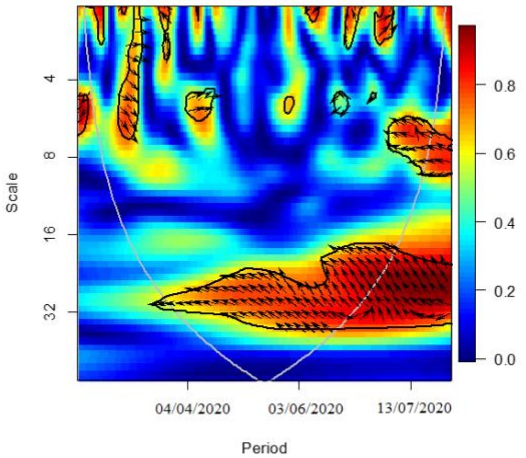
Figure 15. Wavelet Coherence between Nuclear power generation (kWh) and AQI (D-C)	Figure 17. Wavelet Coherence between Wind power production (kWh) and AQI (D-C)
	

Figure 16. Wavelet Coherence between Solar energy production (kWh) and AQI (D-C)