Environmental Science and Pollution Research (2023) 30:15585–15598
https://doi.org/10.1007/s11356-022-23181-8

RESEARCH ARTICLE

Causation between energy consumption and climate change in the countries with the highest global climate risk

Ibrahim Cutcu[1] · Ahmet Keser[2] · Mehmet Vahit Eren[3]

Received: 6 June 2022 / Accepted: 18 September 2022 / Published online: 28 September 2022

Abstract

The study aims to examine *if there is causation between "energy consumption" and "climate change"* through the data of ten countries with the highest Climate Risk Index (CRI) scores. The ten highest CRI score countries include Puerto Rico, Myanmar, Haiti, Philippines, Mozambique, The Bahamas, Bangladesh, Pakistan, Thailand, and Nepal. The annual data for the years 2005–2019 was used because of the data constraints. *CRI* is selected as the dependent variable. As for the independent variables, *the ratios of the energy consumption of the key sectors* indicated by the International Energy Agency (IEA) *to the total energy consumption* are chosen. These key sectors in energy consumption are *industry (IND)*, *transportation (TRA)*, *trade and public services (TPS)*, and *housing (HOU)*. *Economic growth (EG)*, which is one of the main factors affecting climate change in the literature, is included in the model as the control variable. According to the results of the Dumitrescu-Hurlin causality test, *there is one-way causality from transportation towards CRI*, but not any causality between others. It is evaluated that since the transportation sector is heavily dependent on fossil fuels, it has a strong effect on the amount of CO_2 emissions and a significant determining role on climate change.

Keywords Climate change · Energy consumption · Public policies · Climate Risk Index (CRI) · Highest score ten countries in CRI · Economic sectors

Introduction

During the last several decades, humanity has witnessed negative impacts of climate change more severe than ever. Although many efforts have already been made to provide solutions, the matter still preserves its significance. Conducting research in almost all scientific disciplines, implementing better governance, and providing result-oriented, effective policies are only a few among the work to be conducted.

As asserted by Averchenkova et al. (2021a: 1218) "climate change action needs better governance. The technological, economic and behavioural solutions required to radically reduce greenhouse gas emissions are increasingly known". Even if the influence of emissions on climate change is known, studies trying to find answers for the question of "what sectors cause these emissions the most?" is missing. Without producing answers for this question, in other words without reaching a concrete diagnosis on the problem it is impossible to find any solution and/or implement any useful treatment to prevent global warming, which affects almost every aspect of human life in recent years. For example as a consequence of global warming, the intensity and frequency of extreme precipitation events are increasing in most land areas (Trenberth 2011; Lawrence et al. 2013). Within this frame, as asserted by Capstick (2013: 3484) many people refer to climate change as one of the most complicated challenges facing humanity. This might explain why "91% of young Europeans (15–24 years old) agree that tackling climate change can help improve their own health and

Responsible Editor: Arshian Sharif

✉ Ibrahim Cutcu
ibrahim.cutcu@hku.edu.tr

Ahmet Keser
ahmet.keser@hku.edu.tr

Mehmet Vahit Eren
mvahiteren@gmail.com

1 Department of Economics, Hasan Kalyoncu University, Gaziantep, Turkey

2 Department of Political Science and International Relations, Hasan Kalyoncu University, Gaziantep, Turkey

3 Department of Economics, Kilis 7 Aralık University, Kilis, Turkey

well-being" in Future of Europe 2021 report (Eurobarometer 2021).

There are of course many achievements at the international level to protect the future of humanity from the negative impacts of climate change. As mentioned by Yun (2016: 235), the Paris Agreement that was adopted on 13 December 2015 is one of the most important efforts within this frame. During the Paris Climate Change Conference, 14 days of hard negotiations gave the pave for a global mechanism for addressing climate change by 2020 and beyond (Yun 2016: 235). As in the case of China example, many academics around the world study the related issues, policymakers try to develop relevant preventive policies, and lawmakers review their approach to climate change.

Within this frame, there is also an increase in the number of studies focusing on climate change. Some studies concentrate on the impacts of observed trends in climate and what potential influence it might have on some sectors. For example Li et al. (2011) look for the impacts of climate change on agriculture in China. The authors (2011: 86) assert that China has experienced significant climate change in the last 100 years. Air temperature has continued to increase 0.5–0.8 °C on an annual basis, and agriculture is one of the most affected sectors by natural hazards. So we can further take the matter one step ahead and take the assumption of *climate change is one of the main factors increasing the number and impact of natural hazards* into consideration. In other words, as a chain reaction, climate affects the number and severity of the natural hazards and natural hazards affect agriculture sector the most by causing damages. This issue immediately triggers the question, *if climate change affects natural hazards and natural hazards affect the agriculture sector the most, what or which sectors affect and/or cause climate change the most?*. In other words *are there any sectors that cause and/or have a severe influence on climate change?* If so, *which sector causes the most negative impact on it?* If we can find answers to these questions, it means an important step is advanced by having the diagnosis so that treatment can start. Otherwise, the policies produced and all the resources and time spend shall be a waste.

Another research conducted by Stainforth et al. (2013) shows that "hottest summer days are warming faster than the coolest" and this expose "how the regions of greatest warming are quantile and threshold dependent". This finding also urges making research on the regions of the globe, which are the riskiest and most affected by climate change, which motivates the background and shows the significance of our research on the most affected 10 countries.

In another study, Lawrence et al. (2013: 133–134) indicate the importance of the impacts of *human settlements* and *long-lived*, *population increases, transport* and *utility networks, development intensification, and economic growth* to flood risk so to climatic changes give the background for which variables to use in such research. From this point of view, in our study, we use CRI as the dependent variable and others that might have an influence on it as independent variables such as (1) *housing sector* as a variable which represents human settlements, long-lived, and population increases; (2) *trade and public services sector* for utility networks; (3) *transportation sector* for transport; (4) *industry sector* for development intensification; and (5) *economic growth* as a control variable. Fan et al. (2014)'s finding related to the end of the twenty-first century "emphasizes the essential role of emission choices in determining the potential future climate change". So it is also important to find out which sector has the most energy consumption and so produces the most emission. That is why the findings of such research may provide useful information for policymakers to provide solutions in the shape of public policies to prevent and/or at least to slow down climate change.

