Economic activity and climate change.∗

Aránzazu de Juan†, Pilar Poncela‡, Vladimir Rodríguez-Caballero§, and Esther Ruiz¶

1Department of Economic Analysis Quantitative Economics, Universidad Autónoma de Madrid

2ITAM (Mexico) and CREATES (Aarhus University)

3Department of Statistics, Universidad Carlos III de Madrid

14th May 2022

Abstract

In this paper, we survey recent econometric contributions to measure the relationship between economic activity and climate change. Due to the critical relevance of these effects for the well-being of future generations, there is an explosion of publications devoted to measuring this relationship and its main channels. The relation between economic activity and climate change is complex with the possibility of causality running in both directions. Starting from economic activity, the channels that relate economic activity and climate change are energy consumption and the consequent pollution. Hence, we first describe the main econometric contributions about the interactions between economic activity and energy consumption, moving then to describing the contributions on the interactions between economic activity and pollution. Finally, we look at the main results on the relationship between climate change and economic activity. An important consequence of climate change is the increasing occurrence of extreme weather phenomena. Therefore, we also survey contributions on the economic effects of catastrophic climate phenomena.

Keywords: Catastrophic weather, Energy consumption, Environmental Kuznets Curve, Global Warming, Greenhouse Gases, Temperature trends.

∗Financial Support from La Caixa Foundation, grant LCF/PR/SR20-52550012-Climate Change and Economic Challenges for the Spanish Society (ECHASS), is gratefully acknowledged by all the authors. Esther Ruiz also acknowledges financial support from Project PID2019-108079GB-C21 while Pilar Poncela and Arantxa de Juan are supported by Project PID2019-108079GB-C22, both from the Spanish Government. We are also very grateful to Carlos Cuerpo for invaluable comments that help us to focus this paper on relevant problems for policy makers. Any remaining errors are obviously only our responsibility.

†Corresponding author. e-mail: ortega@est-econ.uc3m.es. Address: Dpto. de Estadística, Universidad Carlos III de Madrid, C/ Madrid, 28903 Getafe (Spain).
1 Introduction

Measuring the interactions between economic growth and climate change could give an answer to whether it is socially beneficial for present and near future generations to sacrifice their own consumption to mitigate the latter in favour of generations yet to come and, consequently, it is critical for the design of economic and environmental policies. As Auffhammer (2018) states, “optimal policy design in the context of addressing the biggest environmental market failure in human history requires an understanding of the external cost imposed by additional emissions of greenhouse gases.” In this direction, the European Union (EU) has designed a new strategy for growth directed towards its transformation into a fair and prosperous society with a modern, resource-efficient and competitive economy. As a result of this strategy, in December 2019, the EU launched the European Green Deal plan. Furthermore, as a response to the recent COVID-19 pandemic, the EU has put forward an ambitious and innovative budget for European recovery, the “Next Generation EU” with a budget of 750.000 million Euro. This plan is a game changer with respect to the discussion about climate change as member states receiving financial support should direct one third of their budgets towards the Green Economy and the ecological transition. Relevant policy recommendations need to be based on correct forecasts of the externalities caused by climate change and its mitigation costs. Robust measures of the interactions between environmental variables and the economy are crucial to formulate suitable economic development paths; see Tol (2009, 2014), who points out three of the big unknowns related to climate change, namely, extreme climate scenarios, the very long-term scenarios, and the potential economic and social effects of climate change. In this direction, the European Commission has recognized the need of designing robust quantitative systems for monitoring and forecasting key variables related with the Climate and Energy Framework objectives in order to understand whether the steps taken within each of EU members will produce the desired effects in terms of the European Green Deal plan. It is important to remark that all member states will simultaneously carry out their policies within the “Next Generation EU” plan and, by that, they will generate potential externalities that need to be measured.

Given the implications mentioned above, it is not surprising that, during the last decades, there has been an increasing interest among policy-makers, academics and the society in general, in knowing about the negative externalities of macroeconomic growth, with climate change being among the most relevant and dangerous of these externalities; see, for example, the discussions by Pindyck (2013), Stern (2008) and Stock (2019). Knowing the extent to which climate change affects important macroeconomic magnitudes, and, in particular, growth, has straightforward implications for the design of resilience economic policies. Economic growth based on burning of fossil or carbon-based fuels leads to pollution in the form of emissions of Greenhouse Gases (GHG). Higher atmospheric concentrations of GHG warm the land and oceans with impacts
on temperatures, precipitation patterns, storm location and frequency, river run-off and water availability, among others. These long-run permanent changes in (short-run) weather is what is known as climate change.

The relationship between economic activity and climate change is not unidirectional as the latter may also have an impact on economic magnitudes. In a series of works, Rezai, Foley and Taylor (2012), Taylor, Rezai and Foley (2016) and Rezai, Taylor and Foley (2018) show that climate change generates externalities that may affect important economic variables as, for example, employment, income distribution and growth; see also Weitzman (2009) for a theoretical model of the economic effects of catastrophic climate change and Tanoue et al. (2020) for the effects of floods. There are also several “empirical” popular models proposed to measure climate change and its economic impact. Among them, the most remarkable contribution of Nobel laureate Nordhaus is the proposal of the Dynamic Integrated model of Climate Change and the Economy (DICE), an integrated assessment model (IAM), which is a constrained non-linear dynamic optimization model with an infinite horizon; see, Nordhaus (2019) for a summary of his contributions on the economics of climate change, for which he received in 2018 the Nobel prize in Economics, and Dietz et al. (2021) for a recent analysis of the climate policy implications of different representations of the climate system based on the DICE model. In November 2006, the British Government presented a comprehensive study based on IAMs, The Stern Review on the Economics of Climate Change, according to which “...if we don’t act, the overall costs and risks of climate change will be equivalent to loosing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more...”; see Stern (2007) for the full text of the Review and Nordhaus (2006) and Tol (2006) for enlighting comments on it. Barnett, Brock and Hansen (2021), Hansen (2022), Pindyck (2013, 2017), Stern (2008, 2013, 2016) and Weitzman (2007, 2015) discuss the limitations of models as DICE, which can give an illusory and misleading perception of knowledge and precision. Uncertainty is the “Achilles’ heel” of IAMs of climate change, being of little value for a prudent current policy; see, for example, Hansen (2022), who represents the histogram of temperature projections obtained across various sets of 144 models, reflecting the substantial amount of cross-modelling uncertainty that could emerge from climate IAMs. Recently, Ikefuji et al. (2020) propose to address some of these concerns by proposing a stochastic DICE model and introducing uncertainty about future climate change and economic changes into it.

Instead of focusing on theoretical models or on deterministic models, as those described above, in this paper, we survey over 250 empirical contributions to the literature on measuring the relationship between climate change and economic activity based on using data analysis and econometric models. The complexity of the problem makes it difficult to know where to start. Due to the huge related literature, this is a very ambitious and endless objective. Consequently, we restrict ourselves to survey the main conclusions and econometric issues faced in measuring
this relationship, focusing on contributions appearing in the literature over the last decade. However, to put recent work in a broader context, in some cases, we need to briefly cover some earlier development, overlapping with some portions of available surveys. We want to apologise in advance to the many authors who have contributed to this huge literature and have not been cited in this survey.

The global picture of the channels through which climate change and the economy may be related is well understood. First, economic activity is related with an increase in energy consumption, which is related with pollution. Larger pollution is related with climate change; see, among others, Kaufmann, Kauppi and Stock (2006), Kaufmann et al. (2011), Agliardi, Alexopoulos and Cech (2019), Estrada, Perron and Martínez-López (2013), Chang et al. (2020), Miller and Nam (2020) and Eroğlu, Miller and Yiğit (2022), for some evidence about the long-run relationship between anthropogenic pollution and temperatures. Finally, climate change is itself affecting the economy; see Figure 1 for a chart summarizing these interactions. The first issue found when measuring and testing for the relationships described in Figure 1 is that of defining and measuring the variables involved in the different channels. The first variable that should be defined and measured is climate change itself. In the most recent literature, most measures of climate change are based on temperatures and precipitations. Given the relationship between temperatures and pollution, there is also an interest in measuring pollution, with CO$_2$ emissions being among the most popular measures because of its relevance and weight in total emissions. Finally, one should decide about the economic variables of interest to analyse the impact of climate change. In choosing the variables to focus the analysis on, one should not only choose the magnitudes to be measured but also need to decide about their spatial and temporal coverage and the frequency of observation. For example, one can carry out the analysis considering cross-sectional, panels or time-series data and, in any case, looking at global or local variables observed at different levels of aggregation and at different frequencies.

The second important issue involved in measuring the interactions between climate change and the economic activity is to decide the econometric methodology (models, estimators and tests) to be implemented, which obviously depends on the particular data under analysis; see Petris and Hendry (2013), who outline important hazards that can be encountered when modelling climate-rated time-series data and Auffhammer (2018), who describes several concerns in the empirical analysis of the economic cost of climate change. Here, we list the most relevant:

i. **Endogeneity** due to the potential bi-directional causality between climate change and the economy. Auffhammer et al. (2013) point out that often studies try to estimate the economic impact of climate change under a climate influenced by human activity. For example, agriculture is highly exposed to climate change because its activities directly depend on climatic conditions and, simultaneously, agriculture contributes to climate change through
GHG emissions; see, Agovino et al. (2019). Very recently, in a very important work, Petris (2021) discuss several issues related with the exogeneity assumption and propose a novel methodology to overcome them.

ii. Non-linear relations. For example, non-linear relationships appear in the Environmental Kuznets Curve (EKC), which postulates that the relationship between economic growth and environmental degradation follows an inverted U curve. The seminal and highly influential contribution of Grossman and Krueger (1995) concludes that there is an increase of environmental degradation and pollution in early stages of economic growth, but, beyond some level of income per capita, this relationship reverses with additional income growth leading to environmental improvement.\[1\] When the economy is mainly devoted to the agricultural activity, the environmental quality is higher than when it is mainly driven by industrial production, while when the service sector starts its development, then the environmental quality improves. The long-run relationship between economic growth and environmental degradation could thus be described as an inverted U-shaped curve, known

\[1\] A number of elements related to growth as, for example, changes in the economic structure, technological progress, changes in preferences and increased environmental awareness, would be at the basis of such a relationship; see the survey by Dinda (2004), who summarizes the factors responsible for the shape of the EKC.
after Kuznets (1955) as EKC.

iii. Non-stationarity, with potential different relations in the short or the long run; see, for example, Petris and Allen (2013), who point out that a difficulty with the statistical analysis of the relationship between temperature, GHG concentrations and the economic drives responsible for GHG changes, lies with the fact that each of these time series is non-stationary. In many works, non-stationarity is dealt with by transforming non-stationary data to stationarity. However, in doing this transformation, the information about the long run is lost; see the discussion on non-stationarity of climatic variables by Castle and Hendry (2020). Given that some of the GHGs have an atmospheric lifetime measured in tens of thousands of years, climate change is a long-run phenomenon; see Tol (2009). Therefore, measuring the long-run relationships between climate change and the economy is one the most relevant aspects of the analysis.

iv. Another econometric aspect to take into account when measuring the relations between climate change and the economy is related with the potential presence of structural breaks and/or outliers; see the discussion by Castle and Hendry (2020). To mention a recent example, consider the economic havoc observed during the present recession due to COVID-19, which will affect the state of the business cycle. The COVID-19 pandemic has caused most of the world economies to sink at unprecedented growth rates. COVID-19 has also affected the demand of energy with reductions in energy demand producing large short-run reductions in GHG emissions and uncertain long-run effects; see, for example, Gillingham et al. (2020).

v. An appropriate econometric model should also take into account the externalities due to the relationships among different countries; see, for example, the results in Munir, Lean and Smyth (2020) on the between-country interactions when looking at the relationships between CO₂ emissions, energy consumption and economic growth.

vi. A good econometric model should take into account the uncertainty associated with the measures of climate change and its economic implications: see Weitzman (2020), who points out that deep structural uncertainty lies at the heart of climate change economics and Calel et al. (2020), who show that uncertainty plays a major role in computing the economic cost of climate change. Stern (2008, 2016), Pindyck (2014) and Convery and Wagner (2015) discuss that, by necessity, standard climate-economy models focus on what is known and can be quantified and, consequently, they convey a false sense of precision. Tol (2009, 2014) also argues that the level of uncertainty about the economic effects of climate change is a long-run phenomenon; see Tol (2009). Therefore, measuring the long-run relationships between climate change and the economy is one the most relevant aspects of the analysis.

---

2Note that Kuznets (1955) postulates the inverted U-shape for the relationship between income and income inequality.
change is large and understated, especially in terms of capturing downside risk. Petris et al. (2018) remark the importance of taking into account uncertainty when looking at the economic effects of rising temperature. Finally, an appropriate measure of uncertainty is also important because, when looking at the economic impacts of climate change, analysts and policy-makers are mainly interested not in the average effect but in the left tail of the impact; see Weitzman (2009). In this context, Burke, Hsiang and Miguel (2015) and Petris and Roser (2017) point out that failing to account for climate uncertainty greatly understates the severity of the worst-case scenario.

The rest of the paper is organized as follows. Section 2 revises the measures of climate change usually used in econometric studies. Sections 3, 4 and 5 are devoted to describing the main econometric contributions related to measuring the relationships between economic activity and energy consumption, energy consumption and pollution, and pollution and climate change, respectively. Section 6 reviews the economic effects of catastrophic phenomena related with weather change. Finally, section 7 concludes.

2 Weather variables to measure climate change

In order to measure the relationships between climate change and the economy, it is crucial to start by defining and measuring climate change. This section is devoted to describing the variables often used in the empirical analysis of climate change.

Climate is usually defined as the long-run average of weather in a given location. As stated by Auffhammer et al. (2013), "the difference between weather and climate is basically a matter of time". The choice of weather versus climate as the variable of interest affects the interpretation of the estimated econometric models as measuring short or long-run phenomena. Hsiang and Koop (2018) define climate change as the long-run variation in the joint probability distributions describing the state of the atmosphere, oceans, and fresh water including ice.

In many studies analysing the relationships between climate and economic activity, the measures used for climate change are observations of weather variables, often temperatures and precipitations, obtained from weather stations; see Auffhammer et al. (2013) for a discussion on some common pitfalls that empirical researchers should be aware of when using historical weather data as explanatory variables for the economy. However, one of the most important and popular aspects of climate change is Global Warming (GW), which can be described by the evolving distribution of temperature; see the reports by Intergovernmental Panel on Climate change, IPCC (2014, 2022). Dell, Jones and Olken (2014) also point out that the second most analysed variable for climate change is precipitation. Several important works also analyse ice levels: see Castle and Hendry (2020), Diebold and Rudebush (in press) and Diebold et al. (2021), among others. Other less popular variables are relative humidity, solar radiation, wind speed
and direction and atmospheric pressure.

Given that our goal in this paper is to survey the literature analysing the relationships between climate and the economy, we focus on studies of climate data observed at the frequencies and for the time spans for which economic data are usually available, namely, monthly, quarterly or yearly data observed since the XX century.

As mentioned above, one of the main characteristics of climate change is GW and, consequently, we will mainly focus on describing how GW has been modelled in the related literature. One popular methodology to obtain future projections of climate is to simulate data by General Circulation Models, also known as Global Climate Models (GCMs), which are detailed computer models that numerically approximate fundamental physical laws for representing global climate (temperatures and precipitations) in a given grid in the space; see, for example, IPCC (2014, 2022) for a description and Hsiang et al. (2017) for a recent implementation. GCMs forecast future climate assuming heightened atmospheric concentrations of GHGs. However, there are large discrepancies across point projections of GCMs, without evidence of any model being superior than others for long-term forecasts; see, for example, Beenstock, Reingewertz and Paldor (2016) for a comparison among models and Fernández et al. (2019) for an analysis of projections made by a large number of models for the Iberian peninsula. Furthermore, the majority of GCM projections are point projections without associated measures of their uncertainty; see, Burke, Hsiang and Miguel (2015), who survey the literature on the impacts of climate change and show that the vast majority of estimates of the effects of climate on economic outcomes fail to account for the uncertainty in future temperatures and rainfall. Moreover, they argue that incorporating uncertainty into future economic impact assessments will be critical for providing the best possible information on potential impacts. Finally, Auffhammer et al. (2013) also point out that severe biases due to spatial average can often occur when GCMs are used to simulate future climate; see Fowler, Bleukinsop and Tebaldi (2007) for bias corrections based on regressions between the GCM outputs and observed variables.

