Carbon Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcmt20

# The effect of EPU, trade policy, and financial regulation on $CO_2$ emissions in the United States: evidence from wavelet coherence and frequency domain causality techniques

Dervis Kirikkaleli & Andrew Adewale Alola

**To cite this article:** Dervis Kirikkaleli & Andrew Adewale Alola (2022) The effect of EPU, trade policy, and financial regulation on $CO_2$ emissions in the United States: evidence from wavelet coherence and frequency domain causality techniques, Carbon Management, 13:1, 69-77, DOI: 10.1080/17583004.2021.2014361

**To link to this article:** https://doi.org/10.1080/17583004.2021.2014361



Published online: 19 Dec 2021.

CARBON MANAGEMENT
2022, VOL. 13, NO. 1, 69–77
https://doi.org/10.1080/17583004.2021.2014361



# The effect of EPU, trade policy, and financial regulation on $CO_2$ emissions in the United States: evidence from wavelet coherence and frequency domain causality techniques

Dervis Kirikkaleli[a] and Andrew Adewale Alola[b,c]

[a]Department of Banking and Finance, Faculty of Economic and Administrative Sciences, European University of Lefke, Lefke, Northern Cyprus, Mersin, Turkey; [b]Department of Economics and Finance, Istanbul Gelisim University, Istanbul, Turkey; [c]Department of Economics and Finance, South Ural State University, Chelyabinsk, Russia

**ABSTRACT**

The present study unearths the causal effect of economic policy uncertainty (EPU), trade policies, and financial regulation on $CO_2$ emissions in the United States. Based on this aim, the frequency domain causality and wavelet coherence tests are employed while answering the following questions: (i) Do EPU, trade policy, and financial regulation lead to $CO_2$ emission in the United States, and (ii) if so, why? The findings from wavelet coherence reveal that changes in EPU, trade policies and financial regulation significantly lead to changes in $CO_2$ emissions at different frequency levels, meaning that EPU, trade policies, and financial regulation are important predictors for the $CO_2$ emission in the United States. The consistency of the findings from wavelet coherence is confirmed by the outcomes of frequency domain causality. To the best of our knowledge, until now, no study has explored the causal effect of economic policy uncertainty, trade policies, and financial regulation on the $CO_2$ emission in the United States using single data set and wavelet coherence approach, which allows capturing both the long and short-run causality among the time series variables while combining time and frequency domain causality approaches. Therefore, the present study is likely to attract great interest from policy-makers and researchers in this field. At the same time, it is likely to start a new debate.

**KEYWORDS**

$CO_2$ emission; trade policy; financial regulation; United States; uncertainty

## Introduction

In the global discussion of climate change as one of the pertinent threats to human sustainability, the characteristic dynamics of the global pollutant emissions have availed several conceptual theories that are targeted at mitigating the resulting environmental hazards. As much as several causative factors have been associated with pollutant emissions, amble of mechanisms such as proposed by intergovernmental organizations like the Intergovernmental Panel on Climate Change (IPCC) and other stakeholders are being deployed in different parts of the globe. For instance, the United Nations Framework Convention on Climate Change (UNFCCC) which serves as an environmental treaty, has continuously provided platforms for environmental stakeholders to harmonize environmental hazard mitigation and carbon abetment plans. But despite the policy strategies of the intergovernmental organizations and respective stakeholders' commitments, the global energy-related $CO_2$ emissions rose by a historic 1.7% (representing a record high of 33.1 Gt $CO_2$) [1]. With the global average annual concentration of $CO_2$ in the atmosphere averaging 407.4 ppm in 2018 (2.4 ppm more than 2017), this further serves as a global warning since it is higher than the pre-industrial levels of the range 180 and 280 ppm [1]. The IEA report revealed that the emissions from China, India, and the United States accounted for 85% of the net increase in emissions in 2018. The report also further implied that the decline in emissions observed in the United States in 2017 was reversed, resulting in an increase of 3.1% in $CO_2$ emissions in 2018.

Although the 2018 setback in the carbon mitigation trend of the United States is unexpected, the country's climate actions and policy amidst the trade rift with trade partners and other financial and economic uncertainties are potential causative indicators. For instance, the withdrawal of the United States from the Paris Change Agreement[1] is expected to impact the long-term goals and international cooperation on climate change [2]. In

CONTACT Dervis Kirikkaleli dkirikkaleli@eul.edu.tr Department of Banking and Finance, Faculty of Economic and Administrative Sciences, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Turkey

this regard, the approach to certain energy-environmental policies such as energy portfolio diversification might be short of comprehensive implementation. More importantly, the current policy of the United States, especially the review of its trade policies and agreements with trade partners such as China, the European Union member states, and the North American Free Trade Agreement (NAFTA) partners, are believed to impact the global markets. Consequently, these reviewed policies which target specified goods such as chemicals, solar panels, primary metals, and other inputs have raised potential environmental concerns [3, 4]. A similar perspective has been held for other policy frameworks such as the financial and monetary regulations of the United States government and its financial institutions like the Federal Reserve Banks. For instance, the joint study by the University of Cambridge Institute for Sustainability Leadership (CISL) and the United Nations Environment Programme (UNEP) and Finance Institute (UNEP FI) examined the material link between financial stability and environmental hazards [5]. Hence, the aforementioned indication is a clear suggestion that economic policy uncertainty[2] is not exempt from the narrative of environmental sustainability.