Although the number of studies increases on the matter, the issue still preserves its urgency and every effort which may contribute to the issue worth to be supported. Moreover, despite the increase in the number of researches on climate change, still there is a hole to be filled especially on the main causes of the change. So looking for the economic sectors which can be the main causes of this change has vital importance and still, there is a hole in the existing literature to be filled. Thus, this study aims to fill this gap by analysing the causation between the key sectors and climate change, especially with the data of ten countries most affected by the risks brought by climate change by conducting econometric analyses to provide evidence-based information for the academics studying in political science, economics, and development disciplines and policymakers.

Brief review of literature on climate change for last decade

This chapter respectively scrutinizes the current literature on climate change from 2011 to 2021. Of course, there are many others worth mentioning but with this study's limited space some of those could be mentioned only.

When the current literature is reviewed, it is possible to see that some of the existing studies rely on literature reviews (Li et.al., 2011; Surminski and Lopez 2015); some apply descriptive methods (Yun 2016); some use other qualitative methods relying on collected data by interviews (Steynor and Pasquini 2019; Averchenkova et al. 2021b); some apply content and/or discourse analysis (Averchenkova et al. 2021a); while some others use technological mapping for the study regions (Hohmann et al. 2018; Shi et al. 2018). Some of the researchers clearly assert that "In the contemporary era, the global economies, especially the developing ones, emphasize the relevance of achieving *eco-friendly growth* whereby the *ecological footprint figures are aimed to be contained* alongside *higher economic growth*" (Jahanger et al. 2022: 1) while some research on the other hand focus on some issues directly close to climate change. For example Suki et al. (2020) made a research on the impact of globalization on ecological footprint in the Malaysian economy and their results showed that "overall globalization and economic globalization enhance the level of environmental degradation in the long run, however, political and social globalization help to reduce the level of environmental degradation in the long term" in Malaysia. On the other hand, some of the research provides evidence that there is a relationship between the type of energy resources consumed and the environmental hazards. Sharif et al. (2019: 685) "explored the relationship of renewable and non-renewable energy consumption with carbon emission by using panel data of 74 nations from 1990 to 2015". The outcomes of the research affirmed that "all variables are integrated over the long-run. The results also show that the non-renewable energy consumption has a positive effect on environmental degradation whereas; renewable energy has a negative impact on environmental degradation". Even if this research was not on the sectoral basis, it gives a clue that the sectors relying on non-renewable energy resources may have a significant impact on the environmental hazards and so that on climate change. Another research conducted by Sharif et.al (2020) provides support for this claim. The authors conducted an "autoregressive distributed lag (QARDL) model to analyse the impact of economic growth, tourism, transportation, and globalization on carbon dioxide (CO_2) emissions in the Malaysian economy from 1995 to 2018". When the results of this research are investigated, it is possible to see that "economic growth is significantly positive with CO_2 emissions at lower to upper quantiles", while "tourism has a negative effect on CO_2 emissions at higher quantiles". As can be expected "globalization and transportation services are positive, with CO_2 emissions at upper-middle to higher quantiles". So this last research provides evidence that various sectors have various impacts on environment and climate. To produce effective policies, it is better to see the impacts of each sector on a separate basis on the climate change for the countries and/or regions under investigation. In another study, Doğan et al. (2022: 645) suggest that "environmental taxes effectively reduce emissions for the G7 countries … in a statistically significant way". So their findings show that to allow businesses to shift production towards cleaner methods strict environmental tax laws are needed. After all it is possible to see that there is still a strong need for studies focusing on the causation between climate change and the impacts of economic sectors on it. For example the research findings of a study conducted by Jiang et al. (2022: 346) provided "a hypothetical analysis basis for the power heating industry to control the growth of CO_2e from the viewpoint of input and output" in China as a country case study by focusing on a sector as heating industry. Except for the study of Balsalobre-Lorente (2022: 227) which "analyses the relationship between foreign direct investment, economic growth, urbanization, energy use, and carbon emissions in Brazil, Russia, India, China, and South Africa (BRICS countries) between 1990 and 2014", and found that "energy use is one of the main driving forces of ascending carbon emissions"; most of the current studies concentrated usually on one single country cases such as China (Li et.al., 2011), Austria (Hohmann et al. 2018), the UK (Averchenkova et al. 2021a), the USA (Fan et al. 2014) or New Zealand (Lawrence et al. 2013) or one region of the world as sub-Saharan Africa (Steynor and Pasquini 2019), and Europe (Stainforth et al. 2013). To sum up, the studies usually neglect investigating the causation between economic sectors and climate change. Another gap in the existing literature is the lack of studies focusing on the most affected 10 countries from climate change or in other words relying on the data of the 10 riskiest (most CRI score) countries.

Within this frame, we aim to fill the above-mentioned gaps of the literature by using data from Climate Risk Index (CRI) for the ten highest CRI score countries, which are, namely, Puerto Rico, Myanmar, Haiti, Philippines, Mozambique, The Bahamas, Bangladesh, Pakistan, Thailand, and Nepal for the years 2005–2019. The details of data collection and analysis are given below.

Research method and econometric analysis

The analysis of the study is conducted to test the causation between the energy consumption of each sector and climate change by using the data of the ten riskiest countries. The sectors included in the model are industry (IND), transportation (TRA), trade and public services (TPS), and housing (HOU). These are the key sectors determined by the International Energy Agency (IEA). During the study, the data of these sectors are reached from the joint database, and for each country, the ratio of the energy consumption of each sector to total energy consumption is used in the model. As for the indicator of climate change, the global Climate Risk Index (CRI) is used. The sample group of the study is composed of the 10 highest CRI scored countries, in other words, 10 most affected countries from the climate change. These countries are Puerto Rico, Myanmar, Haiti, Philippines, Mozambique, The Bahamas, Bangladesh, Pakistan, Thailand, and Nepal. But for the analysis, since there is not sufficient data for Puerto Rico and The Bahamas, only the data of the other 8 countries are included in the model. The main criteria in selecting the countries to be included in the sample group are having the most affected countries from climate change and conducting the analysis to investigate the impact of energy consumption on a sectoral basis. That is why the data belonging to the highest CRI score countries are used to conduct the analysis.