Alternatively, instead of using GCMs, many studies on GW focus on analysing the temporal evolution of particular characteristics of temperatures, hot and cold spell duration, frost days, growing season length, ice days, heating and cooling degree days, and start of spring dates; see, for example, the references cited in Diebold and Rudebush (2022). Regarding how data are collected or generated on these analysis, Dell, Jones and Olke (2014) review four types of input weather variables usually found in empirical analysis of climate change: ground station data, recorded in situ in weather stations, gridded data, which interpolate data among ground stations, satellite

Alternatively, many important studies of climate change consider paleo-climate observations. For example, Schmidt et al. (2014) model paleo-climate changes for the Last Glacial Maximum, the mid-Holocene and the Last Millennium, while Castle and Hendry (2020) model climate variability over the Ice Ages.
data with very broad coverage although less precise and reanalysis data, which use a climate model to combine all previous types of data to enlarge the coverage of the databases. Of course, the level of temperature, i.e. the central tendency of the temperature distribution, has attracted the most attention, with many studies finding an upward trend in average daily temperatures; see, for example, Deng and Fu (2019), who compare several methods for extracting cycles from daily temperatures.

3 Economic activity and energy consumption

Kyoto Protocol and Paris Climate Accords have urged that sustainable development has been a critical part of the political climate agenda in the last decade. Thanks to climate agreements, governments have been forced to seek successful energy policies that can help to reduce environmental damage without affecting the economic growth path.4

To establish successful green policies, there has been a growing interest in issues related to economic growth through energy consumption, both from a political and academic perspective. The relationship between energy and economic activity has been analysed for a long time. The early seminal short note of Kraft and Kraft (1978) introduced the necessity of studying the causal relationship between energy consumption and economic growth in the US. Since then, many papers have analysed this conundrum, including different economic mechanisms by which energy consumption and economic growth can be interlinked over time. Literature surveys by Ozturk (2010) and Payne (2010a, 2010b) provide the reader a first look at the literature using standard econometric methods on the original nexus. Tiba and Omri (2017) analyse the literature behind energy-environment-growth nexus. Waheed, Sarwar and Wei (2019) examine the survey of earlier literature that deals with economic growth, energy consumption, and carbon emission. Finally, Mutumba et al. (2021) provide the reader with an extensive meta-analytic investigation of energy consumption and economic growth.

The goal of studying the relationship between economic activity and energy consumption is to identify their causal direction, whose consequences in the design of energy policies can be completely opposed: see the discussions by Apergis and Payne (2011) and Chen, Xie and Liao (2018) on different theories about the relationship between energy use and economic growth. The main hypotheses are described below:

- The Growth Hypothesis, which is supported if there exists unidirectional causality running from energy consumption to economic growth. This case is perhaps the more sensitive

4While the Kyoto protocol adopted in 1997 set top-down legally binding emission reduction targets and sanctions only for developed nations, the Paris Agreement of 2015 requires that all developed and developing countries reduce greenhouse gas emissions. Gaast (2017) describes the three main climate negotiation phases between 2005 and 2015.
for energy policies due to possible direct shocks to the economic growth. This causal relationship has generated intensive participation in the global warming debate regarding the level of carbon emissions and their relationship to economic growth.

- The Conservation Hypothesis, which demands a unidirectional causality from economic growth to energy consumption. This hypothesis would indicate to governments that reducing energy consumption would not affect the growth path and give them the breath to reach climate agreements.

- The Neutrality Hypothesis that indicates the absence of a causal relationship between energy and growth. As in the previous case, energy conservation policies should be encouraged.

- The Feedback Hypothesis, which requires evidence of bidirectional causality, meaning that energy consumption and growth are jointly determined. Therefore, along with the Growth Hypothesis, energy conservation policies need to be defined with the caution of avoiding to shock negatively the economic growth.

Although the literature is vast, there is still no consensus due to the heterogeneity in climate conditions, the econometric methodology employed, or even if the analysis considers only one country or a panel of them, among many other circumstances. However, as mentioned above, the common objective of this literature is clarifying the type of hypothesis supported.

The nexus between energy consumption and economic growth has been analysed using a large variety of procedures. First, it may exhibit strong cross-sectional dependence due to the high economic and financial integration among countries and regions. Consequently, panel data models have been often used in this context; see, for example, Damette and Seghir (2013), Jalil (2014), Liddle and Lung (2015), Kais and Sami (2016) and Acheampong et al. (2021). Many authors also consider the temporal dependence in the panel. For example, Apergis and Payne (2011) fit a panel VECM to 88 countries categorized into four panel according to their income level. They found bidirectional causality in both the short- and long-run for the high and upper-middle income countries. However, in the lower-middle income countries, the causality is unidirectional from electricity consumption to economic growth in the short run while it is bidirectional in the long-run. Finally, they find unidirectional causality from electricity consumption to economic growth for the low income countries. More recently, Lin and Benjamin (2018) also fit a fixed effect panel VECM to represent the relationship between energy consumption, foreign direct investment and economic growth for the MINT countries (Mexico, Indonesia, Nigeria and Turkey). Their conclusions about the directionality of the effects between energy consumption and growth are not uniform across all countries; see also Apergis and Payne (2009) and Kasman and Duman (2015) for applications using panel cointegration and Antonakakis, Chatziantoniou
and Fillis (2017) for panel VAR. It is important to note that many papers involved in the study of the causal link between economic growth and energy consumption (even controlling for other variables such as CO₂ emissions) use Granger Causality (GC) as a vehicle to study the causal relationship. For example, Chen, Xie and Liao (2018) implement the panel Granger causality analysis proposed by Emirmahmutoglu and Kose (2011) to examine the causal relationship between energy consumption and energy growth for 29 Chinese provinces. They conclude that there is a unidirectional causal link running from real output to energy use. However, such tests cannot be considered neither a necessary nor a sufficient condition for causality since it does completely characterize the notion of “cause”; see the discussion by Hendry (2004). In contrast, to analyse the causal link between economic growth and energy consumption and further control variables, Rodríguez-Caballero and Ventosa-Santaularia (2017) propose going back to the original ideas of exogeneity embodied in Engle, Hendry and Richard (1983) and study a causal link through the statistical concepts of weak and super exogeneity.

Very recently, Rodríguez-Caballero (2022) proposes a non-stationary panel data model with multi-level cross-sectional dependence to study the long-run relationship between economic growth and energy consumption in 69 countries. In his model, the commonality between countries is driven by unobservable common factors, which can gather relevant variables affecting all countries such as international shocks generating financial crisis, the sharp decrease in oil prices, or by climate conditions.

Second, in the context of single-equation time series, Shahbaz et al. (2018) propose dealing with potential non-linearities in the nexus between energy use and economic growth by using the quantile-on-quantile (QoQ) methodology recently proposed by Sim and Zhou (2015). QoQ combines quantile regression and non-parametric estimation to regress a quantile of GDP on a quantile of energy consumption and vice-versa. After fitting QoQ to top ten energy-consumption countries, they find a weak effect of economic growth on energy consumption for lower quantiles in some countries and for upper quantiles in others. Furthermore, the effect of energy consumption on energy growth is, in general, even weaker. However, it is important to point out that, although the QoQ is an interesting way of dealing with non-linearity, Shahbaz et al. (2018) do not take into account the non-stationarity of both energy consumption and economic growth and, consequently, their results may be spurious.

Finally, note that climate change can alter energy generation potentials and needs, adding to the route that energy-growth conundrums could follow; see Figure 1. Naturally, climate change could excessively increase the electricity demand for cooling during heat waves. New proposals based on panel data take into account non-linearities as, for example, the panel quantile regression proposed by Zhu et al. (2016)) or the nonlinear panel model proposed by Wang and Wang (2020).
literature is emerging intending to analyse the direct impact of climate change on energy and vice versa, through renewable energy; see, for example, Cronin, Anandarajah and Dessens (2018), Quaschning (2019), Van Ruijven, de Cian and Wing (2019) and Olabi and Abdelkareem (2022). A review of climate change impacts on renewable energies is provided by Solaun and Cerdá (2019).

4 Economic activity and pollution

GHG emissions are a major cause of climate change. They have a strong relationship with energy consumption, which, as described in the previous section, is closely related with economic activity. Since the seminal works of Selden and Song (1994), Grossman and Krueger (1995) and Holtz-Eakin and Selden (1995), the econometric analysis of the relationship between economic activity and pollution has been the focus of an extremely large literature; see the relatively recent surveys by Al-Mulali, Saboori and Ozturk (2015), Moutinho, Varum and Madaleno (2017), Stern (2017), Shahbaz and Sinha (2019), Waheed, Sarwar and Wei (2019), Purcel (2020) and Ul Husnain, Hider and Khan (2021), and the references therein. The number of works is so large that trying to survey this literature seems an impossible mission. Consequently, in this section, we just summarize some of the main findings of the literature on the nexus between economic activity and pollution. Most works assume that the former variable is exogenous and represent the EKC by the following static (long-run) model

\[ e_{it} = \beta_0 i + \beta_1 i y_{it} + \beta_2 i y_{it}^2 + \beta_3 i y_{it}^3 + u_{it}, \tag{1} \]

where \( e_{it} \) represents the logarithmic transformation of the environmental quality proxy in country \( i \) at time \( t \), and \( y_{it} \) is the corresponding logarithmic transformation of the economic measure. For each \( i \), \( u_{it} \) is assumed to be an independent white noise with variance \( \sigma^2_{u_i} \). If \( \beta_{1i} > 0, \beta_{2i} < 0 \) and \( \beta_{3i} = 0 \), then (1) represents an inverted-U shape in the relationship between pollutants and economic activity. Furthermore, when \( \beta_{3i} \neq 0 \), the relationship between pollution and per capita GDP has an N-shaped relationship (which can be inverted depending on the sign of the parameters in (1)); see Moosa (2017) for an interesting discussion on the shape of the relationship between pollution and GDP. For a given country \( i \), if \( \beta_{3i} = 0 \), the turning point of the per capita GDP in which the environmental quality measure, \( e_{it} \), begins to improve is \( y_i^* = -\frac{\beta_1 i}{2\beta_2 i} \).

Next, we describe the variables that have been usually chosen to represent environmental quality and economic activity as well as the methods implemented to estimate model (1).

4.1 Variables to measure pollution and economic activity

With respect to the variables used to measure pollution, empirical studies of the EKC consider at least one of eight possible broad types of pollution, namely, air pollution, water pollution, land...
pollution, radioactive pollution, noise pollution, light pollution, thermal pollution and ocean or marine pollution. However, one of the most enduring sources of GW, and consequently of climate change, is the burning of fossil or carbon-based fuels as coal, oil and natural gas, which leads to emissions of GHG, with carbon dioxide (CO\textsubscript{2}) being among the most important. Consequently, the analysis of the effects of economic growth on the environment has been mainly done considering air pollution, and more specifically CO\textsubscript{2} emissions, which remain accumulated in the atmosphere for a long time; see, for instance, the references listed in Tables 1 and 2 in which we summarize empirical results on the EKC and Al-Mulali, Saboori and Ozturk (2015) and Ul Husnain, Haider and Khan (2021) for similar tables. Very few empirical investigations about the EKC have been done using sulphur dioxide (SO\textsubscript{2}) emissions or other air pollutants; see, for example, Stern and Common (2001) and Taguchi (2013). Finally, it is important to mention that, in a recent study, Altintas and Kassouri (2020) consider two indicators of environmental degradation, namely, ecological footprint and CO\textsubscript{2} emissions, and find evidence for the sensitivity of the EKC hypothesis to the type of environmental degradation proxy used and conclude about the relevance of the ecological footprint as an appropriate environmental tool. Gill et al. (2017) and Rao and Yan (2020) also point out that the EKC has only been proved for a subset of pollutant indicators. Recently, Haider, Bashir and Ul Husnain (2020) find strong support for the EKC using NO\textsubscript{2} as pollutant and Pandey and Mishra (2021) obtain a similar result using SO\textsubscript{2} and NO\textsubscript{2} considering 21 states of India.

With respect to the variables used to represent economic activity, most works usually consider per capita income or Gross Domestic Product (GDP), although alternative explanatory variables have also been added to explain pollution. For example, Pablo-Romero, Cruz and Barata (2017) test the EKC using transport as a proxy for economic activity. Furthermore, according to the Pollutant Heaven Hypothesis, developed countries look for the cheapest options in terms of resources and labour and often set up factories abroad. In this case, even if their economic activity increases, they may not have increases in their pollutant emissions. However, the developing countries that recieve the factories may show larger emissions without having larger GDP. For this reason, many studies of the EKC control for variables related to trade; see, among others, Jebli, Youssef and Ozturk (2016), Tiwary, Shahbaz and Hye (2013), Lau, Choong and Eng (2014), Onafowara and Owoye (2014), Dogan and Turkekul (2016), Anser et al. (2020), Adebayo, Awosusi and Adesola (2020), Khan and Eggoh (2021) and Bidi and Jamil (2021), for recent references.

Alternatively, many works explore the link between the economy and CO\textsubscript{2} emissions through the energy channel; see, inter alia, Ang (2007), Acaravci and Ozturk (2010), Shahbaz, Mutascu and Azim (2013), Smiech and Papiez (2014), Acheampong (2018), Chen, Wang and Zhong

\footnote{Dinda (2004) points out that EKC cannot be generalized for all types of pollutants, being not valid, for example, for industrial water pollution or toxic pollution.}
(2019), Diaz et al. (2019), Usman, Larember and Olanipekun (2019), Munir, Lean and Smyth (2020), Hasmi et al. (2021), Altintas and Kassouri (2020), Saidi and Omri (2020), Khattak et al. (2020), Erdogan (2020), Raza, Shah and Khan (2020) and Cheikh, Zaied and Chevallier (2021). Other authors have also controlled for other variables as Hailemariam, Dzhumashev and Shahbaz (2020), who consider the effect of income inequality, Balaguer and Cantavella (2016), who add fuel prices as an indicator of fuel energy consumption, Hasmi et al. (2020), who consider the effect of geopolitical risk or Usman, Larember and Olanipekun (2019), who consider the effect of democratic regime. Finally, Hipólito Leal and Cardoso Marques (2020) analyse the repercussion of globalization on the environment.

The potential set of variables that drive emissions of CO$_2$ is very large. Furthermore, it is also important to analyse the functional form in which these variables enter the EKC; see the very extensive analysis by Auffhammer and Steinhauser (2012), who compare over 27000 specifications arising from possible permutation of a very limited set of explanatory variables.

Finally, there are authors considering variables that are not properly economic although they are closely related. For example, Wang et al. (2021) analyse the long- and short-run relationships between urbanization and three carbon emission dimensions in OECD high income countries. They conclude that developed countries tend to have the same negative impact of urbanization on carbon emissions, although there are differences on the endowments of different countries; see also Adebayo and Odugbesan (2021), who also consider the role of urbanization on CO$_2$ emissions. Chen, Huang and Lui (2019) consider the effects of emissions on environmental awareness. Beyene and Kotosz (2020) and Aziz et al. (2021) analyse the effect of globalization on CO$_2$ emissions and Anset et al (2020), Aller et al (2020), Lee, Chen and Wu (in press) and Nosheen et al (2021) emphasize the effect of tourism on pollutant emissions.

4.2 Estimators of the EKC

In this subsection, we survey different procedures implemented to estimate the EKC, clasifying them into panel, time series and regression estimators.