Given the above motivation, this study attempts to examine the causal effect of the economic policy uncertainty, trade policy, and financial regulations on pollutant emissions vis-à-vis $CO_2$ emissions in the United States. The knowledge of information transmission resulting from the last global financial crisis (GFC) that affected many economies in 2008–2010 has further revealed the vulnerability of global economies, and especially its main components such as the financial and energy markets. In addition, the recent review changes in the United States' trade policy, especially with the major trade partners, have also demonstrated a significant potential of disrupting the global. Thus, here we consider a novel attempt to understudy the potential relationship arising from the aforementioned circumstances amidst the dimension of regulation in the financial sector and carbon emission.

Additionally, the current study employed the wavelet coherence and frequency domain causality techniques which are notable additions to the present literature. By examining the aforesaid relationship over the period 1990:Q1–2018:Q2, this study is expected to contribute to the present literature from the aforementioned perspective. Beyond the similar conceptual framework expressed by [3, 4], the current study further incorporated the EPU and financial regulations in the environmental sustainability framework of the United States. One of the advantages of the wavelet coherence approach over traditional econometrics methods is its ability to uncover the co-movement between $CO_2$ emissions and EPU, trade policies, and financial regulation at frequency and time dimensions simultaneously. More importantly, the wavelet coherence approach takes into account potential nonlinearity and structural breaks in the relationship among the time series variables. As such, this study does not only present a novel concept but it is also designed to direct or redirect the climate actions and policies of the United States as well as relevant institutions.

The upcoming sections of this study are arranged as follows: section "Concise related studies" presents a synopsis of the related literature. In section "Data and methodology", the description of the data set employed and the econometric method utilized are presented, while section "Empirical findings" interprets the results and offers a discussion. Section "Conclusion" summarizes the study and presents potential policy directions.

## Concise related studies

In recent times, more studies have continued to examine the determinants of environmental sustainability beyond the paradigm path of energy consumption, population, and other related concepts. Accordingly, the unfamiliar determinants of environmental sustainability are now being expanded to cover the dynamics of trade policy, financial regulations, economic policy uncertainty, immigration, and other salient factors [3, 4, 6, 7]. One of the interesting studies that examined the nexus of financial regulations and environmental risks were carried out by the CISL [5]. The results from the CISL conveyed several underlying insights into the complexity, interconnectivity, and unpredictability of environmental hazards. In addition, the CISL report further demonstrated that there is a non-linear impact of environmental sustainability issues on the financial system and the real economy. Another study in a similar perspective [8] considered the role of price volatility and investment uncertainty in determining the varying performance of policy instruments under different market divisions.

Furthermore, by acknowledging the essential role of financial regulations in cutting back carbon emissions, global effort in the investment of green energy implementation of sustainable environmental and economic policies are being upscaled. In this case, the effective financial mechanism toward achieving the limit of 2° C increase in the global mean temperature has been reviewed and presented in previous studies [9–11]. Accordingly, [10] identified the role of the financial system regulators in adapting a mechanism that mitigates the potentially hazardous effects of environmental risks. [10] observed that some major and fast-growing economies have since applied policies and regulations targeting environmental risks, especially since the last economic crisis of 2008. In a similar dimension, [11] opined that macro-prudential financial regulation is essential in facilitating green investment in most emerging economies which are mostly sourced from bank lending, market debt, and market equity.

Moreover, recent studies by [3, 4] carefully examined the role of trade policy in the attainment of environmental sustainability in the United States. Both studies employed the Autoregressive Distributed Lag (ARDL) technique over the period of 1990 to 2018 and reached almost similar results on trade policy and carbon emission nexus. While [3] found a significant and negative relationship between $CO_2$ emissions and trade policy in the short-run, the long-run estimate is not significant. However, [4] posited a similar estimate regarding the nexus of $CO_2$ and trade policy in the United States. In so doing, a significant relationship between the concerned variables is observed, with trade policy exerting an important and positive impact on $CO_2$ emissions in the long-run but a negative impact in the short-run. In general, the two studies further demonstrated that the environmental sustainability targets of the United States could suffer a significant setback if certain government policies such as migration are not reviewed.

In regard to the methodology adopted for this study, the techniques of Breitung and Candelon [12]) and Granger [13] are justified to explore the determinants of $CO_2$ emissions in the current context. In specific, while [13] observed the delay in capturing information or insufficient information about causal variables as the main challenge in investigating a causal relationship, the study, however found a significant possibility of decomposing the existence of cross-spectrum between two variables into two parts within the context of a feedback situation. Moreover, the more recent approach of Breitung and Candelon [12] presented a causality test in the frequency domain. By employing quarterly data for the United States, [12] observed significant evidence that certain indicators exhibit varying properties at different periodical frequencies and business cycle frequencies. Thus, these aforementioned approaches are found to be unique in capturing the determinants of $CO_2$ emission in the United States, especially the techniques have rarely been deployed in this context.

## Data and methodology

The main innovation of this study is to explore the causal effect of economic policy uncertainty, trade policy, and financial regulation on $CO_2$ emission in the United States using the frequency domain causality of [12] and wavelet coherence approach over the period of 1990Q1 to 2018Q2. It is widely accepted that the traditional Granger causality test is a novel approach to estimate the predictive power of one variable for the future another. In the empirical literature, the approach of [13] has been used to describe the causal link between variables. While the current empirical literature in energy and environment fields has focused on Granger causality from economic activity to $CO_2$ emissions in the time domain, we will take a further step by decomposing the Granger causality in the frequency domain and using the wavelet coherence approach which combines time, and frequency causality approaches. While the $CO_2$ data was retrieved from the EIA (the United States Energy Information Administration), the EPU, trade policy, and financial regulation data were retrieved from the https://www.policyuncertainty.com/ of [24]. The dataset is further described in Table 1.