Within this frame initially the model and data set to be used for the tests are introduced and then the method to be employed is assessed. Firstly, the theoretical and conceptual framework of the tests is explained; secondly, the analyses are conducted; and thirdly, the findings of the analyses are interpreted.

Data set and model

In this study, the hypothesis of "*there is a significant causation between 'energy consumption on a sectoral basis' and 'climate change' through the data of most affected countries (8 out of 10 since data constraint for 2)*" is tested. Because of the problems of data constraint and establishing joint data, only the period between the years 2005–2019 is included in the analysis. The information related to the variables of the model, which are determined according to the hypothesis to be tested and in convenience with the literature, is given in Table 1.

Within this frame, the main motivation of the study is determining the causation between climate change and the energy consumption of the key sectors (industry, transportation, trade and public services, and housing). Besides, the study aims to provide useful proposals for the policymakers and politicians by determining the most effective sectors on climate change. Related to the motivation and hypothesis of the study, the independent variable of the model is determined as the CRI. As for the independent variables, the ratios of the energy consumption of the key sectors indicated by the IEA to the total energy consumption are chosen. These key sectors in energy consumption are IND, TRA, TPS, and HOU. Furthermore, EG which is shown as one of the factors affecting climate change in the literature is included in the model as the control variable. Variables are relevant with the assumptions of the current literature mentioned by Lawrence et al. (2013: 133–134) and as explained in the "Introduction". Moreover, since all the variables in the model are index values and ratios, it is not needed to take their logarithms.

By covering the data range of the sample group, the following model is designed to analyse the causation between climate change and energy consumption on a sectoral basis (Eq. 1).

$$CRI_t = \beta_0 + \beta_1 SAN_{it} + \beta_2 ULS_{it} + \beta_3 TCKM_{it} + \beta_3 KON_{it} + \beta_3 EB_{it} + \varepsilon_{it} \quad (1)$$

$i = 1, 2, 3, \ldots$ "N" in the model represents the cross-section data, while $t = 1, 2, 3, \ldots$ The time dimension is "T", and the error term is ε.

Econometric method

To analyse the causation between climate change and energy consumption on the sectorial basis by the annual data of the riskiest countries for the 2005–2019 period in this study, the methodological ranking is given below:

(1) The analysis of the graphics and descriptive statistics belonging to variables.

(2) To analyse the presence of cross-section dependency of variables, CD_{lm1} belongs to Breusch and Pagan (1980), and LM_{adj} test belongs to Pesaran et al. (2008) were utilized.

(3) To determine if the variables in the model have a unit root, the following stationarity tests were applied: Pesaran (2007)'s CADF and Levin et al. (2002)'s Fisher ADF, Fisher PP and Hadri (2002)'s; and Im et al. (2003)'s stationarity tests.

(4) To determine the homogeneity or heterogeneity property of variables, Pesaran and Yamagata (2008) homogeneity test was applied.

(5) Finally, Dumitrescu and Hurlin (2012) panel causality test is used to determine whether there is causality among the variables included in the model.

Table 1 Variables and resources

Variables	Explanation	Resources
CRI	Global Climate Risk Index	Germanwatch Global Climate Risk Index Reports
IND	Energy consumption of the industry sector/total energy consumption	International Energy Agency
TRA	Energy consumption of the transportation sector/total energy consumption	International Energy Agency
TPS	Energy consumption of the trade and public services sector/total energy consumption	International Energy Agency
HOU	Energy consumption of the housing sector/total energy consumption	International Energy Agency
EG	Economic growth	World Bank

The descriptive statistics for the variables

In econometric studies, the descriptive statistics of the variables have to be given before conducting the analyses. Within this frame, it is possible to see the changes and conjectural fluctuations in the variables in the chosen period which permits making interpretations. Related to the riskiest 8 countries suffering from climate change, the graphics and variables can be interpreted as below:

- CRI index is fluctuating generally around the same mean values for all the countries included in the sample group. The highest fluctuation was experienced in Myanmar in 2015.
- When the sectoral energy consumptions are investigated on a country basis, there are various ratios for each country. The highest consumption was experienced in Thailand in 2005. On the other hand, concerning the industry sector, the lowest consumption within the sample group belongs to Nepal.
- When the energy consumptions in the trade and public services sector are investigated, the Philippines is being separated from all others with the highest figures. While Thailand is another country that has high energy consumption, all other 6 countries are gathered around the same mean.
- In the transportation sector again the Philippines has the highest consumption and Thailand follows it again. The other 6 countries again reflect similar means of consumption in this sector.
- When the figures of the housing sector are investigated, the situation is totally different. Even if all the countries in the sample group have various levels of consumption, Nepal has the highest level, while Thailand has the lowest.
- When the data of economic growth are investigated, it is possible to see that Myanmar has the highest growth figures. Haiti is the country, which experiences the lowest level of economic growth. Especially in 2010, Haiti has experienced serious economic turbulence according to graphs given in Fig. 1.

In the study, the question of "if the series belonging to variables included in the model are normally distributed or not?" can be answered by looking at the skewness and kurtosis results are given in Table 2.

When Table 2 is investigated, it is possible to see that since *the skewness of CRI, TRA and TPS are greater than "0"* the graph is left-skewed; and since the skewness values of *other variables are less than "0"* they are right-skewed. For the kurtosis values, because *only TRA and EG variables' values are greater than "3"* the serials are leptokurtic/sharp peak; since other kurtosis values are less than "3" they are platykurtic.

Cross-section dependence test

To determine the presence of cross-section between variables in the studies using panel data analyses, *cross-section dependence* analysis needs to be conducted before the hypothesis tests. In the recent period of a global-village-like world, the dependency between countries has gained strength. Because of this dependency, appearing sudden shocks and/or negative or positive developments in any national economy carries a potential of affecting others. So in econometric studies, the cross-section dependence arising from the problem of "common factor" should be determined.

In case of the lack of cross-section analysis, the related studies in the literature conducted by Phillips and Sul (2003), Andrews (2005), and Pesaran (2006) give biased and inconsistent results. Moreover, if there is cross-section dependence in variables, other authors (Breusch and Pagan 1980; Pesaran 2004) assert that related analyses need to be continued by considering this issue.