4.2.1 Panel data

Estimation of model (1) is usually carried out using panel data and the fixed effects estimator; see, for example, the meta analysis carried out by Sarkodie and Strezov (2019) on the estimation of the EKC. Very recently, instead of the fixed effects estimator, Aller, Ducot and Grechyna (2021) propose using Bayesian Model Averaging and Cluster-LASSO to estimate all possible combinations of the regressors, taking afterwards a weighted average over the candidate models. They conclude that CO$_2$ emissions in high- and medium-income economies are affected by the share of industry in GDP, political polarization and tourism, while, in low-income countries, they
are positively affected by foreign direct investment, the level of democracy and corruption. It is important to point out that the relationship in model (1) may depend on the level of economic development of the countries included in the analysis with low developed countries in the first increasing part of the inverted-U. To account for this heterogeneity, Stern and Common (2001) and Galeotti, Lanza and Pauli (2006) consider specific intercepts and found support of the EKC when applied to a panel with a large number of countries. Moutinho, Varum and Madaleno (2017) also use panel data on different sectors to investigate the EKC in Portuguese and Spanish economic activity sectors.

Estimates of model (1) could be affected by simultaneity biases resulting from the fact that pollutants could also cause economic activity; see the surveys by Tiba and Omri (2017) and Waheed, Sarwar and Wei (2019) on the causal directions between economic growth, energy and pollution. To control for the potential endogeneity of growth, Lin and Liscow (2013) propose an instrumental variable (IV) estimator, which is implemented to a panel of OECD and non-OECD countries. Using several measures of water pollution as pollutants, and controlling for the indices on political rights and civil liberties from Freedom House, Lin and Liscow (2013) find empirical support of the EKC hypothesis and conclude that controlling for variables representing social issues is important in this relationship.

Due to the strong persistence often observed in the variables involved in the estimation of the EKC, panel models have been estimated using procedures designed to deal with this characteristic. Acheampong (2018) proposes an integrated framework to analyse Granger causality between economic growth, energy consumption and carbon emissions, based on a panel Vector Autoregression model estimated using the system-GMM of Blundell and Bond (1998) that takes into account strong persistence. In a very recent work, Munir, Lean and Smyth (2020) propose testing for Granger causality among CO$_2$ emissions, energy consumption and economic growth using the estimator of Westerlund (2007), taking into account not only cointegration but also heterogeneity and cross-sectional dependence. They show that panel unit root and cointegration tests that do not accommodate cross-sectional dependence give mixed and inconclusive results. After implementing the model to the five main countries of the Association of Southeaster Asian Nations (ASEAN-5) over the period 1980-2016, they conclude that in three countries, Indonesia, Malaysia and Thailand, there is unidirectional causation running from GDP to energy consumption. In these countries, energy conservation is unlikely to have much impact on economic growth. For four countries, Malaysia, Philippines, Singapore and Thailand, they find unidirectional causality running from GDP to CO$_2$. They also conclude that three of these countries, Malaysia, Philippines and Thailand, have not yet reached the income turning point suggested by the EKC. For these countries, economic growth can be expected to adversely affect the environment until the turning point is reached. The Westerlund’s (2007) panel cointegration method has also been used in Zafar et al. (2020) to verify long-run relationship between CO$_2$
emissions and GDP, controlling for energy consumption, urban population and industrialization in a panel regression model for 46 countries covering the period 1980-2017. Another application of this methodology can be found in Altintas and Kassouri (2020), who analysed the EKC relationship using a heterogeneous panel for 14 European countries over the period 1990-2014. Alternatively, several authors have implemented the cointegration tests for panel data proposed by Pedroni (2004); see, for example, Erdogan (2020), Lazar et al. (2019), Saidi and Omri (2020), Adebayo, Awosusi and Adesola (2020) and Dogan and Inglesi-Lotz (2020).

Finally, several authors analyse the EKC hypothesis using the panel extension of the Autoregressive Distributed Lag (ARDL) procedure of Pesaran, Shin and Smith (1999, 2001)[1], see Hanif et al. (2019), who support the EKC for a panel of 15 Asian developing countries, observed over the period 1990 - 2013 and Waqih et al. (2019), who also find support for the EKC in a panel of four countries of the South Asian Association for Regional Cooperation (SAARC), observed during the period 1986-2014 based on combining the ARDL approach with the Full Modified OLS.

Given that the channel of the relationship between economic activity and pollution is energy consumption, Marrero (2010) studies the simultaneous relationship between emissions, growth and energy based on a dynamic panel of 24 European countries observed from 1990 to 2006. He concludes that the elasticity between aggregate energy consumption and emissions is significantly greater than zero and below unity. However, he does not find evidence in favour of the EKC hypothesis.

In the context of panel data, several authors have estimated model (1) using procedures from spatial econometrics; see, for example, Kang, Zhai and Yang (2016), who consider a panel of Chinese provinces over the period 1997-2012 and find an inverted-N shaped relationship and Hao et al. (2016), who consider coal consumption as the endogenous variable and find a bell shape relationship. Li and Wang (2019) also apply spatial econometrics to a panel of 30 Chinese provinces. They use carbon intensity of human well-being as the pollutant measure and find an inverted-N shaped relationship.

4.2.2 Time series models

Time series models are also very popular in the context of estimation of the EKC for a given country or territory. A large part of works using time series is based on single-equation models while some of them use multi-equation models; see the selected works reported in Table 2.

As mentioned above, given that the EKC is a long-run phenomena, model (1) could be estimated with the variables in levels after taking into account possible cointegration relationships.

---

[1] Shin, Yu and Greenwood-Nimmo (2014) propose non-linear ARDL tests. More recently, McNown, Sam and Goh (2018) propose a bootstrap correction of the ARDL tests with better properties.
Table 1: Summary of selected works testing the EKC using panel data methods.

| Authors                  | Dependent Variable | Independent Variables                              | Countries               | Sample                | Conclusion                              | Method                                      |
|--------------------------|--------------------|-----------------------------------------------------|-------------------------|-----------------------|-----------------------------------------|---------------------------------------------|
| Adebayo et al. (2020)    | CO$_2$             | EG, Energy use, trade, urbanization                | MINT economies          | 1980 - 2018           | Cointegration CO$_2$ and determinants   | Panel Cointegration, ARDL-MMG               |
| Altintas and Kassemi (2020) | Ecological Footprint, CO$_2$ | Renewable energy, Fossil fuel consumption | 14 European Countries | 1990 - 2014           | Depend                                  | Heterogenous panel                          |
| Anser et al. (2020)      | CO$_2$             | International tourism, social distribution, FDI     | G7 countries            | 1995 - 2015           | Support EKC, PHH and REH                | Panel random Effect and Panel               |
| Beyene and Kottou (2020) | CO$_2$             | Globalization, FDI, Pop. density, Pol.stability     | 12 East African countries | 1990 - 2013           | Support EKC in the short run            | Pedroni's test, Pooled Mean Group          |
| Cai et al. (2020)        | Different pollutants | EG                                                  | China                    | 2003 - 2017           | Different types of EKC                  | Locally weighted smoothed                   |
| Dogan and Inglesi-Lotz (2020) | CO$_2$             | EG, Economic Structure                              | 7 European countries    | 1980 - 2014           | Support EKC                            | Panel UIR, Panel CI tests, FMOLS           |
| Erdogan (2020)           | Ecological Footprint, CO$_2$ | Renewable energy, fossil fuel, consumption | Europe                  | 1990 - 2014           | Sensitivity of the EKC to the pollutant | Cross-section and slope heterogeneity, CI   |
| Haider et al. (2020)     | NO$_2$             | Agricultural land use, exports, EC                  | Developed, developing countries | 1980 - 2012           | Support EKC                            | Pooled mean group approach                  |
| Jiang et al. (2020)      | Air pollution      | EG                                                  | China and South Korea   | 2003 - 2017           | Support EKC                            | Panel data                                 |
| Khattak et al. (2020)    | CO$_2$             | Innovation, renewable energy consumption            | BRICS countries         | 1980 - 2016           | Support EKC                            | Johansen - Fisher, Kao's CI tests          |
| Leal and Marques (2020)  | CO$_2$             | Degree of Globalization                             | 20 OECD countries       | 1990 - 2016           | Support EKC                            | Driskoll - Krazy estimator                 |
| Munir et al. (2020)      | CO$_2$             | Energy consumption, EG                              | ASEAN 5                 | 1980 - 2016           | Inconclusive results                    | Panel VAR                                  |
| Raza et al. (2020)       | Residential energy | EG, renewable energy, development                   | NEXT11 and BRICS countries | 1990 - 2015           | Support EKC                            | FMOLS, Pedroni test, Westerlung (2007)     |
| Saidi and Ouari (2020)   | CO$_2$             | Renewable energy, EG                                | 15 major renewable energy consuming | 1990 - 2014           | Support EKC in the short run            | Pedroni’s test, FMDLS                      |
| Aladin et al. (2021)     | CO$_2$             | EG, Economic freedom                               | BRICS countries         | 1995 - 2018           | Support EKC in the long-run             | Pooled mean Group estimation               |
| Aller et al. (2021)      | CO$_2$             | % in GDP, Pol. polarization, Tourism, FDI           | High and medium income countries | 1995 - 2014           | Support EKC                            | BMA / and Cluster-LASSO                    |
| Aziz et al. (2021)       | CO$_2$             | Nat. resources, renewable energy and globalization | MINT countries          | 1995 - 2018           | Not Support highest quantiles           | Pedroni’s test, FMDLS, DOLS, FE-DOLS       |
| Baksh et al. (2021)      | CO$_2$             | Foreign investment inflows                          | 40 Asian countries      | 1996 - 2016           | FDI positive impact on CO2              | Panel data                                 |
| Boli and Jamil (2021)    | GDP, Trade, FDI, financial and institutional Quality | GDP, Trade, FDI, financial and institutional Quality | Latin American, Caribbean, sub-Saharan | 2000 - 2018           | Support EKC except for sub-Saharan      | Panel data econometric models              |
| Cheikh et al. (2021)     | CO$_2$             | Energy consumption, GDP Growth                      | MENA regions            | 1980 - 2015           | Support EKC                            | Panel smooth transition modeling           |
| Khan and Egoh (2021)     | CO$_2$             | EG, trade, financial development, FDI               | 146 countries           | 1990 - 2016           | Support EKC                            | Smooth threshold Regression model          |
| Pandey and Mishra (2021) | SO$_2$ and NO$_2$  | Net state domestic product, social expenditure     | 21 Indian states        | 2001 - 2018           | N-shaped EKC                           | Panel unit root, cointegration, DOLS       |
| Wang et al. (2021)       | CO$_2$             | Urbanization                                        | OECD countries          | 1960 - 2014           | Support EKC                            | Dynamic Panel ARDL model                   |
| Beyene (in press)        | Environment quality | Decomposed growth                                   | 108 countries           | 2000 - 2018           | Not support EKC                        | Panel mean and quantile regressions        |
| Lee et al. (2022)        | 6 ecological footprints | Tourism development                                 | 99 countries            | 2000 - 2017           | Support EKC                            | Quantile regression approach              |
| Zhong (2022)             | SO$_2$ and CO$_2$  | Income growth and inequality, industrial structure  | China                   | 2011 - 2015           | Support EKC                            | Panel data methods                        |
between $e_{it}$ and $y_{it}$; see, for example, Waheed, Sarwar and Wei (2019), who survey several papers using Johansen cointegration tests and Umar et al. (2020), who employ the combined cointegration and wavelet coherence approaches over the period 1971-2018 to explain the long run and causal effects of innovation, financial development and transportation infrastructure on CO$_2$ emissions in China. Alternatively, a very popular way of dealing with cointegration in the context of testing the EKC hypothesis is based on the ARDL bounds test of Pesaran, Shin and Smith (2001), which allows the possibility of including variables with different order of integration ($I(1)$ or $I(0)$), allowing for long- and short-run relationships and potential bi-directional relations; see the references reported in Table 2 for several examples.

However, it is important to note that the possibility of non-stationarity of the variables involved in the estimation of the EKC opens the door to the estimation of spurious relations; see Wagner (2008), who shows that most studies estimating EKC gave spurious results. For example, Paruolo, Murphy and Janssens-Maenhout (2005) analyze the relation between income and emissions in all countries in the world over the period 1970-2008 based on a VEC model. They conclude that income and emissions seem to be driven by unrelated random walks plus drift.

Furthermore, it is important to point out that standard cointegration procedures may face problems when implemented in a non-linear context as that encountered when dealing with the EKC. Müller-Fürstenberger and Wagner (2007) show that, if $\ln(y_{it})$, where $y_{it}$, is the per capita GDP in region $i$ at time $t$, is a unit root process, its square is not an integrated process of order 1. Therefore, some previous findings obtained using standard unit-root and cointegration techniques both in panel or time series data may be questionable; see Perman and Stern (2003) for a discussion.

Recently, within the context of time-series regressions, some authors have shifted the focus away from the regression in levels in (1) to factor-augmented regressions in which the growth rate of GHG emissions in a given country is modelled as a function of factors extracted from a large (stationary) system of economic variables. Fosten (2019) fits the following diffusion index model to analyse the effects of economic activity on CO$_2$ emissions

$$\varepsilon_t = \alpha + \delta' \tilde{f}_t + \nu_t$$  \hspace{1cm} (2)

where $\varepsilon_t = \Delta \log E_t$ with $E_t$ being yearly CO$_2$ emissions, $\tilde{f}_t$ is the $r \times 1$ vector of Principal Component (PC) factors extracted from a large set $X_t$ of macroeconomic variables and $\nu_t$ is assumed

---

8Note that short-run relations between emissions and the economy are also of interest because some policy instruments, such as emissions trading schemes, use economic incentives to control emissions over a short time spam, with the Regional Greenhouse Gas Initiative in US being an example.

9Fosten (2019) also considers emissions by source and non-linear specifications including polynomials of the factors.
to be a white noise. Finally, $\alpha$ and $\delta = (\delta_1, ..., \delta_r)'$ are parameters. Fosten (2019) also carries out a multi-resolution analysis of $y_t$ and $\tilde{f}_t$ based on discrete wavelet transformations, which decomposes the original monthly series into $J$ different time scales plus a smooth term. After extracting one single factor from 10 selected variables of the data base described by McCracken and Ng (2016) and based on seasonally adjusted monthly data for U.S. observed from April 1978 to December 2018, Fosten (2019) concludes that emissions are not linked to economic activity in the short-run but there are strong linkages when looking at medium-run cycles of around one to three years.

Similarly, Mamipur, Yahoo and Jalalvandi (2019) extract factors from Iranian systems of “social”, “economic” and “environmental” variables and fit the following VAR model to the first differenced factors allowing for bi-directionality in the relations between the three systems

$$\triangle \tilde{F}_t = \Phi \triangle \tilde{F}_{t-1} + a_t$$

where $\tilde{F}_t = (\tilde{f}_{1t}, \tilde{f}_{2t}, \tilde{f}_{3t})'$ is the vector of PC factors extracted from each of the systems.

In the same fashion, Bennedsen, Hillebrand and Koopman (2021) propose the following collapsed Structural Augmented Dynamic Factor Model (SADFM) for US CO$_2$ emissions

$$\begin{bmatrix}
\varepsilon_t \\
x^*_t \\
\tilde{f}_t
\end{bmatrix} =
\begin{bmatrix}
\alpha \\
0 \\
0
\end{bmatrix} +
\begin{bmatrix}
\delta' + \beta' \Lambda^* \\
\Lambda^* \\
I_r
\end{bmatrix}
\begin{bmatrix}
f_t \\
z_t \\
e_t
\end{bmatrix}
+ 
\begin{bmatrix}
u_t \\
v_t \\
e_t
\end{bmatrix}$$

$$f_{t+1} = \Phi f_t + \eta_{t+1}$$

where $\varepsilon_t = \triangle e_t$ with $e_t$ being the log-transformation of per capita CO$_2$ emissions observed yearly from 1960 to 2017, $x^*_t$ is a subvector of $X_t$, with $X_t$ containing the economic variables of special relevance, and $\tilde{f}_t$ is defined as in (2). Finally, $z_t$ are dummy variables that represent outliers; see Bennedsen, Hillebrand and Koopman (2021) for details about the estimation of the parameters, which is related with the two-step iterative procedure of Doz, Giannone and Reichlin (2012). They also consider a model for CO$_2$ emission rates depending on IP variables with time-varying parameters. In an out-of-sample exercise with forecast horizon $h = 1$, their results favour the SADFM with $\delta = 0$ over competing alternatives, and forecast decreases in emissions for 2018.