The frequency-domain causality test of [12] "makes it possible to determine whether the predictive power is concentrated at the quickly fluctuating components or at the slowly fluctuating components. As such, instead of computing a single Granger causality measure for the entire relationship, the Granger causality is calculated for each individual frequency component separately." Notably, the strength and the direction of causality vary between frequency bands [14], which traditional time-domain causality techniques are unable to diagnose. "This approach provides an elegant interpretation of frequency-domain Granger causality as a decomposition of the total spectral interdependence between the two series (based on the bivariate spectral density matrix, and directly related to the coherence) into a sum

**Table 1. Data and descriptive statistics.**

| | $CO_2$ Emission | Economic Policy Uncertainty | Financial Regulation | Trade Policy |
|---|---|---|---|---|
| Source | EIA | EPUI | EPUI | EPUI |
| Code | $CO_2$ | EPU | FR | TP |
| Period | 1990Q1-2018Q2 | | | |
| Mean | 442.5678 | 101.2957 | 71.25464 | 162.2492 |
| Median | 440.8920 | 93.36284 | 39.22161 | 114.0087 |
| Maximum | 522.8550 | 271.8324 | 580.8659 | 1094.156 |
| Minimum | 387.5570 | 45.52693 | 6.459902 | 25.95176 |
| Std. Dev. | 32.24003 | 38.87642 | 91.96568 | 161.6102 |
| Skewness | 0.447003 | 1.199632 | 3.248919 | 2.879750 |
| Kurtosis | 2.553988 | 5.143240 | 15.56467 | 13.69155 |
| Jarque-Bera | 4.741323 | 49.16225 | 950.4405 | 700.5351 |
| Probability | 0.093419 | 0.000000 | 0.000000 | 0.000000 |

Note: The EIA is the United States Energy Information Administration and the online link: https://www.policyuncertainty.com/ is the source of the Economic Policy Uncertainty Index (EPUI).

of 'instantaneous', 'feedforward' and 'feedback' causality terms." Thus, the main innovation of the test is to capture the causal relationship at different time periods which the linear and non-linear time-domain causality tests fail to capture.

In addition to the frequency domain causality test, this study also employs the wavelet coherence approach, initially proposed by [15], to explore the time-frequency relationship between $CO_2$ emission and economic policy uncertainty, trade policy, and financial regulation in the United States. Therefore, this study allows us to decide if there is a causal effect of economic policy uncertainty, trade policy, and financial regulation on $CO_2$ emission in the United States at different frequencies over the period of 1990Q1 to 2018Q2. "The main innovation of wavelet techniques appears where the decomposition of one-dimensional time data into the bi-dimensional time-frequency sphere is allowed" [16]. This allows this study to identify the long-run and short-run relationship among the time series variables. A multi-scale decomposition method brings out a natural framework to show frequency-dependent behavior for exploring the connection between $CO_2$ emission and economic policy uncertainty, trade policy, and financial regulation in the United States. The present study uses a wavelet ($\psi$) approach which is a part of the Morlet wavelet family. The simple equation of $\psi$ is as shown:

$$\psi(t) = \pi^{-\frac{1}{4}}e^{-i\omega_0 t}e^{-\frac{1}{2}t^2}, \mathrm{p(t)}, \quad t = 1,2,3\ldots, \mathrm{T}.$$

where "Frequency, represented by (*f*), and time or location, represented by (*k*), are the main parameters of the wavelet. While a wavelet's particular location in time is the fundamental character of the k parameter, the frequency parameter controls the distended wavelet for localizing various frequencies. By transforming the wavelet equation, $\psi_{k,f}$ can first be constructed" [17]. The equation of the wavelet is transformed by adding frequency and location parameters as in the equation 1:

$$\psi_{k,\ f}(t) = \frac{1}{\sqrt{h}}\psi\left(\frac{t-k}{f}\right),\ k,f \in \mathbb{R},\ f \neq 0 \qquad (1)$$

After adding the time series data p(t), the equation of continuous wavelet function is as follows:

$$W_p(k,\ f) = \int_{-\infty}^{\infty} p(t)\frac{1}{\sqrt{f}}\psi\left(\frac{\overline{tk}}{f}\right)dt, \qquad (2)$$

The Equation 2 is regenerated as in the Equation 3 after adding $\psi$ coefficient in the equation:

$$p(t) = \frac{1}{C_\psi}\int_0^{\infty}\left[\int_{-\infty}^{\infty}\left|W_p(a,\ b)\right|^2 da\right]\frac{db}{b^2}. \qquad (3)$$

To detect the vulnerability of the time series variables, the wavelet power spectrum (*WPS*) is used in the present study.

$$WPS_p(k,\ f) = \left|W_p(k,\ f)\right|^2. \qquad (4)$$

As a next step, the time series variable is transformed by the cross wavelet transform (CWT) approach as presented in equation 5 below[3];

$$W_{pq}(k,\ f) = W_p(k,f)\overline{W_q(k,\ f)}, \qquad (5)$$

where $W_p(k,f)$ and $W_q(k,f)$ indicates the CWT of two-time series variables. The equation of the squared wavelet coherence is as follows;

$$R^2(k,\ f) = \frac{\left|C\left(f^{-1}W_{pq}(k,\ f)\right)\right|^2}{C\left(f^{-1}\left|W_p(k,\ f)\right|^2\right)C\left(f^{-1}\left|W_q(k,\ f)\right|^2\right)} \qquad (6)$$

where $R^2(k,f)$ ranges between 0 and 1. Whenever $R^2(k,f)$ gets close to 1 it indicates that the time series variables are correlated at a particular scale, surrounded by a black line and depicted by a red color. On the other hand, when the value of $R^2(k,f)$ approaches 0 it indicates that there is no correlation between the time series variables and is pictured by the color blue.