So to determine cross-section dependency following tests are used:

- CD_{lm1} test belongs to Breusch and Pagan (1980) is used when the time dimension is smaller than the cross-section dimension ($T > N$).
- CD_{lm2} test developed by Pesaran (2004) is used when the time dimension equals to the cross-section dimension ($T = N$).
- CD_{lm} test belongs to Pesaran (2004) is used when the time dimension is smaller than the cross-section dimension ($T < N$).
- Pesaran et al. (2008)'s LM_{adj} test is used when the time dimension is both smaller ($T < N$) and greater ($T > N$) than the cross-section dimension.

In the study, data of 8 countries (out of 10 riskiest, 2 countries lack data) mostly affected by climate change (Myanmar, Haiti, Philippines, Mozambique, Bangladesh, Pakistan, Thailand, and Nepal) are used. The N term, which means cross-section dimension as mentioned above, is 8 in our equation. T term is 15 for the number of years being analysed since the time dimension encompasses the annual data from the 2005 to 2019. Because $T > N$, Breusch and Pagan's (1980) CD_{lm1} test and Pesaran et al. (2008)'s LM_{adj} tests were used in the analyses.

It is possible to make decisions based on the CD_{lm1} and LM_{adj} results by considering countries and time dimensions in the model, since $T > N$. Again, LM_{adj} test results are considered in general since the CD_{lm1} test may give biased results in cross-section dependence tests. Probability values of all the variables except the CRI are statistically significant at 0.01 level and EB at 0.05 level as is seen in cross-section dependence test results given in Table 3. For the CRI variable, the probability level is not statistically significant according to LM_{adj} test results.

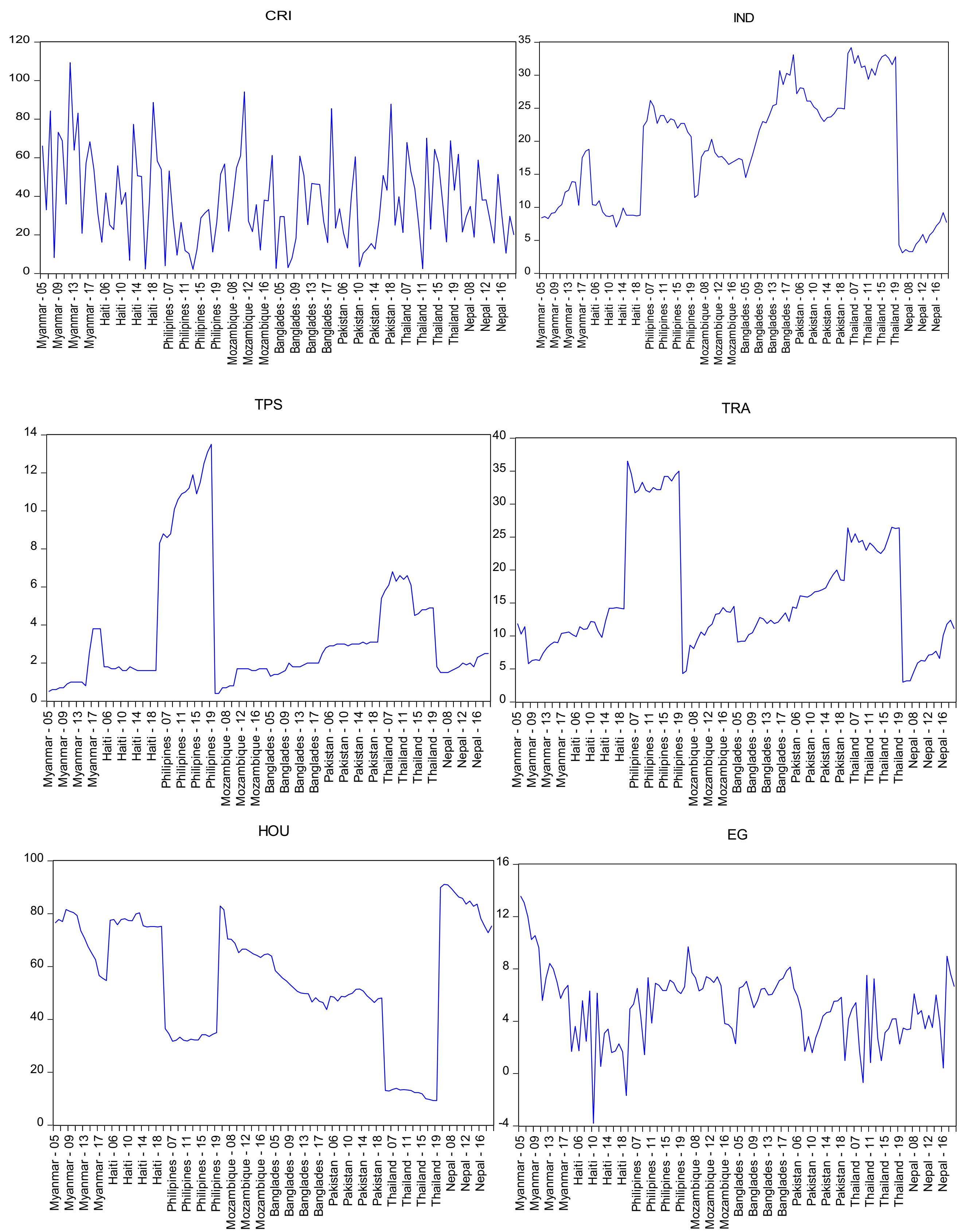

Fig. 1 Distribution of the data of the variables as for the countries and years

Table 2 Descriptive statistics for the variables

	Observation	Mean	Max	Min	Standard deviation	Skewness	Kurtosis	Jarque-Bera
CRI	120	37.66533	109.3300	2.170000	23.17991	0.596397	2.859400	7.212630 (0.027152)
IND	120	18.51750	34.20000	3.100000	8.994636	−0.01619	1.785718	7.377653 (0.025001)
TRA	120	3.447500	13.50000	0.400000	3.187738	1.649659	4.716830	69.16505 (0.000000)
TPS	120	15.64750	36.50000	3.000000	8.707516	0.905277	2.765975	16.66437 (0.000241)
HOU	120	55.59000	91.10000	9.300000	23.21306	−0.49361	2.237310	7.781478 (0.020430)
EG	120	5.195167	13.57000	−3.800.000	2.775546	−0.04137	3.995388	4.988215 (0.082570)