Wavelet analysis has also been implemented by Jammazi and Aloui (2015), who analyse the relationship between energy consumption and economic growth using wavelet windowed cross-correlation for six oil exporting countries from the Gulf Cooperation Council (GCC) region, finding a bi-directional relationship. Kalmaz and Kirikkaleli (2019) also use a wavelet coherence approach to analyse the causal effects between CO$_2$ emissions and energy consumption, trade openness, urbanization and economic growth in Turkey. Finally, another study using wavelet techniques applied to US data is Raza, Shah and Sahrif (2019), who analyse several wavelet measures and conclude that in the short, medium and long-run energy consumption has positive influence over CO$_2$ emissions. They also find unidirectional causality running from energy consumption to CO$_2$ emissions.
Wagner, Grabarczyk and Hong (2020) deal with estimation and testing of the EKC for CO$_2$ emissions. The latter postulates an inverted U-shaped relationship between the level of economic development and CO$_2$ emissions, which in a time series setup implies a polynomial cointegration relationship between the emissions and the log of per capita gross domestic product. Typically, time series panels with small cross-sectional dimension for a limited number of countries are available, and it is quite natural to consider the country-specific EKCs as a system of seemingly unrelated relationships, including deterministic variables, integrated processes, and integer powers of integrated processes as explanatory variables. The authors develop two fully modified ordinary least squares type estimators for systems of seemingly unrelated cointegrating polynomial regressions, which account for serial correlation and for the endogeneity resulting from the existence of a cointegrating relationship. The paper derives the limiting distribution of the two estimators, in terms of a zero mean Gaussian mixture, and asymptotically chi-square Wald tests of linear restrictions, allowing to test for various forms of pooling. Poolability leads to estimation efficiency. Monte Carlo simulations illustrate the finite sample performance of the estimators and the tests. The empirical application considers a panel of 19 industrialized countries for the period 1870–2013 and finds evidence for quadratic cointegrating EKCs for a subset of six countries composed of Austria, Belgium, Finland, the Netherlands, Switzerland and the United Kingdom. The specific form of the EKC differs across these countries, but some group-wise pooling is supported by the tests, leading to sizeable parsimony and greater estimation efficiency. On the contrary, global pooling is strongly rejected.

4.2.3 Regression models

Due to the reduced sample and the heterogeneity of the countries included in the analysis, there are not so many studies using cross-sectional data as those using panel data or time series. For example, Magnani (2001) considers 152 countries in 1970, 1980 and 1990 and analyses the EKC relationship considering three pollutants (CO$_2$, SO$_2$ and nitrous oxide emissions), fitting model (1) in each of the three years. She finds different results depending on the degree of development of the economies. Similar analysis is done in Hill and Magnani (2002), using a sample of 156 countries and the same three previous pollutants. More recently, Chow and Li (2014) estimate the EKC relationship using 132 countries, considering a sample from 1992 to 2004. They estimate the EKC for each year separately and find strong support of the EKC. Finally, Atwi et al. (2018) consider 182 countries and a sample from 1992 to 2011. They estimate the EKC relationship considering both a panel approach and a cross-section approach estimating model (1) for each

$^{11}$Note that all variables in the SADFM are previously transformed to stationarity and, consequently, the diffusion index and SADFM models capture short-run relationships.
year. They find support of the EKC when using panel data approach but not when considering cross-sectional regressions.

4.3 Main conclusions

In general, the results described above are mixed and inconclusive with many open econometric issues; see, for example, the survey by Ul Husnain, Haider and Khan (2021). The empirical studies described in this section produce results that differ significantly depending on the period, the set of countries, the variables included, or the method of analysis. In general, regardless of the estimator implemented, most studies are based on annual data that is observed over a relatively short span of time. Recently, many works estimate the EKC using single-equation time series models and the ARDL methodology. Consequently, one could expect weak results when dealing with non-stationary data. Upon the basis of the studies reported in Tables 1 and 2 we can conclude that there is not a strong support to the EKC. Evidence of an EKC is weak when we look at the worldwide level.

Finally, it is important to remark that most models in the literature focus on in-sample predictions of per capita CO₂ emissions. However, Auffhammer and Steinhauser (2012) argue that the interest is on out-of-sample forecasting of aggregate emissions. They argue the need for a shift in the emission forecasting literature toward criteria based on out-of-sample ability to predict total emissions versus the standard approach of selecting per capita models based on in-sample fit.

5 Economic activity and climate change

In this section, we survey the contributions looking at the (potential) effects of climate change on the economy and, in particular, on GDP. Several recent reviews are available. Tol (2009, 2014) describes the vast amount of research devoted to this topic. Focusing on GDP, he summarizes the results of several studies that use different methodologies to estimate the welfare cost (as percentage of GDP) of an increase on average temperature, where the main conclusions are that, on average, the effect is negative, being more pronounced in countries in Africa, Asia and South America. However, this effect is found to be positive for some European countries. Dell, Jones and Olken (2014) revise the literature of the effects of different climate variables (temperatures, precipitation and wind-storms) over economic outcomes, pointing out how the temporal dimension (exploited using panel data models) helps in identifying their effects. Apart from economic growth, Dell, Jones and Olken (2014) also review the effect on different outcomes as energy, labour productivity, industrial output and agriculture, among others. Burke, Hsiang and Miguel (2015) review the literature on the impacts of climate change on agricultural productivity and economic growth. The survey by Hsiang (2016) points out the main econometric issues in order
Table 2: Summary of selected works testing the EKC using time series methods.

| Authors                  | Dependent Variable | Independent Variables | Countries                | Sample       | Conclusion                                                                 | Method                        |
|--------------------------|--------------------|-----------------------|--------------------------|--------------|----------------------------------------------------------------------------|-------------------------------|
| Adejumo (2020)           | CO₂                | EG                    | Nigeria                  | 1970 - 2014  | Bidirectional relation environment and EG                                      | ARDL                          |
| Koondhar et al. (2020)   | CO₂, NO₂           | Agricultural GDP, fertilizers, energy cons., grains | China                    | 1998 - 2018  | Support EKC                                                                | ARDL                          |
| Pata and Aydin (2020)    | CO₂                | Hydropower energy cons., EG, 6 hydropower cons. | 6 hydropower cons.       | 1965 - 2016  | Not support EKC                                                            | Fourier bootstrapp ARDL       |
| Rahman (2020)            | Enc. cons., CO₂    | EG, Pop. density, trade | India                    | 1971 - 2011  | Different effects of EG on energy and CO₂                                    | ARDL                          |
| Rahman and Wu (2020)     | CO₂                | Renew. Energy Cons., EG, trade, urbanization | Australia and Canada     | 1960 - 2015  | Different results LR and SR for each country                                  | ARDL, VECM                    |
| Rao and Yan (2020)       | Different pollutants| EG                    | Wuhan (China)            | 1996 - 2015  | Not support EKC for all pollutants                                          | LABS/LASSO model              |
| Rasouli et al. (2020)    | CO₂                | Enc. cons., EG, financial development | India                    | 1971 - 2014  | Validate conventional EKC                                                   | ARDL, VECM                    |
| Sethi et al. (2020)      | CO₂                | Globalization, EG, Financial development | India                    | 1980 - 2015  | Financial development not contribute to CO₂                                  | ARDL, VECM                    |
| Zhu and Ben-Salah (2020) | CO₂                | Pop., Affluence and Technology, Urbanization, Energy Cons. | Gulf cooperation Council | 1980 - 2017  | Determinants of CO₂/ volatility of EKC                                      | PMG-ARDL approach             |
| Mehmood (2021)           | CO₂                | Globalization         | Singapore                 | 1970 - 2014  | Support EKC in Singapore                                                     | ARDL                          |
| Mele and Magazzino (2021)| PM₂₅, CO₂, NO₂      | EG                    | India                    | 1980 - 2018  | Unidirectional causality EG and pollution                                    | Yamamoto test                 |
| Marshid (2021)           | CO₂, NO₂, CH₄      | LPG cons. FDI, trade  | 6 Asian Economies         | 1980 - 2016  | Support EKC India, Bangladesh, Sri Lanka, Bhutan                            | ARDL                          |
| Naseem et al. (2021)     | GDP per capita     | Energy and non-Energy factors on UC | Pakistan                 | 1985 - 2018  | Substitution of factors to improve EG                                       | Ridge Regression              |
| Oguna et al. (2021)      | CO₂                | Income pc increases, Income pc decreases | US                      | 1990.01 - 2010 | EKC supported for decomposed model                                           | ARDL                          |
| Patiolo et al. (2021)    | CO₂                | Sectoral decomposition of GDP | Colombia                  | 1971 - 2017  | Additive and Multiplicative decomposition                                  | DSGE models                   |
| Rahman et al. (2021)     | Economic progress  | Urbanization, energy use, fossil energy and CO₂ | China                    | 1975 - 2017  | Asymmetric influence                                                        | Non linear ARDL               |
| Sahabul et al. (2021)    | CO₂                | Income pc, energy use, trade, oil price | India                    | 1980 - 2019  | Asymmetric long term impact on CO₂                                          | Non linear ARDL               |
| Sokara et al. (2021)     | Ecological footprint| EG, urbanization, FDI, trade | Nigeria                  | 1977 - 2016  | Only EG contributes to diminish environment                                  | ARDL                          |
| Villanthenkodath et al. (2021)| CO₂ | EG and its components | India                    | 1971 - 2014  | Conventional EKC hypothesis does not hold                                    | ARDL                          |
| Xiang and Xu (2021)      | GDP annual growth  | Electricity prod. from different fuels, CO₂ emissions | China                    | 1995 - 2015  | Rem. ene prod contributes to increase in GDP                                 | ARDL                          |
| Can Gong et al. (2022)   | CO₂                | Volatility of EG      | Turkey                    | 1980 - 2015  | Support EKC                                                                 | ARDL                          |
| Hashmi et al. (2022)     | CO₂                | GDP, Geopolitical risk and energy | Global                   | 1970 - 2015  | Support EKC                                                                 | ARDL                          |
| Killm-Ata and Likhachev (in press) | CO₂ | EG, ene. cons., pop., trade and financial development | Russia                  | 1990 - 2020  | EKC supported                                                                | ARDL                          |
| Liu et al. (2022)        | Ecological footprint| tourism, EG, ene. cons., trade, FDI | Pakistan                 | 1980 - 2017  | EKC depends on the independent variables                                   | ARDL, Bayer and Hanck         |
| Massagany and Budhnoo (in press) | CO₂ | Income, fossil and rene. ene. cons., forest restoration policies | Indonesia              | 1970 - 2017  | EKC supported                                                                | ARDL                          |
| Seri and de Juan (in press) | CO₂ | GDP and other control variables | Latin American countries | 1970 - 2018  | Support EKC depending on country                                             | ARDL, VECM                    |

EG= Economic Growth, FDI=Foreign Direct Investment; Renew Ene: renewable energy; ene. cons. = energy consumption; Pop = population; pc = per capita;
to detect the effects of climate in social and economic outcomes. Hsiang and Kopp (2018) explain the physical science of climate change and presents evidence towards the rise of temperatures being due to human emissions. Finally, Nordhaus (2019) addresses climate change as externalities and describes the policy tools that are used in order to predict the effect of climate change in the economy. In this section, we summarize the main conclusions from these reviews and update them with the most recent contributions to the literature.

5.1 GHG and Global Warming

First, we survey works analysing the relationship between GHG emissions and GW. It is important to note that GW consists of two components: the greenhouse effect and the solar radiation effect, with both working in opposite directions. While an increase in GHG contributes to GW, more pollution causes an increase in aerosols (small particles that reflect and absorb sunlight in the atmosphere), so that less sunlight reaches the Earth. This phenomena is known as global dimming. Note that, in spite of its name, Magnus, Melenberg and Muris (2011) point out that global dimming is primarily a local (or regional) effect. Because of the dimming the Earth becomes cooler: the solar radiation effect. In practice, only the sum of the GHG and the solar radiation effects is observed. Magnus, Melenberg and Muris (2011) gather data from a large number of weather stations around the world for the period 1959–2002 and use dynamic panel data methods to separate both effects. They decompose the estimated temperature change of 0.73°C (averaged over the weather stations) into a greenhouse effect of 1.87°C, a solar radiation effect of −1.09°C, and a small remainder term. Similarly, Phillips, Leirvick and Storelvmo (2020) use dynamic panel data methods to analyse the sensitivity of Earth’s climate to a given increase in atmospheric GHG concentrations. Their analysis is based on spatio-temporal data of annual global surface temperatures, solar radiation and GHG concentrations observed over the last half century to 2010. They conclude that atmospheric aerosol effects masked approximately one-third of the continental warming due to the increasing GHG concentrations over this period; see also Storelvmo et al. (2016) for similar conclusions. Petris and Hendry (2013) also conclude that there is a relationship between CO₂ and temperature supporting the anthropogenic forcing of climate change; see also Petris and Allen (2013), Estrada and Perron (2014), Stock (2019), Castle and Hendry (2020), Kim et al. (2020) and Estrada, Kim and Perron (2021a, 2021b), among many others. Very recently, Chen, Gao and Vahid (in press) use the common features perspective and establish that global temperatures and GHG share a common trend without conditioning on a particular type of trend and considering the possibility of endogeneity.
5.2 Temperatures and economic activity

Many studies analyse the effect of climate change on a particular sector or characteristic of the economy, which in the medium or long-run would affect growth. For instance, many papers focus on the effects of climate change on agriculture (Schlenker and Roberts, 2009, Burke and Emerick, 2016, Iizumi and Ramankutty, 2016, Hsiang et al., 2017 and Gallic and Vermandel, 2020), exports (Jones and Olken, 2010), labour productivity (Seppänen, Fisk and Lei, 2006), energy demand (Auffhammer and Mansur, 2012), health (Deschênes and Greenstone, 2011, and Deryugina et al., 2019), conflict (Miguel, Satyanath and Sergenti, 2004, Hsiang, Burke and Miguel, 2013, Hsiang and Burke, 2014) and crime and aggression (Miguel, 2005), among other outcomes; see also Carleton and Hsiang (2016) for various social and economic impacts of climate.

Earlier studies rely on cross-sectional regressions of several regions or countries observed in a given moment of time. The main finding of these early studies is the negative correlation between temperature and income per capita while there is no so clear connection between precipitation and income; see Dell et al. (2014). Dell, Jones, and Olken (2009) show at country level that in 2000 an increase in 1°C translates into 8.5% lower income per capita. Using municipal data for 12 American countries, they find that this drop is reduced to 1-2% for municipal or province data, pointing out that other differences among countries besides climate change might be also responsible for the larger differences found among countries. However, even controlling for country fixed effects, Nordhaus (2006) concludes that 20% of the income differences between rich industrial regions and Africa can be due to geographical variables, among them, temperature and precipitation.

The same conclusion still holds in panel data analysis, the negative correlation between temperature and income per capita, although sometimes this is only found statistically significant for poorer countries. For instance, in a very well known work, Dell, Jones and Olken (2012), using a panel of countries observed from 1950 to 2003, conclude that there is a strong negative relationship between economic growth and warmer-than-average temperatures in poor countries while in rich countries this relationship is not significant. They also conclude that the effect of an increase of 1°C in annual temperature reduces income per capita growth rate by 1.4%. Hsiang (2010) finds a more negative effect for Caribbean countries, with national output falling by 2.5%. Moreover, when looking at temperature shocks, the effect turns out to be statistically significant only in the hottest season. However, some authors also find a negative effect of warm temperature on economic growth in rich countries. Burke, Hsiang and Miguel (2015) unify the seemingly contradictory results by accounting for non-linearity. They show that overall economic productivity is non-linear in temperature for all countries considered, with productivity picking at an annual average temperature of 13°C and declining strongly at higher temperatures. In spite of these results, there is no agreement in the literature on how the relation between GDP
and temperature should be modelled. Newell, Prest and Sexton (2021) estimate more than 800 models!, depending on whether the effect of the temperature is linear or quadratic, GDP should be considered in levels or growth rates and the nature of some additional terms (trend, country fixed effects, time fixed effects, interaction fixed effects) to be included in the model, with mixed results in the outcomes pointing out the great uncertainty regarding model selection. Moreover, in an out of sample forecasting exercise, the effect of projections of unmitigated warming on GDP by 2100 also ranges from negative to positive depending on the model.