However, obtaining the value of $R^2(k,f)$ does not provide any way to distinguish positive correlation from the negative; thus "[18] postulated a means by which to detect the wavelet coherence differences through indications of deferrals in the wavering of two-time series" [19]. The equation of the wavelet coherence approach is constructed as follows;

$$\phi_{pq}(k,\ f) = \tan^{-1}\left(\frac{L\{C(f^{-1}W_{pq}(k,\ f))\}}{O\{C(f^{-1}W_{pq}(k,\ f))\}}\right), \qquad (7)$$

where L and $O$ denote an imaginary operator and a real part operator, respectively. Phase differences are indicated by black arrows in wavelet coherence figures. While the x-axis represents the time, the y-axis refers to frequency. In the wavelet coherence figures, the cone-shaped white line indicates the cone of impact. The color scale on the right side of the figure represents the level of correlation between the time series variables. The color red, the higher the correlation between the variables with respect to $R^2$ in equation (6). In the wavelet coherence, the arrows pointing to the down, right-down, and left-up indicate that Variable 1 leads Variable 2, while the arrows pointing to the up, right-up, and left-down indicates that Variable 1 lags Variable 2. Moreover, the arrows pointing to the right indicate that the time series variables are positively correlated (in-phase) while the arrows pointing to the left indicate that the variables are negatively correlated. In the wavelet coherence figure, the first variable is CO2 emissions, while trade policy, EPU and financial regulation are the second variables.

## Empirical findings

Based on the main novelty and proposition of this study; to explore the causal effect of economic policy uncertainty, trade policy, and financial regulation on $CO_2$ emissions in the United States, the frequency domain causality test of [12] and wavelet coherence test is employed. The outcomes of the frequency domain causality test of [12] Breitung and Candelon (2006) are reported in Figures 1–3. While the blue and red lines represent 10% and 5% significance levels, respectively, the blue line is the test statistics. In the figures, the x-axis provides information about the frequency which ranges between the intervals of (0, $\pi$). As mentioned by [12], the intervals of (0, 1) in the x-axis indicate the long-term, while the intervals of (1.01, 2) and the intervals of (2.01, 3) indicate the

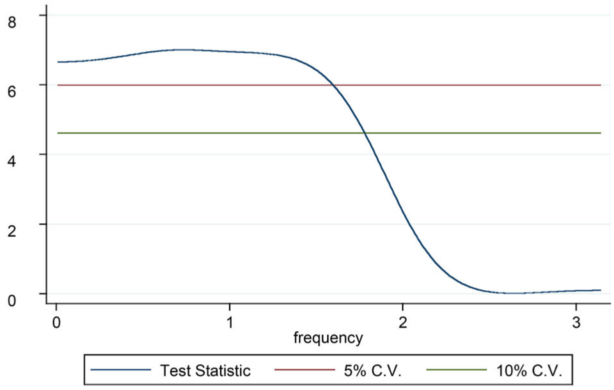


**Figure 1. Spectral Breitung Candelon causality from trade policy to $CO_2$ emission.**

medium-term and short-term, respectively. In the y-axis of Figures 1–3, the magnitude of t-stats and critical values are reported. Whenever the blue line is over the green and red lines allow us to reject the null hypothesis that the independent variable does not significantly causal dependent variable at the specific intervals of (0, $\pi$). Figure 1 reports the outcome of the frequency domain causality test of Breitung and Candelon (2006) to capture whether there is a causal linkage from trade policy to $CO_2$ emission in the United States. As illustrated in Figure 1, trade policy Granger causes $CO_2$ emission over the long- and medium-terms within (0.00, 1.00) and (1.00, 1.80) frequency bands, respectively, implying that the implied volatility of trade policy in the United States predicts the implied volatility of the $CO_2$ emissions. This is an obvious carbon emission-trade scenario in most developed countries, especially in the United States and the European countries which are associated with $CO_2$ imports (outsourced carbon). Indicatively, the United States is the world's largest importer of $CO_2$ in 2017, while China is the world's largest exporter of carbon emissions, followed by Russia [20]. In addition, the recent review of trade policies of the United States government with its trading partners -such as China and the European countries- especially on agricultural commodities is enough to disrupt the manufacturing, production, and subsequently the environmental sustainability dynamics [3, 4].

Figure 2 reveals that at the 5% significance level, the null hypothesis of EPU does not Granger-cause $CO_2$ emission can be rejected for frequencies in the intervals 0 and 0.7 for the long-term and in the internals 1.00 and 3.00 for the medium and long terms. Therefore, in the long, medium, and short terms, EPU is an important predictor for future $CO_2$ emission in the United States. Accordingly, [21] implied that there is a significant