(1) The values in "( )" indicate the probability values

(2) If coefficient of skewness (CoS) > 0, positively skewed

(3) CoS = 0 or approximately close to 0, symmetric/data is normally distributed

(4) CoS < 0, negatively skewed

(5) If coefficient of kurtosis (CoK) < 3, the data distribution is platykurtic

(6) CoK is = 3 or approximately close to 3, data distribution is mesokurtic

(7) CoK > 3, data distribution is leptokurtic/sharp peak

The main hypothesis of "there is no cross-section dependence between countries" is denied for IND, TRA, TPS, HOU, and EG variables with reference to LM_{adj} test results, and the hypothesis of "there is cross-section dependence between countries" is accepted. This situation is consistent with the modern global world's status; any shock effect in one of the 8 highest CRI scored countries shall affect others as well. So policy and decision-makers in the countries of the sample group should take the current events into account and make their policy decisions by taking the bilateral influence among the variables. But for the CRI variable the tests did not result in cross-section dependence.

Panel unit root test

To solve the spurious regression problem, stationarity tests should be performed in econometric analyses. Analyses shall not provide realistic results if variables are with unit roots in series according to Granger and Newbold (1974). According

Table 3 Cross-section dependency test results

Variables	CD tests	CD_{lm1} (Breusch and Pagan 1980)	CD_{lm2} (Pesaran 2004)	CD (Pesaran 2004)	LM_{adj} (Pesaran et al. 2008)
CRI	*T* statistics	30.21940	0.296580	0.219879	0.010866
	Probability value	0.3528	0.7668	0.8260	0.9913
IND	*T* statistics	106.9821*	10.55442*	−0.601148	10.26871*
	Probability value	0.0000	0.0000	0.5477	0.0000
TRA	*T* statistics	127.3044*	13.27010*	8.016113*	12.98439*
	Probability value	0.0000	0.0000	0.0000	0.0000
TPS	*T* statistics	197.6008*	22.66387*	3.782732*	22.37815*
	Probability value	0.0000	0.0000	0.0000	0.0000
HOU	*T* statistics	141.5385*	15.17222*	7.766253*	14.88650*
	Probability value	0.0000	0.0000	0.0000	0.0000
EG	*T* statistics	57.19706*	3.901621*	0.424616	3.615907*
	Probability value	0.0009	0.0001	0.6711	0.0003

*, **, and *** in order indicate a dependence between the sections at 1%, 5%, and 10% significance levels

to Gujarati (1999), a series is stationary if the variance and average of a series do not change in time and also the covariance between the periods is based on the distance between two periods only, not the period of this covariance.

Whether countries in the sample are independent of each other is the key issue that needs to be considered in stationarity tests of panel data analyses. Unit root tests of panel data analyses consist of the first- and second-generation tests within this scope. Based on homogeneity and heterogeneity characteristics of countries, the first-generation unit root tests are divided into two groups. According to Göçer et al. (2012: 457) for the homogeneity assumption, the most frequently applied tests are Levin et al. (2002), Hadri (2002), and Breitung (2005). Based on heterogeneity assumption on the other hand, analyses such as Im et al. (2003), Maddala and Wu (1999), and Choi (2001) are used.

The cross-section dependence is not considered by the first-generation unit root tests, while the second-generation unit root tests perform this issue. So the second-generation tests are preferred since a shock that one of the countries in the panel faces may affect all others as well. Due to the presence of cross-section dependence among the IND, TRA, TPS, HOU, and EG variables within this study, second-generation unit root tests have to be used. Adversely because there is not cross-section dependence for CRI variable, first-generation unit root tests should be applied for CRI. That is why for IND, TRA, TPS, HOU, and EG variables CADF unit root test, which is mostly preferred in the literature, and for the CRI variable Im, Pesaran and Shin (IPS); Levin, Lin and Chu; Fisher ADF, Fisher PP and Hadri's stationarity tests have to be used.

CADF unit root test applied for IND, TRA, TPS, HOU, and EG variables is developed by Pesaran (2007). The main differences of CADF unit root test from others in literature are as follows:

- When the countries included in the model and time dimension are taken into consideration, it provides consistent results for situations of $T > N$. In this study for cross-section dimension $N = 8$. The time dimension $T = 15$, since it includes the annual data for the period of 2005–2019. Because $T > N$, CADF unit root test, which is mostly preferred at the literature, is used.
- During the analyses, a test statistics value is calculated for all units consisting of the model, and after applying the arithmetic means of these tests, CIPS (cross-sectional augmented IPS) test statistics is calculated for the whole panel.
- When applying the CAF test, an extended version with lagged cross-section mean of ADF regression is used. In this way, the regression model of CADF shall be reduced to a level of estimation by OLS for Eq. 1 (Pesaran 2007: 269).

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it}$$

The values of CADF and CIPS test statistics produced by CADF unit root tests are compared by Pesaran (2007)'s critical table values provided by Monte Carlo simulations, and the hypotheses were tested for stationarity. If the calculated absolute values of CADF and CIPS test statistics are bigger than critical table values, the basic hypothesis (there is a unit root in the serial) is denied and the alternative hypothesis (there is not a unit root in the serial) is accepted for the overall panel (Pesaran 2007: 265–312). Within the study, the stationary status of the serials of the model's variables IND, TRA, TPS, HOU, and EG for 8 most affected countries from the climate change is analysed for the overall panel and for the cross-section units consisting of the panel via CADF unit root test (constant model and constant-trend model), and the results are given in Tables 4 and 5 with Pesaran (2007)'s critical table values.