As regards precipitation, the conclusion is even less clear. Dell, Jones and Olken (2012) conclude that fluctuations in mean precipitation do not affect income per capita growth rate. However, Barrios, Bertinelli and Strobl (2010) found that, using standardized variables (the so-called weather anomalies) to account for climate fluctuations, higher rainfall is associated with higher growth rates in poor countries but not in rich ones; see, also, the literature review in their paper that suggests the inconclusive results regarding the effects of precipitation on growth. The reasons might be the type of precipitation variable used, the additional regressors or control variables introduced in the analysis and the sample used.

Recently, Kahn et al. (2021) study the long-term impact of climate change on economic activity across countries using a panel model in which productivity is affected by deviations of temperature and precipitations from their long-term moving average historical norms. They analyse a panel of 174 countries observed annually from 1964 to 2014 and estimate the parameters using the half-panel jacknife fixed effects estimator of Chudick, Pesaran and Yang (2018), which allows to deal with biases due to temperature only being weakly exogenous. Also they allow for dynamics and feedback effects in the interconnections of climatic and macroeconomic variables, distinguishing between level and growth effects. They conclude that per-capita real output growth is adversely affected by persistent changes in temperature above and below its historical norm, but they do not obtain any statistically significant effect for changes in precipitation. Their empirical findings pertain to poor or rich, and hot or cold countries alike. However, the effects vary significantly across countries. One of the reasons that cold countries are also affected by climate change is the faster pace with which temperatures are rising in these regions when compared with that in hot countries. Also, the marginal effects of weather shocks are larger in low-income countries because they have lower capacity to deal with the consequences of climate change.

Another branch of the literature with estimations relating climate variables and GDP growth is when climate variables are used as instruments of growth in first stage estimations using instrumental variables. Within this type of estimations, we also find mixed evidence of the relation between precipitations and economic growth. For instance, Miguel, Satayanath and Sergenti (2004) and Miguel and Satyanath (2011) found that variations in precipitations are positively related to GDP growth rate in panel studies although the relation seems to be weakening with
Agreement between precipitation and per capita income growth. In all these estimations the $R^2$ is quite low.

In the context of time series regressions, evidence for common breaks in temperature and radiative forcing could be consistent with the attribution of climate change to economic activity; see the editorial by Hillebrand, Petris and Proietti (2020).

6 Economic effects of catastrophic weather phenomena

Climate change is likely to affect economies not only through warming, but also via an increase in extreme events like cold snaps and heat waves, floods and droughts, hurricanes, higher sea levels, and so on. Figure 2 plots the number of annual weather and climate related disasters in US with a cost over one billion-dollar to illustrate this increase. This figure also plots the direct costs adjusted for inflation using the Consumer Price Index (CPI), together with 95% confidence intervals as well as the 5-year average costs. See Smith and Katz (2013), who describe the methodology used to estimate the US billion-dollar disaster loss, and conclude the costs are underestimated in roughly 10-15%, and Smith and Matthews (2015) for a description of the Monte Carlo simulations used to obtain the confidence intervals. Figure 2 suggests that increasing trends in both the annual frequency of billion-dollar events and in the annual aggregate loss from these events.

Hoeppe (2016) shows that direct losses are generally estimated using catastrophe models and measured using empirical data on losses. Most estimates of the economic impacts of natural disasters are based on regressions of aggregate variables (measured at the country level) on some measure of disasters, such as their number, the monetary damages or the number of fatalities.

The question of whether natural disasters affect economic growth is ultimately an empirical one; see the arguments in Cavallo et al. (2013). The economic losses of natural disasters have been increasing over the last few decades, with the number of natural disasters causing substantial losses increasing by a factor of three since 1980; see Pindyck (2013), who stresses the importance of measuring the effects of climate change including the possibility of catastrophic outcomes, Schewe et al. (2019), who warn against the under-estimation of the impacts of climate extremes.

---

12 This plot was obtained from https://www.ncei.noaa.gov/access/monitoring/billions/time-series on 17th April 2022.
by global models, and the reviews by Cavallo and Noy (2011), Botzen, Deschênes and Sanders (2019) and Hoppe (2016) or the meta-analysis by Klomp and Valckx (2014).

Most of this literature focus on short-run analysis. An exception is Cavallo et al. (2013), who investigate the sign and size of the short- and long-run effects of large natural disasters on growth using event study with synthetic control groups. They conclude that, once one control for political changes, even extremely large disasters do not play any significant effect on economic growth.

The literature considers different types of extreme events as inputs for the models in order to estimate their economic effect. As in Felbermayr et al. (2022), we focus only on weather related events (windstorms, intense precipitation, droughts and cold spells) as input variables.

When using windstorms as input variable and based on a sample covering the period 1950-2008, Nordhaus (2010) finds that, for the US, windstorms cost on average 0.07% of GDP. However, Hsiang (2010) finds no average significant impact of cyclones on income using data of 28 Caribbean countries, although the effect can be positive in some sectors (construction) while negative in some others (tourism). Moreover, Strobl (2011), after proposing a novel hurricane destruction index, estimates the impact of hurricanes in US and concludes that they have at least a negative effect of 0.45 percentage points in coastal counties. The effect of windstorms in rich countries seems to be temporary and compensated through government transfers. For instance, at the county level in the US, Deryugina (2017) shows that 10 years after the hurricane, there is no effect on county income due direct and indirect government transfers in the form of unemployment insurance and public medical payments pointing out that the fiscal costs of natural disasters have been significantly underestimated due to these indirect transfers. In the particular case of hurricane Katrina in the US, Deryugina, Kawano and Levitt (2018) use a panel of tax return data and find that the effect of the hurricane on income was small and transitory, although it had a strong effect on where people live. Camargo and Hsiang (2016) survey the literature about the link between tropical cyclones and climate and also analyse their socio-economic impact, concluding that the direct and secondary economic impact of tropical cyclones is larger than previously thought.

Another set of studies use night-light emissions as proxy for economic activity and then the relation between night-light emission and economic growth, (see Bertinelli and Strobl, 2013 for the Caribbean, Elliot, Strobl and Sun, 2015, for China or Fellbermayr et al., 2022, for the whole globe) and then translate these results into GDP (for instance, Fellbermayr et al., 2022, use an elasticity of 0.37 of lights to GDP). The reasons for using night-light emissions are that they are available for the whole globe at the appropriate granularity (spatial resolution and

13Mittnik, Semmler and Haider (2020) analyse the link between CO2 emissions and the frequency of climate related disasters.
time frequency), they also account for the informal economy and their measurement error is not correlated with the level of income per capita; see Felbermayr et al. (2022). The three analyses previously mentioned for the Caribbean, China and the whole globe, find negative effects of windstorms on night-light emission although Felbermayr et al. (2022) find positive small spatial spillover effects.\(^{14}\)

Willner, Otto and Levermann (2018) show that the absence of enough adaptation to *pluvial floods* may provoke economic losses of around 17% in the global trade network with China being the country with the most serious losses. However, Duan et al. (2022) find that in China an additional day of heavy rainfall (more than 50 mm accumulated in 24 h) is associated with a 0.0092 percentage point increase in output. The rationale behind this contradicting result is as follows: Although there are clearly risks to floods and landslides from frequent precipitation in a short period, heavy rain helps economic development and the storage of water resources. There are also studies that use night-light emissions in order to see the economic effects of floods. Felbermayr et al. (2022) use night-light emissions and, contrary to Duan et al. (2021), find a negative relation between extreme precipitation and local income growth using regression fixed effects models. They also find that local income growth rebounds. Kokornik-Mina et al. (2020) also relate floods with night-light emissions although they focus on cities. They find that economic activity is disrupted only briefly after a flood, returning to previous levels quickly.

Regarding *extreme temperatures*, there are analyses that focus on droughts or the effect of too high temperatures while other study cold spells. For the first one, Felbermayr et al. (2022) built a Standardized Precipitation-Evapotranspiration Index, SPEI, and find that a unit increase of this index results in an increase of 0.8 percentage points in local night-light emission, with negative spillover effects resulting in a 0.44 decrease. For China, Duan et al. (2022) study the effect of extreme heat (defined as the number of days that the mean temperature is higher than 32°C) and conclude that an additional day of extreme heat reduces GDP by 0.0006 percentage points with a heterogeneous impact across sectors, being the highest impact on industry, where an additional day of extreme heat implies that GDP loss increases 0.45%; see Zhang et al. (2018).

For *cold spells*, Felbermayr et al. (2022) find that their cold anomaly measure is negatively related to lights growth contemporaneously and in the next period. However, Duan et al. (2022) study the effect of extreme cold for China (defined as the number of days that the mean temperature is lower than −12°C) and do not find a significant relation.

All in all, the main conclusion about the impact of natural disasters on income or GDP seems to be negative for all extreme input variables but heavy rain. However, this effect depends on the country being poor or rich. For the latter, the effects seem to be small and transitory, probably,

\(^{14}\)Although the three studies look for spatial spillover effects, only Felbermayr et al. (2022) include them directly in the model and find strong evidence of them with one lag.
due to the support of governments in form of transfers or other indirect insurance.

7 Conclusions

Relevant policy recommendations need to be based, among other considerations, on correct forecasts of the economic externalities caused by climate change. Consequently, robust measures of the interactions between environmental variables and the economy are crucial to formulate suitable economic development paths. In this paper, we survey over 250 econometric contributions to the literature on measuring these interactions over the last decade.

Credible quantitative modelling of climate change and its relations with economic activity is still in its very early stages. The steps forward taken during the last decades faces important econometric issues as, for example, endogeneity, non-stationarity, non-linearity and the importance of extreme events. The contributions in this area are not only crucial because of their implications for society, they are also a challenge for econometricians. Previous quantitative analysis of the externalities of climate change on the economy are limited in their conclusions because they only consider partial aspects of the environmental and economic variables and their relationships.

The global picture of the channels through which climate change and the economy may be related are well understood. First, economic activity causes an increase in energy consumption, which causes pollution. Larger pollution is related with climate change. Finally, climate change is itself affecting the economy.

However, the first issue faced to begin with is defining climate change. Climate is usually defined as the long-run average of weather in a given location (or globally) and climate change as the long-run variation in the joint probability distributions describing the state of the atmosphere, oceans, and fresh water including ice. In many studies analysing the relationship between climate change and economic activity, the measures used for the former are observations of weather variables, often temperatures and precipitations, obtained from weather stations. A majority of studies of climate change measure it by looking at temperatures and mainly to average temperatures.

With respect to the first channel, the nexus between energy consumption and economic growth has been analysed since long based mainly on panel data. Evidence on causality between energy consumption and economic growth still remains ambiguous.

There is also a huge and still growing literature on the nexus between economic activity and pollution. Most works focus on estimation of EKC based on either panel data or time series models. However, the time span considered in empirical studies is often relatively short while the variables considered are non-stationary. Consequently, the results are mixed and inconclusive.

With respect to the works looking at the relationship between economic activity and climate
change, many papers focus on the effects of the latter on particular sectors while other, looking at a more aggregate level, find a negative correlation between temperature and income per capita (mainly in poorer countries). However, once more, evidence is mixed.

Finally, we survey the literature on the economic effects of catastrophic weather phenomena, which mainly focus on short-term effects. As before, the results are mixed, however, the empirical evidence seems to point to a negative relation between weather extreme events (but heavy precipitation) and economic growth in poorer countries.

On top of describing what is known about the nexus between climate change and economic activity, this survey shows that a lot of work is required by econometricians in this very socially relevant topic. This analysis involves non-stationarity, endogeneity and non-linearity together with relatively short spans of data, being an important challenge for econometricians. Furthermore, the current approaches understated the large uncertainty around the economic effects of climate change, in particular they do not capture the downside risk. Very few empirical studies deal with the uncertainty problem around climate change. Pindyck (2014) and Convery and Wagner (2015) already discuss that standard climate-economy models fall victim of two important fallacies in dealing with uncertainty: by necessity, they focus on what is known and can be quantified and they convey a false sense of precision. According to our survey the same problem can be pointed out after several years.

References

[1] Acaravci, A. and I. Ozturk (2010), On the relationship between energy consumption, CO₂ emissions and economic growth in Europe, Energy, 35(1), 5412-5420.

[2] Acheampong, A.O. (2018), Economic growth, CO₂ emissions and energy consumption: What causes what and where?, Energy Economics, 74, 677-692.

[3] Acheampong, A.O., E. Boateng, M. Ampobsah and J. Dzator (2021), Revisiting the economic growth–energy consumption nexus: Does globalization matter?, Energy Economics, 102, 105472.

[4] Adebayo, T.S. and J.A. Odugbesan (2021), Modelling CO₂ emissions in South Africa: Empirical evidence from ARDL based bounds and wavelet coherence techniques, Environmental Science and Pollution Research, 28, 9377-9389.

[5] Adebayo, T.S., I. Awosusi and I. Adesola (2020), Determinants of CO₂ emissions in emerging markets: An empirical evidence from MINT economies, International Journal of Renewable Energy Development, 9(3), 411-422.
[6] Adejuno, O.O. (2020), Environmental quality vs economic growth in a developing economy: complements and conflicts, *Environmental Science and Pollution Research*, 27(21), 6163–6179.

[7] Agliardi, E., T. Alexopoulos and C. Cech (2019), On the relationship between GHGs and global temperature anomalies: Multi-level rolling analysis and copula calibration, *Environmental and Resource Economics*, 72, 109-133.

[8] Agovino, M., M. Casaccia, M. Ciommi, M. Ferrara and K. Marchesano (2019), Agriculture, climate change and sustainability: The case of EU-28, *Ecological Indicators*, 105, 525-543.

[9] Akadin, S.S., A.A. Alola and O. Usman (2021), Energy mix outlook and the EKC hypothesis in BRICS countries: a perspective of economic freedom vs Economic growth, *Environmental Science and Pollution Research*, 28, 8922 - 8926.

[10] Aller, C., L. Ductor and D. Grechyna (2021), Robust determinants of CO2 emissions, *Energy Economics*, 96, 105154.

[11] Al-Mulali, U., B. Saboori and I. Ozturk (2015), Investigating the environmental Kuznets curve hypothesis in Vietnam, *Energy Policy*, 76, 123-131.

[12] Altintas, H. and Y. Kassouri (2020), Is the environmental Kuznets curve in Europe related to the per-capita ecological footprint or CO2 emissions?, *Ecological Indicators*, 113, 106187.

[13] Ang, J.B. (2007), CO2 emissions, energy consumption and output in France, *Energy Policy*, 35(10), 4772-4778.

[14] Anser, M.K., Z. Yousaf, A.A. Nassani, M.M.Q. Abro and K. Zaman (2020), International tourism, social distribution, and environmental Kuznets curve: Evidence from a panel of G-7 countries, *Environmental Science and Pollution Research*, 27, 2707-2720.

[15] Antonakakis, N., I. Chatziantoniou and G. Fillis (2017), Energy consumption, CO2 emissions, and economic growth: An ethical dilemma, *Renewable and Sustainable Energy Reviews*, 68, 808–824.

[16] Apergis, N. and J.E. Payne (2009), Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model, *Energy Economics*, 31(2), 211-216.

[17] Apergis, N. and J.E. Payne (2011), A dynamic panel study of economic development and the electricity consumption-growth nexus, *Energy Economics*, 33(5), 770-781.