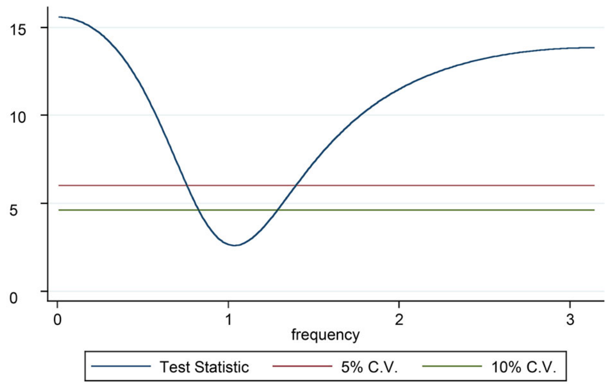


**Figure 2. Spectral Breitung Candelon causality EPU to $CO_2$ emission.**

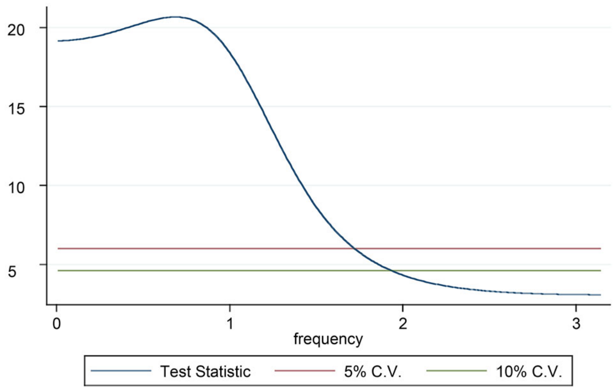


**Figure 3. Spectral Breitung Candelon causality from financial regulation to $CO_2$ emission.**

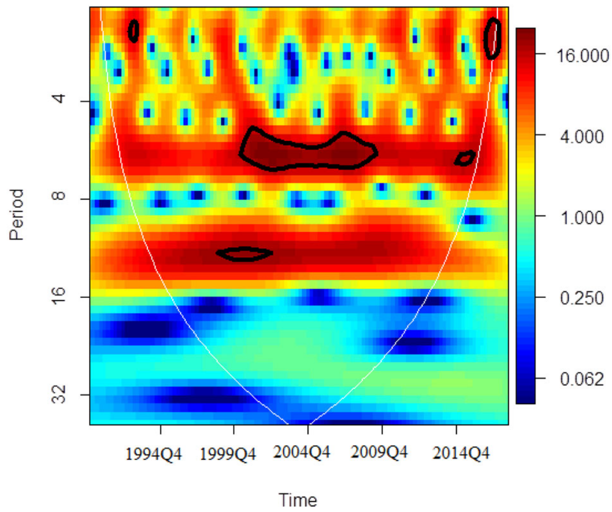


**Figure 4. Wavelet power spectral for $CO_2$ emission.**

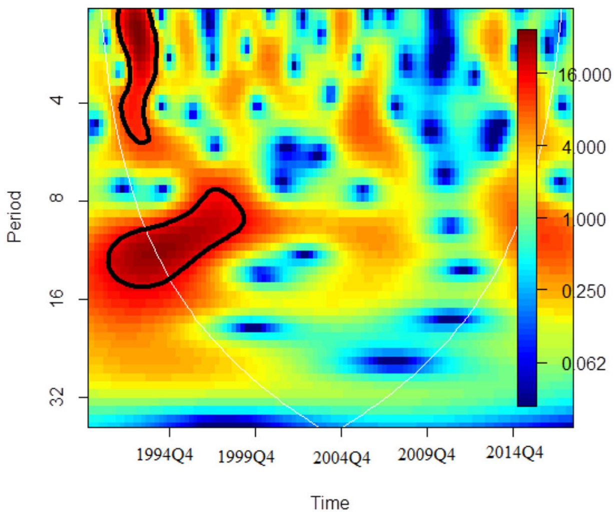


**Figure 5. Wavelet power spectral for EPU.**

effect of financial and economic shocks (such as the credit market and stock market shocks) on energy consumption and carbon dioxide. Figure 3 represents that at the 5% significance level, the null hypothesis of financial regulation does not Granger-cause $CO_2$ emission can be rejected for frequencies in the intervals 0.00 and 1.85, implying that financial regulation has a long- to the medium-term predictive power of the implied volatility of $CO_2$ emission. Although the concept of carbon finance has been explored for the underpinning of financial cost of green practices by carbon emission mitigation [22], the form of financial and monetary policies employed by respective institutions is believed to affect the dynamics of environmental quality. In the literature, the role of financial regulators leading to financial development has been examined and found to have a significant impact on the carbon emission trajectory [23].

To capture the significant vulnerabilities of the EPU, trade policy, financial regulation, and $CO_2$ emission variables over the period of 1990Q1 to 2018Q2, the wavelet power spectral test is applied for the case of the United States before exploring the time-frequency dependency among the time series variables. Figures 4–7 present the wavelet power spectral for the variables of $CO_2$ emission, EPU, trade policy, and financial regulation, respectively. In the figures, the white cone-shaped curve reports the cone of influence demonstrating an edge below where the wavelet power is affected because of discontinuity; while the thick black shape indicates a 5% significant level determined by Monte Carlo simulations. As shown in Figure 4, $CO_2$ emission was very high between 1999 and 2009 at 8 quarter scales (medium frequency). There are significant vulnerabilities between 1992 and 1998 for the variables of EPU and financial regulation at different frequencies. During the period of 1999 to 2004, as depicted in Figure 7, trade policy in the United States was significantly vulnerable.