When CADF test results in Table 4 are evaluated, various stationary levels are seen for the countries included in the panel. As for the variables:

(1) The IND variable is stationary at 1% significance level in Philippines and 5% significance level in Mozambique. In other countries, it is unit rooted. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, the IND variable is stationary at the 5% significance level.
(2) The TRA variable is stationary at 5% significance level in Haiti, Philippines, and Pakistan, and at 10% significance level in Myanmar. In other countries, it is unit rooted. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the entire panel, the TRA variable is stationary at the 1% significance level.
(3) The TPS variable is stationary at the 5% significance level in Haiti and at 10% significance level in Bangladesh. In other countries, it is unit rooted. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, it has been tested that the TPS variable has unit root at the level. When the difference of the variable is taken, it is seen that it becomes stationary at the 10% level.
(4) The HOU variable is stationary at the 1% significance level in Mozambique, and at 10% significance level in Thailand and Nepal. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel in general, the HOU variable is stationary at the 1% significance level.
(5) The EG variable is stationary at 10% significance level in Haiti and Thailand. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, it is tested that the EG variable has a unit root at the level. When the difference of the variable is taken, it is seen that it becomes stationary at the 10% level.

Table 4 CADF unit root test results (constant model)

Country	IND	TRA	TPS	ΔTPS	HOU	EG	ΔEG
Myanmar	−2.76	−3.14***	−2.00	−1.878	−2.99	−1.50	−1.918
Haiti	−3.01	−4.43**	−3.59**	−1.502	−2.52	−3.44***	−3.916**
Philippines	−4.83*	−4.39**	−2.44	−3.675**	−3.05	−2.11	−2.575
Mozambique	−4.30**	−2.04	−1.38	−1.124	−6.32*	0.30	−1.868
Bangladesh	−1.29	−1.53	−3.30***	−2.125	−1.64	−0.62	−3.208***
Pakistan	−1.31	−3.93**	−0.81	−1.694	−0.92	−0.73	−1.323
Thailand	−2.11	0.44	−0.98	−2.850	−3.44***	−3.30***	−0.791
Nepal	−1.37	−2.23	−2.15	−2.229	−3.14***	−1.18	−2.454
CIPS statistics	−2.62**	−2.66*	−2.08	−2.234***	−3.00*	−1.57	−2.257***

(1) CADF table critical values for constant model: 1%: −4.65, 5%: −3.53, 10%: −3.06; CIPS table critical values: 1%: −2.66, 5%: −2.37, 10%: −2.22

(2) Stationary at *1%, **5%, and ***10% statistical significance levels

(3) Lag lengths are selected according to Schwarz criteria

(4) "Δ" symbol shows that the difference of the variable is calculated

Table 5 CADF unit root test results (constant and constant-trend model)

Country	IND	TRA	TPS	ΔTPS	HOU	EG	ΔEG
Myanmar	−2.958	−3.670***	−2.455	−3.409	−2.135	−3.134	−1.198
Haiti	−1.929	−1.619	−1.226	−5.702*	−3.942***	−3.403	−4.586***
Philippines	−6.553*	−1.182	−3.205	−3.408	−3.534	−1.171	−2.168
Mozambique	−4.077***	−8.537*	−0.518	−2.054	−5.330**	−0.911	−2.756
Bangladesh	−1.887	−0.799	−3.032	−1.805	−2.579	−1.650	−7.043*
Pakistan	−0.922	−4.709**	−1.569	−1.834	−2.915	−1.994	−0.642
Thailand	−3.104	−3.508	−3.360	−2.683	−3.952***	−0.923	−1.451
Nepal	−2.352	−2.111	−3.251	−0.283	−2.896	−1.364	−2.199
CIPS statistics	−2.973**	−3.267*	−2.327	−2.775***	−3.410*	−1.819	−2.765***

(1) CADF table critical values for constant and constant-trend model: 1%: −5.44, 5%: −4.17, 10%: −3.64; CIPS table critical values: 1%: −3.24, 5%: −2.93, 10%: −2.76

(2) The signs *, **, and *** indicate that they are statistically stationary at 1%, 5%, and 10% significance levels, respectively

(3) The lag lengths were chosen according to the Schwarz information criterion

(4) "Δ" symbol shows that the difference of the variable is calculated

When the CADF test results for the IND, TRA, TPS, HOU, and EG variables in Table 5 are examined, different stability structures come to the fore in the countries that make up the panel. Looking at the variables:

(1) The IND variable is stationary at 1% significance level in Philippines and 5% significance level in Mozambique. In other countries, it is unit rooted. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, the IND variable is stationary at the 5% significance level.

(2) The TRA variable is stationary at 1% significance level in Mozambique, 5% significance level in Pakistan, and 10% significance level in Myanmar. In other countries, it is unit rooted. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the entire panel, the TRA variable is stationary at the 1% significance level.

(3) The TPS variable has unit root in all countries at its level value. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, it has been tested that the TPS variable has unit root at the level. When the difference of the variable is taken, it is seen that it becomes stationary at the 10% level.

(4) The HOU variable is stationary at the 5% significance level in Mozambique, and at 10% significance level in Thailand and Haiti. Looking at the CIPS statistics,

which shows the results of the stationarity analysis for the entire panel, the HOU variable is stationary at the 1% level.

(5) The EG variable, on the other hand, has a unit root in all countries in its level value. Looking at the CIPS statistics, which shows the results of the stationarity analysis for the panel as a whole, it has been determined that the EG variable has unit root at the level. When the difference of the variable is taken, it is seen that it becomes stationary at the 10% level.

Since there is no cross-section dependence for the CRI variable included in the model, the stationarity is analysed via first-generation unit root tests. If the probability value is close to "0", the series are accepted as stationary, but if it is close to "1" it indicates the presence of unit roots. In Table 6, the unit root test results of the CRI variable in constant and constant-trend models are given. According to the results obtained in the constant model, the CRI variable was found to be stationary at the 1% significance level in all tests. When the unit root test results of the constant-trend model are examined, the test results except for the IPS and Fisher ADF tests show that the CRI variable is stationary at the level. It is seen that the CRI variable becomes stationary when the test is re-applied by taking the difference in the IPS and Fisher ADF tests.