[18] Atwi, M., R. Barberon, J. Mur and A. Angulo (2018), CO2 Kuznets curve revisited: from cross-section to panel data models, *Journal of Regional Research*, 40, 169-196.
[19] Auffhammer, M. (2018), Quantifying economic damages from climate change, *Journal of Economic Perspectives*, 32(4), 33-52.

[20] Auffhammer, M. and E.T. Mansur (2014), Measuring climatic impacts on energy expenditures: A review of the empirical literature, *Energy Economics*, 46, 522-530.

[21] Auffhammer, M. and R. Steinhauser (2012), Forecasting the path of US CO\textsubscript{2} emissions using state-level information, *Review of Economics and Statistics*, 94(1), 172-185.

[22] Auffhammer, M., S.M. Hsiang, W. Schlenker and A. Sobel (2013), Using weather data and climate model output in economic analyses of climate change, *Review of Environmental Economics and Policy*, 7(2), 181-198.

[23] Aziz, N., A. Sharif, A. Raza and K. Jermsittiparsert (2021), The role of natural resources, globalization and renewable energy in testing the EKC hypothesis in MINT countries: new evidence from method of moments quantile regression approach, *Environmental Science and Pollution Research*, 28, 13454 - 13468.

[24] Bakhsh, S., H. Yin and M. Shabir (2021), Foreign investment and CO\textsubscript{2} emissions: do technological innovation and institutional quality matter? Evidence from system GMM approach, *Environmental Science and Pollution Research*, 28, 19424 - 19438.

[25] Balaguer, J. and M. Cantavella (2016), Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874-2011), *Ecological Indicators*, 60, 853-859.

[26] Barnett, M., W. Brock and L.P. Hansen (2021), Climate change uncertainty spillover in the macroeconomy, *NBER Macroeconomics*, 36.

[27] Barrios, S., L. Bertinelli and E. Stobl (2010), Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy, *Review of Economics and Statistics*, 92(2), 350–366.

[28] Beenstock, M., Y. Reingewertz and N. Paldor (2016), Testing the historic tracking of climate models, *International Journal of Forecasting*, 32(4), 1234-1248.

[29] Bennedsen, M., E. Hillebrand and S.J. Koopman (2021), Modeling, forecasting, and nowcasting U.S. CO\textsubscript{2} emissions using many macroeconomic predictors, *Energy Economics*, 96, 105118.

[30] Bertinelli, L. and E. Strobl (2013), Quantifying the local economic growth impact of hurricane strikes: An analysis from outer space for the Caribbean, *Journal of Applied Meteorology and Climatology*, 52(8), 1688-1697.
[31] Beyene, S.D. (in press), Going beyond the traditional EKC hypothesis: a panel quantile approach, *International Journal of Environmental Studies*.

[32] Beyene, S. D. and B. Kotosz (2020), Testing the environmental Kuznets curve hypothesis: an empirical study for East African countries, *International Journal of Environmental Studies*, 77(4), 636 - 654.

[33] Bidi, F. and M. Jamil (2021), Testing environmental Kuznets curve (EKC) hypothesis in different regions, *Environmental Science and Pollution Research*, 28, 13581 - 13594.

[34] Blundell, R. and S. Bond (1998), Initial conditions and moment restrictions in dynamic panel data models, *Journal of Econometrics*, 87(1), 115-143.

[35] Botzen, W.J.W., O. Deschenes and M. Sanders (2019), The economic impacts of natural disasters: A review of models and empirical studies, *Review of Environmental Economics and Policy*, 13(2), 167-188.

[36] Burke, M. and K. Emerick (2016), Adaptation to climate change: Evidence from US agriculture, *American Economic Journal: Economic Policy*, 8(3), 106-140.

[37] Burke, P.J. and A. Leigh (2010), Do output contractions trigger democratic change? *American Economic Journal: Macroeconomics*, 2(4), 124-57.

[38] Burke, M., S.M. Hsiang and E. Miguel (2015), Global non-linear effect of temperature on economic production, *Nature*, 15725.

[39] Burke, M., J. Dykema, D.B. Lobell, E. Miguel and S. Satyanah (2015), Incorporating climate uncertainty into estimates of climate change impacts, *Review of Economics and Statistics*, 97(2), 461-471.

[40] Cai, H., Y. Mei, J. Chen, Z. Wu, L. Lan, and D. Zhu (2020), An analysis of the relation between water pollution and economic growth in China by considering the contemporaneous correlation of water pollutions, *Journal of Cleaner Production*, 276, 122783.

[41] Calel, R., S.C. Chapman, D.A. Stainforth and N.W. Watkins (2020), Temperature variability implies greater economic damages from climate change, *Nature Communications*, 11(1), 1-5.

[42] Camargo, S. and S. Hsiang (2016), Tropical cyclones: From the influence of climate to their socioeconomic impacts, in Chavez, M., M. Ghil and J. Urrutia-Fucugauchi (eds.), *Extreme Events: Observations, Modeling, and Economics, Geophysical Monograph* 214, chapter 18, American Geophysical Union, John Wiley and Sons, Inc.
[43] Can Genç, M., A. Ekinci and B. Sakarya (2022), The impact of output volatility on CO₂ emissions in Turkey: testing EKC hypothesis with Fourier stationarity test, *Environmental Science and Pollution Research*, 29(2), 3008–3021.

[44] Carleton, T. and S. Hsiang (2016), Social and economic impacts of climate, *Social Sciences*, 353(6304).

[45] Castle, J. and D.F. Hendry (2020), Climate econometrics: an overview, *Foundations and Trends in Econometrics*, 10(3-4), 145-322.

[46] Cavallo, E. and I. Noy (2011), Natural disasters and the economy: A survey, *International Review of Environmental and Resource Economics*, 5, 63-102.

[47] Cavallo, E., S. Galiani, I. Noy and J. Pantano (2013), Catastrophic natural disasters and economic growth, *Review of Economics and Statistics*, 95(5), 1549-1561.

[48] Chang, Y., R.K. Kaufmann, C.S. Kim, J.I. Millers, J.Y. Park and S. Park (2020), Evaluating trends in time series of distributions: A spatial fingerprint of human effects on climate, *Journal of Econometrics*, 214(1), 274-294.

[49] Cheikh, N.B., Y.B. Zaied and J. Chevallier (2021), On the nonlinear relationship between energy use and CO₂ emissions within an EKC framework: Evidence from panel smooth transition regression in the MENA region, *Research in International Business and Finance*, 55, 101331.

[50] Chen, L. J. Gao and F. Vahid (in press), Global temperatures and greenhouse gases: A common features approach, *Journal of Econometrics*.

[51] Chen, X., B. Huang and C.-T. Lui (2019), Environmental awareness and environmental Kuznets curve, *Economic Modeling*, 77, 2-11.

[52] Chen, Y., Z. Wang and Z. Zhong (2019), CO₂ emissions, economic growth, renewable and non-renewable energy production and foreign trade in China, *Renewable Energy*, 131, 208-2016.

[53] Chen, S.W., Z. Xie and Y. Liao (2018), Energy consumption promotes economic growth or economic growth causes energy use in China?; A panel data analysis, *Empirical Economics*, 55, 1019-1043.

[54] Chow, G.C. and J. Li (2014), Environmental Kuznets curve: conclusive econometric evidence for CO₂, *Pacific Economic Review*, 19(1), 1-7.

[55] Christensen, P., K. Gillingham and W. Nordhaus (2018), Uncertainty in forecasts of long-run economic growth, *PNAS*, 115(21), 5409-5414.
[56] Chudick, A., M.H. Pesaran and J.-C. Yang (2018), Half-panel jackknife fixed-effects estimation of linear panels with weakly exogenous regressors, *Journal of Applied Econometrics*, 33(6), 816-836.

[57] Convery, F.J. and G. Wagner (2015), Managing uncertain climates: Some guidance for policy makers and researchers, *Review of Environmental Economics and Policy*, 9(2), 304-320.

[58] Cronin, J., G. Anandarajah and O. Dessens (2018), Climate change impacts on the energy system: a review of trends and gaps, *Climatic Change*, 151(2), 79-93.

[59] Damette, O. and M. Seghir (2013), Energy as a driver of growth in oil exporting countries?, *Energy Economics*, 37, 193–199.

[60] Dell, M., B.F. Jones and B.A. Olken, (2009), Temperature and income: Reconciling new cross-sectional and panel estimates, *American Economic Review*, 99, 198–204.

[61] Dell, M., B.F. Jones and B.A. Olken (2012), Temperature shocks and economic growth: evidence from the last half century, *American Economic Review: Macroeconomics*, 4(3), 66-95.

[62] Dell, M., B.F. Jones and B.A. Olken (2014), What do we learn from the weather? The new climate-economy literature, *Journal of Economic Literature*, 52(3):740.

[63] Deng, Q. and Z. Fu (2019), Comparison of methods for extracting annual cycle with changing amplitude in climate series, *Climate Dynamics*, 52, 5059-5070.

[64] Deryugina, T. (2017), The fiscal cost of hurricanes: Disaster aid versus social insurance, *American Economic Journal: Economic Policy*, 9(3).

[65] Deryugina, T., L. Kawano and S. Levitt, (2018), The economic impact of hurricane Katrina on its victims: Evidence from individual tax returns, *American Economic Journal: Applied Economics*, 10(2), 202–233.

[66] Deryugina, T., G. Hentel, N.H. Miller, D. Molitor and J. Reif (2019), The mortality and medical costs of air pollution: Evidence from changes in wind direction, *American Economic Review*, 109(12), 4178-4219.

[67] Deschênes, O. and M. Greenstone (2011), Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US, *American Economic Journal: Applied Economics*, 3(4), 152–85.

[68] Díaz, A., G.A. Marrero, L.A. Puch and J. Rodríguez (2019), Economic growth, energy intensity and the energy mix, *Energy Economics*, 81, 1056-1077.
[69] Diebold, F.X. and G.D. Rudebusch (in press), Probability assessment of an ice-free Arctic: Comparing statistics and climate model projections, *Journal of Econometrics*.

[70] Diebold, F.X. and G.D. Rudebusch (2022), On the evolution of US temperature dynamics, in Chudik, A., C. Hsiao and A. Timmermann (eds.), *Essays in Honor of M. Hashem Pesaran: Prediction and Macro Modeling*, Advances in Econometrics, 43A, Emerald Publishing Limited.

[71] Diebold, F.X., M. Göbel, P.G. Coulombe, G.D. Rudebusch and B. Zhang (2021), Optimal combination of Arctic sea ice extent measures: A dynamic factor modeling approach, *International Journal of Forecasting*, 37(4), 1509-1519.

[72] Dietz, S., A. Rezai, F. van der Ploeg and F. Venmans (2021), Are economists getting climate dynamics right and does it matter?, *Journal of the Association of Environmental and Resource Economists*, 8(5), 895-921.

[73] Dinda, S. (2004), Environmental Kuznets Curve hypothesis: A survey, *Ecological Economics*, 49, 431-455.

[74] Dogan, E. and R. Inglesi-Lotz (2020), The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries, *Environmental Science and Pollution Research*, 27, 12717–12724.

[75] Dogan, E. and B. Turkekul (2016), CO₂ emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA, *Environmental Science and Pollution Research*, 23(2), 1203-1213.

[76] Doz, C., D. Giannone and L. Reichlin (2012), A quasi-maximum likelihood approach for large, approximate dynamic factor models, *Review of Economics and Statistics*, 94(4), 1014-1024.

[77] Duan, H., D. Yuan, Z. Cai and S. Wang (2022), Valuing the impact of climate change on China’s economic growth, *Economic Analysis and Policy*, 74, 155-174.

[78] Elliott, R., E. Strobl and P. Sun (2015), The local impact of typhoons on economic activity in China: A view from outer space, *Journal of Urban Economics*, 88, 50-66.

[79] Emirmahmutoglu, F. and N. Kose (2011), Testing for Granger causality in heterogeneous mixed models, *Economic Modelling*, 28, 870-876.

[80] Engle, R.F., D.F. Hendry and J.-F. Richard (1983), Exogeneity, *Econometrica*, 51(2), 277–304.
[81] Erdogan, S. (2020), Analyzing the environmental Kuznets curve hypothesis: The role of disaggregated transport infrastructure investments, *Sustainable Cities and Society*, 61, 102338.

[82] Eroğlu, B.A., J.I. Miller and T. Yiğit (2022), Time-varying cointegration and the Kalman filter, *Econometric Reviews*, 41(1), 1-21.

[83] Estrada, F. and P. Perron (2014), Detection and attribution of climate change through econometric methods, *Boletín de la Sociedad Matemática Mexicana*, 20, 107-136.

[84] Estrada, F., D. Kim and P. Perron (2021a), Spatial variations in the warming trend and the transition to more severe weather in midlatitudes, *Scientific Reports*, 11(145).

[85] Estrada, F., D. Kim and P. Perron (2021b), Anthropogenic influence in observed regional warming trends and the implied social time emergence, *Communications, Earth & Environment*, 2, 31.

[86] Estrada, F., P. Perron and B. Martínez-López (2013), Statistically derived contributions of diverse human influences to twentieth-century temperature changes, *Nature Geoscience*, 6(12), 1050-1055.

[87] Felbermayr, G., J. Gröschl, M. Sanders, V. Schippers and T. Steinwachs (2022), The economic impact of weather anomalies, *World Development*, 151, 105745.

[88] Fernández, J. et al. (2019), Consistency of climate change projections from multiple global and regional model intercomparison projects, *Climate Dynamics*, 52(1-2), 1139-1156.

[89] Fosten, J. (2019), CO₂ emissions and economic activity: A short-to-medium run perspective, *Energy Economics*, 83, 415-429.

[90] Fowler, H.J., S. Bleukinsop and C. Tebaldi (2007), Linking climate change modelling to impact studies: recent advances in downscaling techniques for hydrological modelling, *International Journal of Climatology*, 27(12), 1547-1578.

[91] Gaast, W. (2017), Towards a future climate policy—from the Kyoto Protocol to the Paris Agreement, in Gaast, W. (ed.), *International Climate Negotiation Factors*, Springer.

[92] Galeotti, M.A. Lanza and F. Pauli (2006), Reassessing the environmental Kuznets curve for CO₂ emissions: A robustness exercise, *Ecological Economics*, 57, 152-163.

[93] Gallic E. and G. Vermandel (2020), Weather shocks, *European Economic Review*, 124, 103409.

[94] Gill, A.R., K.K. Viswanathan and S. Hassan (2017), Is environmental Kuznets curve still relevant?, *International Journal of Energy Economics and Policy*, 7(1), 156-165.
[95] Gillingham, K.T., C.R. Knittel, J. Li, M. Ovaere and M. Reguant (2020), The short-run and long-run effects of Covid-19 on energy and the environment, Joule.

[96] Grossman, G.M. and A.B. Krueger (1995), Economic growth and the environment, Quarterly Journal of Economics, 110(2), 353-377.

[97] Haider, A., A. Bashir and M.S. Ul Husnain (2020), Impact of the agricultural land use and economic growth on nutrious oxide emissions: evidence from developed and developing countries. Science of Total Environment, 741, 140421.

[98] Hailemariam, A., R. Dzhumashev and M. Shahbaz (2020), Carbon emissions, income inequality and economic development, Empirical Economics, 59, 1139-1159.

[99] Hanif, I., S.M.F. Raza, P. Gago-de-Santos and Q. Abbas (2019), Fossil fuel, foreign direct investment and economic growth have triggered CO₂ emissions in emerging Asian economies: some empirical evidence, Energy, 171, 493-501.

[100] Hansen, P.R. (2005), A test for superior predictive ability, Journal of Business and Economic Statistics, 23, 365-380.

[101] Hansen, L.P. (2022), Central banking challenges posed by uncertain climate change and natural disaster, Journal of Monetary Economics, 125, 1-25.

[102] Hao, Y., Y. Liu, J.H. Weng and Y. Gao (2016), Does the environmental Kuznets curve for coal consumption in China exist? New evidence for spatial econometric analysis, Energy, 114, 1214-1223.