Based on the main aim of this study, time-frequency dependency between $CO_2$ emissions and trade policy, EPU and financial regulation in the United States using wavelet coherence approach which combines both time and frequency domain

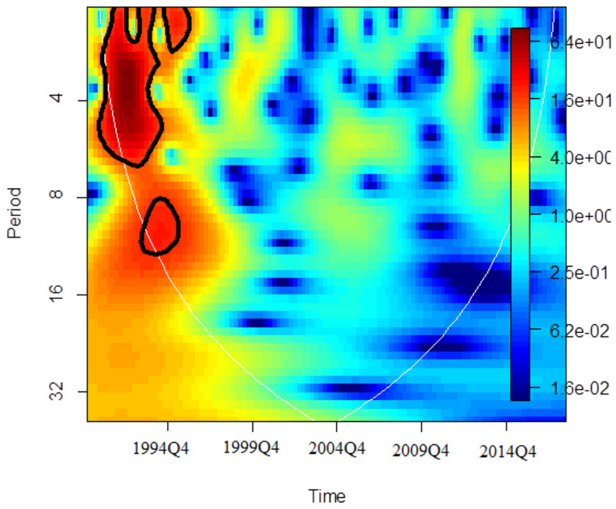


**Figure 6.** **Wavelet power spectral for financial regulation.**

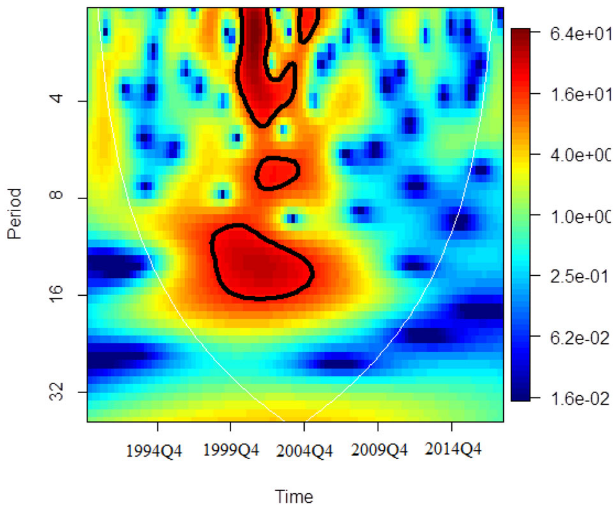


**Figure 7.** **Wavelet power spectral for trade policy.**

causality tests. While the x-axis represents the time, the y-axis refers to frequency. As in Figures 8–10, the cone-shaped white line indicates the cone of impact. The color scale on the right side of the figure represents the level of correlation between the time series varaibles. The color red, the higher the correlation between the variables with respect to $R^2$ in equation (6). The thick black shape in Figures 8–10 indicates a 5% significant level, which is tested against AR(1). Figures 8–10 present the wavelet coherence (i) between $CO_2$ emission and trade policy, (ii), between $CO_2$ emission and EPU, and (iii) between $CO_2$ emission and financial regulation. To obtain upward and right-up pointing arrows in the thick black shape at 8 and-16 periods (at the medium-term) between 1998 and 2018 in Figure 8 indicates that changes in trade policy in the United States significantly cause changes in $CO_2$ emissions. These findings underline that trade policy in the United States is an important predictor of $CO_2$ emissions.

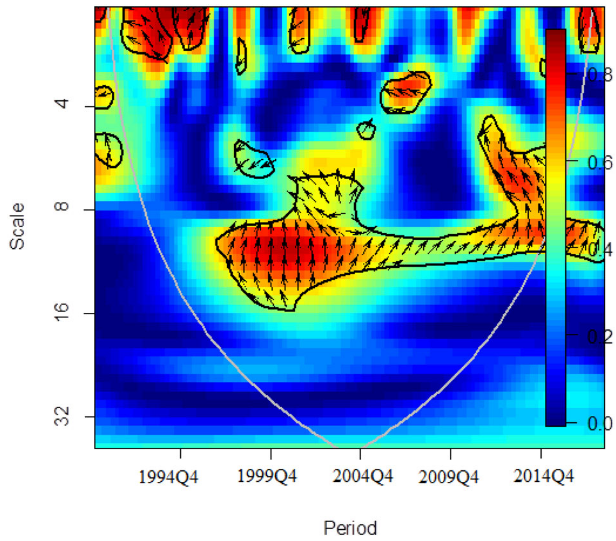


**Figure 8.** **Wavelet coherence between $CO_2$ emission and trade policy.**

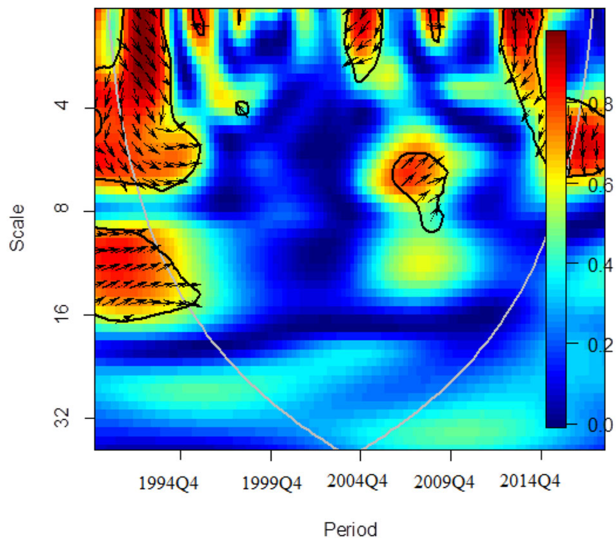


**Figure 9.** **Wavelet coherence between $CO_2$ emission and EPU.**

As shown in Figure 9, while changes in $CO_2$ emission significantly lead to changes in EPU between 1992 and 1994 and between 2012 and 2014 in the short run, EPU was an important predictor in $CO_2$ emission in 2004, 2008, and 2009. Figure 10 clearly presents that the null hypothesis that financial regulation does not Granger cause $CO_2$ emission can be rejected at different frequencies and different time periods since the majority of the arrows pointing upward and right-up arrows in the thick black shape. The result also implies that changes in financial regulations significantly lead to changes in $CO_2$ emissions in the United States. It is worthy to mention that the findings of wavelet coherence are in line with the findings of the frequency domain causality test.