Within the study which investigates the causation between climate change and energy consumption on the sectoral basis in the 8 riskiest countries for the years between 2005 and 2019, we see that the variables of the model do not have the same level of stationarity according to unit root test results. Some of the variables in the model are stationary at level values, while others are with unit roots. Panel ARDL cointegration test can be conducted in those econometric studies in which the variables do not have the same level of stationarity. That is why for the rest of the analysis the causality between the variables is tested via Dumitrescu-Hurlin test.

Dumitrescu-Hurlin causality test

The cointegration in econometric studies does not provide any information regarding the causality and its direction between the variables. That is why to test the causality between the variables, the causality analysis developed by Dumitrescu and Hurlin (2012) is applied.

The main reason for choosing this analysis is its usefulness even in situations when there is not any cointegration. Moreover, this test is one of the causality analysis methods providing effective results in cases of presence or absence of cross-section dependence. In this method, constant slope coefficients for each country are calculated separately, and cross-section dependence is taken into consideration (Dumitrescu and Hurlin 2012: 1457). The causality test results are given in Table 7.

When the results of the causality test between the climate change and energy consumptions on the sectoral basis given in Table 6 are investigated, it is possible to see that, there is one-way causality from TRA variable to CRI variable. There is not any statistically significant causality between other variables. The analyses carried out were tested on the stationary levels of the variables included in the model.

Results, findings, and discussion

It is important to provide solutions for climate change on the basis of empiric research. So, all studies from all disciplines carry out significant importance for policymakers. From this point of view, we examined "if there is a causation between Climate Change (Global Climate Risk Index – CRI) and Energy Consumption of Economic Sectors" in a novel sample group of 8 countries (since data of 2 countries out of 10 riskiest are not included in the analyses because of data constraint) with certain measurable factors. The economic sectors are industry, transportation, trade and public services, and housing. Economic growth is also included in the model as the control variable. The countries in the sample group are initially determined as Puerto Rico, Myanmar, Haiti, Philippines, Mozambique, The Bahamas, Bangladesh, Pakistan, Thailand, and Nepal. But since there is not sufficient data for Puerto Rico and The Bahamas, only the data of 8 countries are included in the analyses.

Table 6 CRI variable unit root test results for constant and constant-trend models

Tests	Constant model		Constant-trend model			
	At the level		At the level		Difference is calculated	
	Test statistics	Probability value	Test statistics	Probability value	Test statistics	Probability value
Im, Pesaran and Shin	−2.5778*	0.0050	−1.2458	0.1094	−3.6973*	0.0001
Levin, Lin and Chu	−3.2124*	0.0007	−2.9970*	0.0014	–	–
Fisher ADF-chi-square	31.3538**	0.0121	22.0681	0.1410	42.7504*	0.0003
Fisher PP-chi-square	84.8081*	0.0000	78.0888*	0.0000	–	–
Hadri-Z test	1.4377**	0.0753	4.7337*	0.0000	–	–

Note: the signs *, **, and *** indicate that they are statistically stationary at 1%, 5%, and 10% percent significance levels respectively

Table 7 Dumitrescu-Hurlin causality test results

Direction of the causality	*Test*	*Test statistics*	*Probability values (10%)*
CRI ≠> IND	Z-bar	0.7925	0.5475
	Z-bar tilde	0.1911	0.8417
IND ≠> CRI	Z-bar	−0.6760	0.6071
	Z-bar tilde	−0.7682	0.4183
CRI ≠> TRA	Z-bar	−0.2188	0.8530
	Z-bar tilde	−0.4695	0.6248
TRA ≠> CRI	Z-bar	3.5633	0.0583*
	Z-bar tilde	2.0010	0.0583*
CRI ≠> ΔTPS	Z-bar	3.1692	0.1217
	Z-bar tilde	0.9529	0.1990
ΔTPS ≠> CRI	Z-bar	−1.0313	0.3511
	Z-bar tilde	−1.0002	0.2028
CRI ≠> HOU	Z-bar	−0.1974	0.8796
	Z-bar tilde	−0.4555	0.6362
HOU ≠> CRI	Z-bar	2.5092	0.1445
	Z-bar tilde	1.3124	0.1508
CRI ≠> ΔEG	Z-bar	1.1784	0.4715
	Z-bar tilde	0.0220	0.9747
ΔEG ≠> CRI	Z-bar	0.7306	0.5311
	Z-bar tilde	0.1506	0.8821

"*" indicates causality between the variables at 10% significance level. "≠>" sign shows the direction of the causality. Test statistics are attained by 789 iterations. The "Δ" symbol indicates that the causality test is applied with the difference value of the variable

When the existing literature is reviewed to compare the findings of this research, we see that Stainforth et al. (2013) translate observations of weather, into observations of climate change and expose how the regions of greatest warming are quantile and threshold dependent. The authors found that for Europe the response is greatest in a band from Northern France to Denmark. Although the findings of the research are significant and show the importance of studying especially the problems faced in riskiest areas of climate change, the study does not provide any information on the causes of this change and/or the impacts of any economic sectors on the issue. So evaluating the findings together with our research, the significance of a study investigating these problems in the regions which are most affected by climate change can be understood clearly. So our research, which was conducted by using the data of the 8/10 most affected countries, try to fill this gap.

After the causality analysis on the climate change and energy consumptions on the sectoral basis, we found that there is one-way causality from TRA variable to CRI, while the results do not reach any statistically significant causality between other variables. The causality between the transportation sector and climate change can be interpreted by reference to the increasing share of transportation in energy consumption and its direct influence on CO_2 emissions. Moreover, this sector's dependent status on fossil fuels is a determinant factor behind air pollution and global warming. This finding is also convenient with the research results of Sharif et al. (2020) that various industrial sectors might have different impacts on environmental hazards and climate; and Godil et al. (2021) who found that "Renewable energy consumption and innovation show a negative impact on emissions of CO_2 related to transport. It depicts that due to the increase in renewable energy and innovation, the CO_2 emission in the transport sector is likely to decrease; however, an increase in the GDP of a country will upsurge the emission of CO_2 in the transportation sector in China". So the findings of this research on the impacts of transportation sector within the most affected 8 countries from the climate change also supports the previous findings with the data of other case studies and/or samples. After making research on other sample countries, this finding may be more generalized.