[103] Hashmi, S.M., R. Bhowmik, R. Inglesi-Lotz and Q.R. Syed (2022), Investigating the environmental Kuznets curve hypothesis amidst geopolitical risk: Global evidence using bootstrap ARDL approach, Environmental Science and Pollution Research, 29, 24049-24062.

[104] Haug, A.A. and M. Ucal (2019), The role of trade and FDI for CO₂ emissions in Turkey: nonlinear relationships, Energy Economics, 81, 297-307.

[105] Hendry, D.F.(2004), Causality and exogeneity in non-stationary economic time series. Contributions to Economic Analysis, 269, 21-48.

[106] Hill, R. and E. Magnani (2002), An explanation of the conceptual and empirical basics of the environmental Kuznets curve, Australian Economic Papers, 21(2), 239-254.

[107] Hillebrand, E., F. Petris and T. Proietti (2020), Econometric models of climate change: Introduction by the guest editors, Journal of Econometrics, 214(1), 1-5.
[108] Hipólito Leal, P. and A. Cardoso Marques (2020), Rediscovering the EKC hypothesis for the 20 highest CO$_2$ emitters among OECD countries by level of globalization, *International Economics*, 164, 36-47.

[109] Hoeppe, P. (2016), Trends in weather related disaster-consequences for insurers and society, *Weather and Climate Extremes*, 11, 70-79.

[110] Holtz-Eakin, D. and T.M. Selden (1995), Stoking the fires? CO$_2$ emissions and economic growth, *Journal of Public Economy*, 57(1), 85-101.

[111] Hsiang, S.M. (2010), Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America, *Proceedings of the National Academy of Sciences*, 107(35), 1537–1572.

[112] Hsiang, S.M. (2016), Climate Econometrics, *Annual Review of Resource Economics*, 8, 43-75.

[113] Hsiang, S.M. and M. Burke (2014), Climate, conflict, and social stability: What does the evidence say, *Climatic Change*, 123, 39-55.

[114] Hsiang, S.M., M. Burke and E. Miguel (2013), Quantifying the influence of climate on human conflict, *Science*, 341, 6151.

[115] Hsiang, S.M. and A.S. Jina (2014), The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones, NBER Working Paper 20352.

[116] Hsiang, S. and R.E. Koop (2018), An economist’s guide to climate change science, *Journal of Economic Perspectives*, 32, 3-32.

[117] Hsiang, S., R. Koop, A. Jina, J. Rising, M. Delgado, S. Mohan, D.J. Rasmussen, R. Muir-Wood, P. Wilson, M. Oppenheimer, K. Larsen and T. Houser (2017), Estimating economic damage from climate change in the United States, *Science*, 356, 1362-1369.

[118] Iizumi T. and N. Ramankutty (2016), Changes in yield variability of major crops for 1981-2010 explained by climate change, *Environmental Research Letters*, 11, 034003.

[119] Ikefuji, M., R.J.A. Laeven, J.R. Magnus and C. Muris (2020), Expected utility and catastrophic risk in a stochastic economy-climate model, *Journal of Econometrics*, 214(1), 110-129.

[120] IPCC (2014), Climate Change 2014: Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.
[121] IPCC (2022), AR6 Synthesis report: Climate Change 2022. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, ....(eds.)]. IPCC, Geneva, Switzerland.

[122] Iwata, H., K. Okada and S. Samreth (2010), Empirical study on the environmental Kuznets curve for CO\textsubscript{2} in France: the role of nuclear energy, Energy Policy, 38(8), 4057-4063.

[123] Jalil, A. (2014), Energy–growth conundrum in energy exporting and importing countries: Evidence from heterogeneous panel methods robust to cross-sectional dependence, Energy Economics, 44, 314–324.

[124] Jammazi, R. and C. Aloui (2015), Environment degradation, economic growth and energy consumption nexus: a wavelet-windowed cross-correlation approach, Physica A., 436, 110-125.

[125] Jebli, M.B., S.B. Youssef and I. Ozturk (2016), Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries, Ecological Indicators, 60, 824-831.

[126] Jiang, H., E. Kim, and Y. Woo (2020), The relationship between economic growth and air pollution. A regional comparison between China and South Korea, International Journal of Environment Research and Public Health, 17, 2761.

[127] Jones, B.F. and B.A. Olken, (2010), Climate Shocks and Exports, American Economic Review, 100(2), 454–59.

[128] Kahn, M.E., K. Mohades, R.N.C. Ng, M.H. Pesaran, M. Raissi and J.-C. Yang (2021), Long-term macroeconomic effects of climate change: A cross-country analysis, Energy Economics, 104, 105624.

[129] Kais, S. and H. Sami (2016), An econometric study of the impact of economic growth and energy use on carbon emissions: panel data evidence from fifty eight countries, Renewable and Sustainable Energy Reviews, 59, 1101-1110.

[130] Kalmaz, D.B. and D. Kirikkaleli (2019), Modeling CO\textsubscript{2} emissions in an emerging market: empirical finding from ARDL-based bounds wavelet coherence approach, Environmental Science and Pollution Research, 26, 5210-5220.

[131] Kang, Y.Q., T. Zhai and Y.Y. Yang (2016), Environmental Kuznets curve for CO\textsubscript{2} emissions in China: a spatial panel data approach, Ecological Indicators, 63, 231-239.

[132] Kasman, A. and Y.S. Duman (2015), CO\textsubscript{2} emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis, Economic Modelling, 44, 97-103.
[133] Kaufmann, R.K., H. Kauppi and J.H. Stock (2006), Emissions, concentrations and temperature: a time series analysis, *Climate Change*, 77, 249-278.

[134] Kaufmann, R.K., H. Kauppi, M.L. Mann and J.H. Stock (2011), Reconciling anthropogenic climate change with observed temperature 1998-2008, *Proceedings of the National Academy of Sciences*, 108, 11790-11793.

[135] Khan, M. and J. Eggoh (2021), Investigating the direct and indirect linkages between economic development and CO₂ emissions. A PSTR analysis. *Environmental Science and Pollution Research*, 28, 10039 - 10052.

[136] Khattak, S.I., M. Ahmed, Z.U. Khan and A. Khan (2020), Exploring the impact of innovation, renewable energy consumption from BRICS economies, *Environmental Science and Pollution Research*, 27, 13866 - 13881.

[137] Kilinc-Ata, N.and V.L. Likhachev (in press), Validation of the environmental Kuznets curve hypothesis and role of carbon emission policies in the case of Russian Federation, *Environmental Science and Pollution Research*.

[138] Kim, D., T. Oka, F. Estrada and P. Perron (2020), Inference related to common breaks in a multivariate system with joined segmented trends with applications to global and hemispheric temperatures, *Journal of Econometrics*, 214, 130-152.

[139] Klomp, J. and K. Valckx (2014), Natural disasters and economic growth: A meta-analysis, *Global Environmental Change*, 26, 183-195.

[140] Kocornik-Mina, A., T.K.J. McDermott, G. Michaels and F. Rauch (2020), Flooded cities, *American Economic Journal: Applied Economics*, 12(2), 35–66.

[141] Koondhar, M. A., H. Li, S. Bold and R. Kong (2020), Looking back over the past two decades on the nexus between air pollution, energy consumption, and agricultural productivity in China: a qualitative analysis based on the ARDL bounds testing model, *Environmental Science and Pollution Research*, 27, 13575 - 13589.

[142] Kraft, J. and A. Kraft (1978), On the relationship between energy and GNP, *The Journal of Energy and Development*, 3(2), 401-403.

[143] Kuznets, S. (1955), Economic growth and income inequality, *American Economic Review*, 49, 1-28.

[144] Lau. L.-S., C.-K. Choong and Y.-K. Eng (2014), Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter?, *Energy Policy*, 68, 490-497.
[145] Lazăr, D., A. Minea and A.-A. Purcel (2019), Pollution and economic growth: Evidence from Central and Eastern European countries, *Energy Economics*, 81, 1121–1131.

[146] Leal, P.H. and A.C. Marques (2020), Rediscovering the EKC hypothesis for the 20 highest CO₂ emitters among OECD countries by level of globalization, *International Economics*, 164, 36 - 47.

[147] Lee, C.C., M.P. Chen and W. Wu (in press), The criticality of tourism development, economic complexity, and country security on ecological footprint, *Environmental Science and Pollution Research*.

[148] Li, J and S. Wang (2019), Spatial effects of economic performance on the carbon intensity of human well-being: the environmental Kuznets curve in Chinese provinces, *Journal of Cleaner Production*, 233, 681-694.

[149] Liddle, B. and S. Lung (2015), Revisiting energy consumption and GDP causality: Importance of a priori hypothesis testing, disaggregated data, and heterogeneous panels, *Applied Energy*, 142, 44–55.

[150] Lin, B. and I.N. Benjamin (2018), Causal relationships between energy consumption, foreign direct investment and economic growth in MINT: Evidence from panel dynamic ordinary least square models, *Journal of Cleaner Production*, 197(1), 708-720.

[151] Lin, C.Y.C. and Z.D. Liscow (2013), Endogeneity in the environmental Kuznets curve: An instrumental variable approach, *American Journal of Agricultural Economics*, 95(2), 268-274.

[152] Liu, Y., F. Sadiq, W. Ali and T. Kumail (2022), Does tourism development, energy consumption, trade openness and economic growth matters for ecological footprint: Testing the Environmental Kuznets Curve and pollution haven hypothesis for Pakistan, *Energy*, 245(15), 123208.

[153] Magnani, E. (2001), The environmental Kuznets curve: development path or policy result?, *Environmental Modelling and Software*, 16, 157-165.

[154] Magnus, J.R., R. Melenberg and C. Muris (2011), Global warming and local dimming: The statistical evidence, *Journal of the American Statistical Association*, 106.

[155] Mamipour, S., M. Yahoo and S. Jalalvandi (2019), An empirical analysis of the relationship between the environment, economy, and society: Results of a PCA-VAR model for Iran, *Ecological Indicators*, 102, 760-769.

[156] Marrero, G.A. (2010), Greenhouse gases emissions, growth and the energy mix in Europe, *Energy Economics*, 32(6), 1356-1363.
[157] Massagony, A. and B. Budiono (in press), Is the Environmental Kuznets Curve (EKC) hypothesis valid on CO\textsubscript{2} emissions in Indonesia?, *International Journal of Environmental Studies*.

[158] McCracken, M.W. and S. Ng (2016), FRED-MD: A monthly database for macroeconomic research, *Journal of Business & Economic Statistics*, 34(4), 574-589.

[159] McNown, R., S.Y. Sam and S.K. Goh (2018), Bootstrapping the autoregressive distributed lag test for cointegration, *Applied Economics*, 50(13), 1509-1521.

[160] Mehmood, U. (2021), Globalization-driven CO\textsubscript{2} emissions in Singapore: an application of ARDL approach, *Environment Science and Pollution Research*, 28, 11317 - 11322.

[161] Mele, M. and C. Magazzino (2021), Pollution, economic growth, and COVID-19 deaths in India: a machine learning evidence, *Environment Science and Pollution Research*, 28, 2669 - 2677.

[162] Miguel, E. (2005), Poverty and witch killing, *Review of Economic Studies*, 72(4), 1153–72.

[163] Miguel, E., S. Satyanath and E. Sergenti (2004), Economic shocks and civil conflict: An instrumental variables approach, *Journal of Political Economy*, 112(4), 725–53.

[164] Miguel, E. and S. Satyanath (2011), Re-examining economic shocks and civil conflict, *American Economic Journal: Applied Economics*, 3(4), 228-232.

[165] Miller, J.I. and K. Nam (2020), Dating Hiatuses: a statistical model of the recent slowdown in global warming and the next one, *Earth System Dynamics*, 11, 1123-1132.

[166] Miller, S., K. Chua, J. Coggins and H. Mohtadi (2021), Heat waves, climate change, and economic output, *Journal of the European Economic Association*, 19(5), 2658-2694.

[167] Mittnik, S., W. Semmler and A. Haider (2020), Climate disaster risks: Empirics and a multi-phase dynamic model, *Econometrics*, 8(3), 33.

[168] Moosa, I.A. (2017), The econometrics of the environmental Kuznets curve: an illustration using Australian CO\textsubscript{2} emissions, *Applied Economics*, 49(49), 4927-4945.

[169] Moutinho, V., C. Varum and M. Madaleno (2017), How economic growth affects emissions? An investigation of the environmental Kuznets curve in Portuguese and Spanish economic activity sectors, *Energy Policy*, 106, 326-344.

[170] Müller-Fürstenberger, G. and M. Wagner (2007), Exploring the environmental Kuznets hypothesis: theoretical and econometric problems, *Ecological Economics*, 62, 648-660.
[171] Munir, Q., H.H. Lean and R. Smyth (2020), CO2 emissions, energy consumption and economic growth in the ASEAN-5 countries: A cross-sectional dependence approach, *Energy Economics*, 85, 104571.

[172] Murshed, M. (2021), LPG consumption and environmental Kuznets curve hypothesis in South Asia: A time-series ARDL analysis with multiple structural breaks, *Environmental Science and Pollution Research*, 28(7), 8337-8372.

[173] Mutumba, G.S., T. Odongo, N.F. Okurut and V. Bagire (2021), A survey of literature on energy consumption and economic growth, *Energy Reports*, 7, 9150-9239.

[174] Naeem, M., S. Anwar and S. Nasreen (2021), Empirical analysis of CO2 emissions and sustainable use of energy sources in Pakistan, *Environment Science and Pollution Research*, 28, 16420 - 16433.

[175] Newell, R., B. Prest and S. Sexton, (2021), The GDP-temperature relationship: Implications for climate change damages, *Journal of Environmental Economics and Management*, 108, 102445.

[176] Nordhaus, W.D. (2006), Geography and macroeconomics: New Data and new findings, *Proceedings of the National Academy of Sciences*, 103(10), 3510–3517.

[177] Nordhaus, W.D. (2007), A review of the Stern Review on the Economics of Climate Change, *Journal of Economic Literature*, 45(3), 686-702.

[178] Nordhaus, W.D. (2010), The Economics of hurricanes and implications of global warming, *Climate Change Economics*, 1(1), 1–20.

[179] Nordhaus, W.D. (2019), Climate change: The ultimate challenge for economics, *American Economic Review*, 109(6), 1991-2014.

[180] Olabi, A.G. and M.A. Abdelkareem (2022), Renewable energy and climate change, *Renewable and Sustainable Energy Reviews*, 158, 112111.

[181] Onafowora, O.A. and O. Owoye (2014), Bounds testing approach to analysis of the environmental Kuznets, *Energy Economics*, 44, 47-62.

[182] Ougan, S., C. Isik, and D. Ozdemir (2021), Economic growth and environmental degradation: evidence from the US case environmental Kuznets curve hypothesis with application of decomposition, *Journal of Environmental Economics and Policy*, 10(1), 14 - 21.

[183] Ozturk, I. (2010), A literature survey on energy-growth nexus, *Energy Policy*, 38(1), 340-349.
[184] Pablo-Romero, M., L. Cruz and E. Barata (2017), Testing the transport energy-environmental Kuznets curve hypothesis in the EU27 countries, *Energy Economics*, 62, 257-269.

[185] Pandey S. and M. Mishra (2021), Investigating Environmental Kuznets Curve: A Panel Data Analysis for India, *Review of Development and Change*, 26(2), 137-152.

[186] Paruolo, P., B. Murphy and G. Janssens-Maenhout (2005), Do emissions and income have a common trend? A country-specific time-series global analysis, *Stochastic Environmental Research and Risk Assessment*, 29, 93-1007.

[187] Pata, U.K. and M. Aydin (2020), Testing the EKC hypothesis for the top six hydropower energy-consuming countries: Evidence from Fourier bootstrap ARDL procedure, *Journal of Cleaner Production*, 264, 121699.

[188] Patiño, L.I., V. Alcántara and E. Padilla (2021), Driving forces of CO₂ emissions and energy intensity in Colombia, *Energy Policy*, 151, 112130.