Overall, the nexus of $CO_2$ emission, EPU, trade policy, and financial regulation is central to the

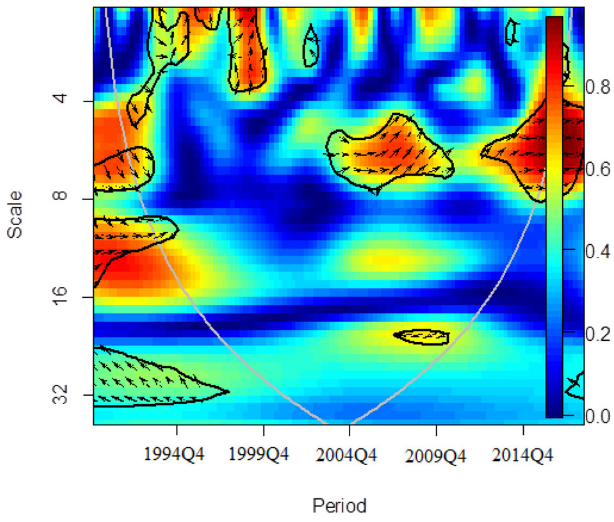


**Figure 10.** Wavelet coherence between $CO_2$ emission and financial regulation.
Note: when the value of $R^2(k,f)$ approaches 0 it indicates that there is no correlation between the time series variables and is pictured by the color blue. When $R^2(k,f)$ approach to the value of one indicates that there is a correlation among the time series variables. In the wavelet coherence figures, the direction of the arrow represents the direction of the causality or correlation between $CO_2$ emission and its determinants. While arrows pointing to the left indicate a negative correlation among the variables, arrows point to the right represent the positive correlation. Also, arrows pointing to the up, right-up, or left-down show that the second variable causes the first variable, whereas arrows pointing to the down, right-down, or left-up indicate that changes in the first variable significantly lead to changes in the second variable. In Figures 8–10, the first variable is $CO_2$ emissions while trade policy, EPU and financial regulation are the second variables.

global economic and financial market stability. In essence, the case of the United States is a unique one considering the economic relevance of the country. In specific, a disruption in the global energy market, and especially the United States energy market or policies (such as trade or economic-related policy) often spur an economic shift or disruptions across the globe, thus affecting energy demand and consumption that indirectly impact the GHG emissions. For instance, the coronavirus (COVID-19) pandemic (a naturally unforeseen event) disrupted the global energy market, thus causing a desirable decrease in the global energy-related emissions in 2020 since economic activities were downsized across the globe [25–28].

## Conclusion

This study proposes to close a gap in the relevant literature by exploring the causal effect of EPU, trade policy, and financial regulation on $CO_2$ emissions in the United States using the frequency domain causality of [12] and wavelet coherence approach. The empirical findings of the study clearly reveal that the null hypothesis that EPU, trade policy, and financial regulation do not Granger cause $CO_2$ emission in the United States can be rejected, implying how EPU, trade policy, and financial regulation are important predictors of $CO_2$ emission. The consistency of the findings from wavelet coherence is confirmed by the outcomes of frequency domain causality [12]. Although this study provides strong and consistent empirical findings for the United States, further studies should consider advancing the argument by focusing on other countries. Since no study has been conducted to explore the causal effect of economic policy uncertainty, trade policy, and financial regulation on $CO_2$ emission in the United States by using a single dataset and wavelet coherence approach which allows capturing both the long and short-run causality among the time series variables, future research approach should consider applying the concept in the current study to other countries. Importantly, the case of China and other high-volume trading countries (such as the leading European countries) could be examined in subsequent studies.

However, the outcome of the present study provides insightful perspectives to intergovernmental agencies, governments, and other environmental stakeholders that are crucial for policy decision-making. From policy perspectives, more climate actions, and regulations that holistically consider the perspective of carbon emission import (carbon outsourcing) could further serve as an effective carbon mitigation guideline. Additionally, since economic policy uncertainty is found to affect carbon emissions, any proposed or adopted policy targeted at addressing economic turmoil especially during financial and economic crises should incorporate the environmental dimension of the economy. Also, financial institutions or regulators could do more good to the environment by further reviewing the effectiveness of the existing carbon financing policies such as the carbon tax, carbon credit, and subsidy policies.

## Notes

1. The United Nations Framework Convention on Climate Change (UNFCCC) reported that the President of the United States announced the government's withdrawal from the Paris Climate Change Agreement. Additional information on the subject is available at *https://unfccc.int/news/unfccc-statement-on-the-us-decision-to-withdraw-from-paris-agreement*.
2. The Economic Policy Uncertainty (EPU) is a constructed index from the search results from 10 big newspapers. Additional information is available at *https://www.policyuncertainty.com/us_monthly.html*.
3. p(t) and q(t) are the time series variables.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Dervis Kirikkaleli http://orcid.org/0000-0001-5733-5045

## Data availability statement

The data that support the findings of this study are available from the corresponding author, Dervis Kirikkaleli, upon reasonable request.