According to Lawrence et al. (2013: 133–134) due to climatic changes, flood risk is increasing especially by the exposure of human settlements, transportation and utility networks, population increases, and economic growth. In other words, flood risk is increasing because of climate change and climate change is increasing because of the impacts of *human settlements* and *population increase*, *transportation*, and *economic growth*. So our research on 8/10 riskiest countries provides evidence supporting the impact of transportation on climate change by reaching not only a simple relationship but causation as well. But for the other variables, namely, *human settlements* and *population increase* which is represented by *housing* in our study, and *economic growth*, which is used as a control variable, it is not possible to reach causation. In some other research, the authors find a relationship between electricity generation (EGEN) and economic growth (IPI) in Singapore (Sharif et al. 2017: 686) but they did not analyse the relationship with climate change.

There are of course many efforts to produce solutions regarding climate change. As mentioned by Surminski and Lopez (2015: 267), the Warsaw agreement, which receives a positive achievement by establishing "Warsaw international mechanism for loss and damage", suggests that there is a growing acceptance of international support for climate change victims. To reduce loss and damage caused by the adverse effects of climate change, the Cancún Adaptation Framework highlights the need to strengthen international cooperation (UNFCCC 2011; Surminski and Lopez 2015: 267), but it is a fact that without eliminating the problems, which cause climate change, all the policies produced shall fall in a status of providing temporary precautions, which do not really take the real problem away. That is why as in the case of all policy analysis efforts, the progress for providing policies on finding solutions for climate change has to start with the problem definition so that a useful treatment related to the diagnosis as means of public policies could be designed. So the finding of this study which provides empirical evidence on the issue that the transportation sector has a causal effect on climate change in the sample group countries may fill this gap at least for a group of countries suffering the most from the climate change phenomenon. Furthermore, not only these countries but all the countries around the world have to contribute to the matter as much as they can. Not only China as mentioned by Yun (2016: 235) but all the countries have to follow the principles such as the *creation of a future of win-win cooperation* with each country contributing to the best of its ability; a *future of the rule of law*, *fairness*, *and justice*; and a *future of inclusiveness*, *mutual learning*, and *common development* to facilitate the implementation of the Paris Agreement and participate in the design of international systems. So eliminating the determined problems causing climate change has to be given priority by all policymakers.

Even if Steynor and Pasquini (2019: 8) assert that “one approach to deepening contextual knowledge for climate services is through an understanding of climate change risk perceptions”, the findings of our study show the importance of studying the *risks themselves* but *not only the perceptions* of the people. This does not mean that studying perceptions is unnecessary since the need for producing better policies for preventing climate change may only start when there is a strong perception of the urgency of this issue. Changing perceptions and public opinion may help carry the issue to the agenda of policymakers. As in the case of the UK Climate Change Act of 2018, many policymakers in different countries are already trying to develop new regulations; the parliaments and lawmakers are passing new acts on the issue or updating the existing ones according to the new information provided by the scientific researches. But as asserted by Averchenkova et al. (2021b), “it is less clear whether that commitment will lead to effective policy implementation or not”. Indeed not only the implementation but also the design-phase of the climate policies is still at an age of crawling.

Conclusion

There is much work to do on the issue to provide answers for the problems. However, as mentioned before the most important matter is problem definition so that humanity can find correct solutions for their problems to save the future. Well-functioning governance at the national and international level on climate change has to be established and supported by all the stakeholders. As demonstrated by Sinha et al. (2022), their study reached a finding that all inequality components are rising during the study period of 1990–2019 at the global scale which is a negative signal for Sustainable Development Goals. Policymakers have to be aware that in order to provide a sustainable social, economic, and ecologic environment, climate change should be given the 1st priority with all its dimensions. To support this progress, it is important to conduct empiric studies, which provide evidence-based results to contribute to making better policies. Studying the causality between various variables and climate change one of those and has utmost importance to find an effective treatment for the problem. So this research tries to fill some aspects of this gap, by investigating the causation between the energy consumption of key economic sectors and climate change in the 10 highest CRI score (most affected by climate risk) countries.

Key economic sectors included in the study are industry, transportation, trade and public services, and housing. As for the control variable, economic growth is used in the model. Although the countries included in the sample group are Puerto Rico, Myanmar, Haiti, Philippines, Mozambique, The Bahamas, Bangladesh, Pakistan, Thailand, and Nepal, only the data of 8 countries are included in the analyses, since there is not sufficient data for Puerto Rico and The Bahamas for the years between 2005 and 2019. So the results and findings of the research have to be evaluated within the limitations of these four sectors as industry, transportation, trade and public services, and housing, and with the 8 countries whose data were included in the analysis. Another limitation of the study is the time period covered since the annual data for the years 2005–2019 was used because of the data constraints for other years.

The results of this study support the hypothesis of “*there is a significant one way causation between ‘energy consumption of transportation sector’ and ‘climate change’ through the data of ten highest CRI score countries*”. The causality analysis results also show that there is not any statistically significant causation between other sectors and climate change.

To conclude, if we integrate the findings of our study with the findings of Fan et al. (2014), emphasizing the significant role of emissions in determining the potential future climate change, it is so important for the policymakers to provide solutions to decrease the carbon emission produced especially by the transportation sector. Because our results show that the negative impacts of transportation by producing emissions directly have a causality effect on climate change. This does not mean that other sectors do not have any impact but at least for the 8 countries whose data was analysed within 10 riskiest countries in the sample size, we could not find any direct causation for other sectors. So at least for these countries, priority should be given to transportation sector and for sure this policy has to be supported by the preventions in other sectors.

Last but not least, new research including other sectors in the sample countries with the same method or conducting time series analysis in a single country as a case study can be conducted to enrich the scientific information to prevent and/or at least slow down the global warming and the speed of the climate change by the researchers.

Author contribution IC contributed to the planning, literature review, data collection, econometric analysis and issues related to economics within the study. AK contributed to the planning, literature review, data collection and writing the discussion and conclusion parts within the study. MVE contributed to the literature review, econometric analysis and issues related to international economics within the study.

Data availability Data used in our analysis are available as Supplementary Material.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication All authors consent to publish in the journal of "*Environmental Science and Pollution Research*".

Conflict of interest The authors declare no competing interests.

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