[189] Payne, J.E. (2010a), Survey on international evidence on the causal relationship between energy consumption and growth, *Journal of Economic Studies*, 37(1), 53-95.

[190] Payne, J.E. (2010b), A survey of the electricity consumption-growth literature, *Applied Energy*, 87(3), 723-731.

[191] Pedroni, P (2004), Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis, *Econometric Theory*, 20, 597-625.

[192] Perman, R. and D.I. Stern (2003), Evidence from panel unit root and cointegration test that the environmental Kuznets curve does not exist, *The Australian Journal of Agricultural and Resource Economics*, 47, 325-347.

[193] Pesaran, M.H., Y. Shin and R.J. Smith (1999), Pooled mean group estimation of dynamic heterogeneous panels, *Journal of the American Statistical Association*, 94, 621-634.

[194] Pesaran, M.H., Y. Shin and R.J. Smith (2001), Bounds testing approaches to the analysis of level relationships, *Journal of Applied Econometrics*, 16, 289-326.

[195] Petris, F. (2021), Exogeneity in climate econometrics, *Energy Economics*, 96, 105122.

[196] Petris, F. and M.R. Allen (2013), Climate science: breaks in trends, *Nature Geoscience*, 6, 992-993.
[198] Petris, F. and D.F. Hendry (2013), Comment on “Polynomial cointegration tests of anthropogenic impact on global warming” by Beenstock et al. (2012)-some hazards in econometric modelling of climate change, *Earth System Dynamics*, 4, 375-384.

[199] Petris, F. and M. Roser (2017), Carbon dioxide emission-intensity in climate projections: comparing the observational record to socio-economic scenarios, *Energy*, 135, 718-725.

[200] Petris, F., M. Schwarz, K. Tang, K. Hanstein and M.R. Allen (2018), Uncertain impacts on economic growth when stabilizing global temperatures at 1.5°C or 2°C, *Philosophical Transactions of the Royal Society A*, 376(2119).

[201] Phillips, P.C.B., T. Leirvick and T. Storelvmo (2020), Econometric estimate of Earth’s transient climate sensitivity, *Journal of Econometrics*, 214(1), 6-32.

[202] Pindyck, R.S. (2013), Climate change policy, what do the models tell us?, *Journal of Economic Literature*, 51(3), 860-872.

[203] Pindyck, R.S. (2014), Risk and return in the design of environmental policy, *Journal of the Association of Environmental and Resource Economists*, 1(3), 395-418.

[204] Pindyck, R.S. (2017), The use and misuse of models for climate policy, *Review of Environmental Economics and Policy*, 11(19, 100–114.

[205] Purcell, A.A. (2020), New insights into the environmental Kuznets curve hypothesis in developing and transition economies: a literature survey, *Environmental Economics and Policy Studies*, 22, 585-631.

[206] Quasching, V.V. (2019), *Renewable energy and climate change*, John Wiley & Sons.

[207] Rahman, M.M. (2020), Explaining the effects of economic growth, population density and international trade on energy consumption and environmental quality in India, *International Journal of Energy Sector Management*, 14(6), 1177 - 1203.

[208] Rahman, M.M. and X.B. Wu (2020), The nexus between renewable energy, economic growth, trade, urbanization and environmental quality: a comparative study for Australia and Canada, *Renewable Energy*, 155, 617 - 627.

[209] Rao, C. and B. Yan (2020), Study on the interactive influence between economic growth and environmental pollution, *Environmental Science and Pollution Research*, 27, 39442-39465.

[210] Rasool, H., M.A. Malik and M. Tarique (2020), The curvilinear relationship between environmental pollution and economic growth. Evidence from India, *International Journal of Energy Sector Management*, 14(5), 891 - 910.
[211] Raza, S.A., N. Shah and A. Sharif (2019), Time frequency relationship between energy consumption, economic growth and environmental degradation in the United States: evidence from transportation sector, *Energy*, 173, 706-720.

[212] Raza, S. A., N. Shah and K.A. Khan (2020), Residential energy environmental Kuznets curve in emerging economies: the role of economic growth, renewable energy consumption, and financial development, *Environmental Science and Pollution Research*, 27, 5620 - 5629.

[213] Rehman, A., H. Ma, M.Z. Chishti, I. Ozturk, M. Irgan and M. Ahmar (2021), Asymmetric investigation to track the effect of urbanization energy utilization, fossil fuel energy and CO₂ emission on economic efficiency in China: another outlook, *Environment Science and Pollution Research*, 28, 17319 - 17330.

[214] Rezai, A., D.K. Foley and L. Taylor (2012), Global warming and economic externalities, *Economic Theory*, 49, 329-351.

[215] Rezai, A., L. Taylor and D. Foley (2018), Economic growth, income distribution and climate change, *Ecological Economics*, 146, 164-172.

[216] Rodríguez-Caballero, C.V. (2022), Energy consumption and GDP: a panel data analysis with multi-level cross-sectional dependence, *Econometrics and Statistics*, 23, 128-146.

[217] Rodríguez-Caballero, C.V. and D. Ventosa-Santaularia (2017), Energy-growth long-term relationship under structural breaks. Evidence from Canada, 17 Latin American economies and the USA, *Energy Economics*, 61, 121-134.

[218] Saidi, K. and A. Omri (2020), The impact of renewable energy on carbon emissions and economic growth in 15 mayor renewable energy consuming countries, *Environmental Research*, 186, 109567.

[219] Sarkodie, S.A. and V. Strezov (2019), A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis, *Science of the Total Environment*, 649, 128-145.

[220] Schewe, J., S.N. Gosling, C. Reyer *et al.* (2019), State-of-the-art global models underestimate impacts from climate extremes, *Nat Commun*, 10, 1005.

[221] Schlenker, W. and M.J. Roberts (2009), Nonlinear temperature effects indicate severe damages to us crop yields under climate change, Proc. Natl Acad. Sci. USA 106, 15594 - 15598.

[222] Schmidt, G.A. *et al.*, 2014, Using paleo-climate comparisons to constrain future projections in CMIP5, *Climate of the Past*, 10, 221-250.
[223] Selden, T.M. and D. Song (1994), Environmental quality and development: is there a Kuznets curve for air pollution emission?, *Journal of Environmental Economy Management*, 27(2), 147-162.

[224] Seppänen, O., W.J. Fisk and Q.H. Lei (2006), Effect of Temperature on Task Performance in Office Environment, Berkeley, Calif.: Lawrence Berkeley National Laboratory.

[225] Seri, C. and A. de Juan, (in press), CO$_2$ emissions and income growth in Latin America: long-term patterns and determinants, *Environment, Development and Sustainability*.

[226] Sethi, P., D. Chakrabarti and S. Bhattacharjee (2020), Globalization, financial development and economic growth: perils on the environmental sustainability of an emerging economy, *Journal of Policy Modeling*, 42, 520 - 535.

[227] Shahbaz, M. and A. Sinha (2019), Environmental Kuznets curve for CO$_2$ emissions: a literature survey, *Journal of Economic Studies*, 46(1), 106-168.

[228] Shahbaz, M., M. Mutascu and P. Azim (2013), Environmental Kuznets curve in Romania and the role of energy consumption, *Renewable and Sustainable Energy Reviews*, 18, 165-173.

[229] Shahbaz, M., R. Sherma, A. Sinha and Z. Jiao (2021), Analyzing nonlinear impact of economic growth drivers on CO$_2$ emissions: designing an SDG framework for India, *Energy Policy*, 148, 111965.

[230] Shahbaz, M., M. Zakaria, S.J.H. Shahzad and M.K. Mahalik (2018), The energy consumption and economic growth nexus in top ten energy-consuming countries: Fresh evidence from using the quantile-on-quantile approach, *Energy Economics*, 71, 282-301.

[231] Shin, Y., B. Yu and M.J. Greenwood-Nimmo (2014), Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework, in Horrace, W.C. and R.C. Sickles (eds.), *Feetschrift in Honor of Peter Schmidt: Econometric Methods and Applications*, Springer, New York.

[232] Sim, N. and H. Zhou (2015), Oil prices, US stock return, and the dependence between their quantiles, *Journal of Banking and Finance*, 55, 1-8.

[233] Smiech, S. and M. Papiez (2014), Energy consumption and economic growth in the light of meeting the targets of energy policy in the EU: the bootstrap panel Granger causality approach, *Energy Policy*, 71, 118-129.

[234] Smith, A.B. and R.W. Katz (2013), US billion-dollar weather and climate disasters: data, sources, trends, accuracy and biases, *Natural Hazards*, 67, 387-410.
[235] Smith, A.B. and J.L. Matthews (2015), Quantifying uncertainty and variable sensitivity within the US billion-dollar weather and climate disaster cost estimates, *Natural Hazards*, 77, 1829-1851.

[236] Solarin, S.A., S.P. Nathaniel, F.V. Bekun, A.M. Okunola and A. Alhassan (2021), Towards achieving environmental sustainability: environmental quality versus economic growth in a developing country on ecological footprint via dynamic simulations of ARDL, *Environment Science and Pollution Research*, 28, 17942 - 17959.

[237] Solaun, K. and E. Cerdá (2019), Climate change impacts on renewable energy generation. A review of quantitative projections, *Renewable and Sustainable Energy Reviews*, 116, 109415.

[238] Stern, D.I. (2017), The environmental Kuznets curve after 25 years, *Journal of Bioeconomics*, 19, 7-28.

[239] Stern, D.I. and M.S. Common (2001), Is there an environmental Kuznets curve for sulphur? *Journal of Environmental Economics and Management* 41, 162-178.

[240] Stern, N. (2007), *The Economics of Climate Change: The Stern Review*, Cambridge University Press.

[241] Stern, N. (2008), The economics of climate change, *American Economic Review*, 98(2), 1-37.

[242] Stern, N. (2013), The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models, *Journal of Economic Literature*, 51(3), 838-859.

[243] Stern, N. (2016), Economics: current climate models are grossly misleading, *Nature News*, 530(7591), 407-409.

[244] Stock, J.H. (2019), Climate change, climate policy, and economic growth, *NBER Macroeconomics Annual*, 34.

[245] Storelvmo, T., T. Leirvik, U. Lohmann, P.C.B. Phillips and M. Wild (2016), Disentangling greenhouse warming and aerosol cooling to reveal Earth’s climate sensitivity, *Natural Geoscience*, 9(4), 286-289.

[246] Strobl, E. (2011), The economic growth impact of hurricanes: Evidence from US coastal counties, *Review of Economics and Statistics*, 93(2), 575-589.

[247] Taguchi, H. (2013), The environmental Kuznets curve in Asia: the case of sulphur and carbon emissions, *Asia-Pacific Development Journal*, 19(2), 77-92.
[248] Tanoue, M., R. Taguchi, S. Nakata, S. Watanabe, S. Fujimori and Y. Hirabayashi (2020), Estimation of direct and indirect losses caused by a flood with long-lasting inundation: Application to the 2011 Thailand flood, Water Resources Research, 56, e2019WR026092.

[249] Taylor, L., A. Rezai and D.F. Foley (2016), An integrated approach to climate change, income distribution, employment, and economic growth, Ecological Economics, 121, 196-205.

[250] Tiba, S. and A. Omri (2017), Literature survey on the relationship between energy, environment and economic growth, Renewable and Sustainable Energy Reviews, 69, 1129-1146.

[251] Tiwari, A.K., M. Shahbaz, Q.M.A. Hye (2013), The environmental Kuznets curve and the role of coal consumption in India: co-integration and causality analysis in an open economy, Renewable and Sustainable Energy Reviews, 18, 519-527.

[252] Tol, R.S.J. (2006), The Stern review of the economics of climate change: A comment, Energy & Environment, 17(6), 977-981.

[253] Tol, R. (2009), The economic effects of climate change, Journal of Economic Perspectives, 23(2), 29-51.

[254] Tol, R. (2014), Correction and update: The economic effects of climate change, Journal of Economic Perspectives, 28(2), 221-226.

[255] Ul Husnain, M.I., A. Haider, M.A. Khan (2021), Does the environmental Kuznets curve reliably explain a developmental issue? Environmental Science and Pollution Research, 28, 11469-11485.

[256] Umar, M., X. Ji, D. Kirikkaleli and Q. Xu (2020), COP21 roadmap: Do innovation, financial development, and transportation infrastructure matter for environmental sustainability in China?, Journal of Environmental Management, 271, 111026.

[257] Usman, O., P.T. Larember and I.O. Olanipekun (2019), Revisiting the environmental Kuznets curve (EKC) hypothesis in India: the effects of energy consumption and democracy, Environmental Science and Pollution Research, 26, 13390-13400.

[258] Van Ruijven, B.J., E. de Cian and I.S. Wing (2019), Amplification of future energy demand growth due to climate change, Nature Communications, 10(1), 1-12.

[259] Villanthenkodath, M.A., M. Gupta, S. Saini, and M. Sahoo (2021), Impact of Economic Structure on the Environmental Kuznets Curve (EKC) hypothesis in India, Journal of Economic Structures, 10(28), 1 - 17.

[260] Waheed, R., S. Sarwar and C. Wei (2019), The survey of economic growth, energy consumption and carbon emission, Energy Reports, 5, 1103-1115.
[261] Waqih, M.A.U., N.H. Butto, N.H. Ghumro, S. Kumar and M.A. Salam (2019), Rising environmental degradation and impact of foreign direct investment: An empirical evidence from SAARC region, *Journal of Environmental Management*, 243, 472-480.

[262] Wagner, M. (2008), The carbon Kuznets curve: A cloudy picture emitted bad econometrics, *Resource and Energy Economics*, 30, 388-408.

[263] Wagner, M., P. Grabarczyk and S.H. Hong (2020), Fully modified OLS estimation and inference for seemingly unrelated cointegrated Kuznets curve for carbon dioxide emission, *Journal of Econometrics*, 214(1), 216-255.

[264] Wang, W.-Z., L.-C. Liu, H. Liao and Y.-M. Wei (2021), Impacts of urbanization on carbon emissions: An empirical analysis from OECD countries, *Energy Policy*, 151, 112171.

[265] Wang, Q. and L. Wang (2020), Renewable energy consumption and economic growth in OECD countries: A nonlinear panel data analysis, *Energy*, 207, 118200.

[266] Weitzman, M.L. (2007), A review of the Stern Review on the Economics of Climate Change, *Journal of Economic Literature*, 45(3), 703-724.

[267] Weitzman, M.L. (2009), On modeling and interpreting the economics of catastrophic climate change, *Review of Economics and Statistics*, 91(1), 1-19.

[268] Weitzman, M.L. (2015), A review of William Nordhaus’ The Climate Casino: Risk, Uncertainty, and Economics for a Warming World, *Review of Environmental Economics and Policy*, 9(1), 145-156.

[269] Weitzman, M.L. (2020), Fat-tailed uncertainty in the economics of climate change, *Review of Environmental Economics and Policy*, 5(2), 275-292.

[270] Westerlund, J. (2007), Testing for error correction in panel data, *Oxford Bulletin of Economics and Statistics*, 69(6), 709-748.

[271] Willner, S.N., C. Otto and A. Levermann (2018), Global economic response to river floods, *Nature Climate Change*, 8(7), 594-598.

[272] Xiang, J. and D. Xu (2021), Relationship between energy consumption, economic growth and environmental pollution in China, *Environmental Research*, 194, 110718.

[273] Zafar, A., S. Ullah, M.T. Majeed and R. Yasmeen (2020), Environmental pollution in Asian economies: Does the industrialization matter?, *OPEC Energy Review*, September, 227-248.

[274] Zhang P., O. Deschénes, K. Meng and J. Zhang (2018), Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants, *J. Environ. Econ. Manag.*, 88, 1-17.
[275] Zhu, H., L. Duan, Y. Guo and K. Yu (2016), The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression, *Economic Modelling*, 58, 237–248.

[276] Zmani, M. and O. Ben-Salha (2020), An empirical analysis of the determinants of CO$_2$ emissions in GCC countries, *International Journal of Sustainable Development and World Energy*, 27(5), 469 - 480.