## References


1. IEA I. Global energy & CO2 status report 2017. [updated 2017; cited 2019 Sep 05]. Available from: https://www.iea.org/geco/emissions/.
2. Zhang YX, Chao QC, Zheng QH, et al. The withdrawal of the US from the paris agreement and its impact on global climate change governance. Adv Clim Change Res. 2017;8(4):213–219. doi:10.1016/j.accre.2017.08.005.
3. Alola AA. Carbon emissions and the trilemma of trade policy, migration policy and health care in the US. Carbon Manag. 2019;10(2):209–218. doi:10.1080/17583004.2019.1577180.
4. Alola AA. The trilemma of trade, monetary and immigration policies in the United States: Accounting for environmental sustainability. Sci Total Environ. 2019;658:260–267. doi:10.1016/j.scitotenv.2018.12.212.
5. CISL. Banking and Sustainability: Time for Convergence. 2015. [updated 2015; cited 2019 Sep 11]. Available from: https://www.cisl.cam.ac.uk/business-action/sustainable-finance/banking-environment-initiative/programme/financial-regulation.
6. Alola AA, Saint Akadiri S, Akadiri AC, et al. Cooling and heating degree days in the US: the role of macroeconomic variables and its impact on environmental sustainability. Sci Total Environ. 2019;695:133832. doi:10.1016/j.scitotenv.2019.133832.
7. Alola AA, Yalçiner K, Alola UV, et al. The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe largest states. Sci Total Environ. 2019;674:307–315. doi:10.1016/j.scitotenv.2019.04.163.
8. Blazquez J, Nezamuddin N, Zamrik T. Economic policy instruments and market uncertainty: exploring the impact on renewables adoption. Renew Sust Energ Rev. 2018;94:224–233. doi:10.1016/j.rser.2018.05.050.
9. Bowen A, Campiglio E, Tavoni M. A macroeconomic perspective on climate change mitigation: Meeting the financing challenge. Clim Change Econ. 2014;05(01):1440005. doi:10.1142/S2010007814400053.
10. CISL.Stability and Sustainability in Banking Reform: Are Environmental Risks Missing in Basel III?. 2014. [updated 2014; cited 2019 Sep 11]. Available from: https://www.cisl.cam.ac.uk/research/research/current-work/risks-basel.
11. Campiglio E. Beyond carbon pricing: the role of banking and monetary policy in financing the transition to a low-carbon economy. Ecol Econ. 2016;121:220–230. doi:10.1016/j.ecolecon.2015.03.020.
12. Breitung J, Candelon B. Testing for short-and long-run causality: a frequency-domain approach. J. Econom. 2006; 132(2):363–378. doi:10.1016/j.jeconom.2005.02.004.
13. Granger CW. Investigating causal relations by econometric models and cross-spectral methods. Econometrica. 1969;37(3):424–438. doi:10.2307/1912791.
14. Lemmens A, Croux C, Dekimpe MG. Measuring and testing granger causality over the spectrum: an application to European production expectation surveys. Int J Forecast. 2008;24(3):414–431. doi:10.1016/j.ijforecast.2008.03.004.
15. Goupillaud P, Grossmann A, Morlet J. Cycle-octave and related transforms in seismic signal analysis. Geoexploration. 1984;23(1):85–102. doi:10.1016/0016-7142(84)90025-5.
16. Kalmaz DB, Kirikkaleli D. Modeling $CO_2$ emissions in an emerging market: empirical finding from ARDL-based bounds and wavelet coherence approaches. Environ Sci Pollut Res. 2019;26(5):5210–5220. doi:10.1007/s11356-018-3920-z.
17. Kirikkaleli D, Gokmenoglu KK. Sovereign credit risk and economic risk in Turkey: Empirical evidence from a wavelet coherence approach. Borsa Istanbul Review. 2020;20(2):144–152. doi:10.1016/j.bir.2019.06.003.
18. Torrence C, Compo GP. A practical guide to wavelet analysis. Bull Amer Meteor Soc. 1998;79(1):61–78. doi:10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2.
19. Pal D, Mitra SK. Time-frequency contained co-movement of crude oil and world food prices: a wavelet-based analysis. Energy Econ. 2017;62:230–239. doi:10.1016/j.eneco.2016.12.020.
20. Carbonbrief. Mapped: The world's largest CO2 importers and exporters. 2017. [updated 2017; cited 2019 Sep 09]. Available from: https://www.carbonbrief.org/mapped-worlds-largest-co2-importers-exporters.
21. Ziaei SM. Effects of financial development indicators on energy consumption and CO2 emission of European, east asian and oceania countries. Renew Sust Energy Rev. 2015;42:752–759.
22. Miroshnychenko I, Barontini R, Testa F. Green practices and financial performance: a global outlook. J Cleaner Prod. 2017;147:340–351. doi:10.1016/j.jclepro.2017.01.058.
23. Campiglio E, Dafermos Y, Monnin P, et al. Climate change challenges for Central banks and financial regulators. Nature Clim Change. 2018;8(6):462–468. doi:10.1038/s41558-018-0175-0.
24. Baker SR, Bloom N, Davis SJ. Measuring economic policy uncertainty. Q J Econ. 2016;131(4):1593–1636. doi:10.1093/qje/qjw024.
25. IEA. Global Energy Review 2020. 2020a. (Accessed 28 January 2021).
26. IEA. The impact of the Covid-19 crisis on clean energy progress. 2020b. (Accessed 28 January 2021).
27. Mulvaney D, Busby J, Bazilian MD. Pandemic disruptions in energy and the environment. Elementa: Science of the Anthropocene. 2020;8(1):052. doi:10.1525/elementa.052.
28. Alola AA, Victor FB. Pandemic outbreaks (COVID-19) and sectoral carbon emissions in the United States: a spillover effect evidence from diebold and yilmaz index. Energy Environ. 2020;32(5):945–955.