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Climate change and the Macroeconomy: Evidence from Oil-Exporting countries

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Climate change and the macroeconomy: Evidence from oil-exporting countries

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Abstract

Climate change significantly threatens the global economy, particularly oil-exporting countries. These countries are vulnerable to the impacts of climate change due to their reliance on the oil industry, which not only contributes to greenhouse gas emissions but also exposes them to the volatility of the global oil market. This paper investigates the relationship between climate change and the macroeconomy, focusing on oil-exporting countries. We examine the evidence on how climate change affects these countries' economic performance and how their governments are responding to this challenge. We find that climate change is likely to have significant economic impacts on oil-exporting countries. We also find that many of these countries need to implement policies and strategies at a faster pace to promote sustainable development and reduce their greenhouse gas emissions.

JEL Classification

C33, N5, Q43, Q51, Q54, Q58

Keywords

Climate change, global warming, macro economy, mitigation and adaptation, oil-exporting countries.

Executive Summary

Climate change and economic growth are closely intertwined, and both will determine the course of human civilization. With the Earth's climate undergoing rapid and unprecedented transformations, mainly fueled by intense human activities since the Industrial Revolution, the potential effects on economic growth are becoming increasingly apparent. This intertwined relationship has sparked global concern and created an urgent need for transformative action to address these challenges.

The consequences and effects of climate change are vast and complex. The rise in average temperatures has manifested itself in various forms, such as melting of the polar ice caps, increased frequency and intensity of extreme weather events, rising sea levels, changing precipitation patterns, and disruptions to ecosystems and biodiversity. The effects of these changes on humanity are profound and include economic, social and environmental dimensions.

On the other hand, economic growth is a basic aspiration of all countries and is a criterion for development and prosperity. The traditional model of economic growth, based on the extraction and consumption of natural resources, is often fueled by the very processes that contribute to climate change. Historically, industrialization, urbanization, and population growth have led to economic expansion, lifting millions out of poverty, and fostering technological progress. However, this growth has come at a high cost, putting enormous pressure on natural resources, inflating pollution levels, and driving carbon emissions to precarious levels.

In the past, economic growth was seen as a potential impediment to climate change mitigation due to its inherent and carbon-intensive nature. However, this traditional view is increasingly challenged by the emergence of a new paradigm that envisions a symbiotic relationship between economic growth and climate action. Policymakers and economists have often found themselves torn between economic prosperity and environmental conservation, assuming that environmental protection will inevitably stifle economic growth. However, this perspective has evolved as societies and governments have recognized that climate change is not only an environmental challenge but also an economic and social challenge. From this perspective, the challenge of addressing climate change has become a catalyst for transformative economic growth rather than a hindrance.

Understanding the complex links between climate change and economic growth is essential to devising effective strategies that ensure a sustainable and resilient future. Embracing renewable energy sources, developing clean technologies, promoting circular economy principles, and investing in green infrastructure are just a few examples of initiatives that have the potential to boost economic growth while mitigating the effects of climate change.

This work contributes to the relevant literature by examining the relationship between climate change and economic growth in oil-exporting countries using the latest econometric techniques. Data for 23 oil-exporting countries were collected during the period from 1995 to 2020. The challenge of climate change in these countries opens new opportunities for economic diversification, innovation, job creation, and sustainable investment. Green sectors, such as renewable energies, energy efficiency, and climate-smart agriculture, have the potential to not only drive economic expansion but also promote social justice and inclusiveness.

Many studies have used temperatures and extreme weather events as an indicator of climate change, which represents a severe simplification of the effects of climate change. Therefore, in this study, we use an expanded set of indicators that show vulnerability and readiness to adapt to the effects of climate change. The empirical results of the study confirm that readiness for climate change, through the deployment of the necessary policies and the expansion of structural reforms, has a positive impact on economic growth. These results also have another important effect of mitigating vulnerabilities that may affect economic growth.

الملخص التنفيذي

هناك ترابط وثيق بين التغير المناخي والنمو الاقتصادي، وكلاهما سيحددان مسار الحضارة الإنسانية. ومع تعرض مناخ الأرض لتحولات سريعة وغير مسبوقة، تغذيها بشكل أساسي الأنشطة البشرية المكثفة منذ الثورة الصناعية، فإن الآثار المحتملة على النمو الاقتصادي أصبحت واضحة بشكل متزايد. وأثارت هذه العلاقة المتشابكة قلقًا عالميًا، وخلقت حاجة ملحة للعمل التحويلي لمواجهة هذه التحديات.

كما أن عواقب وآثار تغير المناخ واسعة ومعقدة. وقد تجلى ارتفاع متوسط درجات الحرارة في أشكال مختلفة، مثل ذوبان القمم الجليدية القطبية، وزيادة تواتر وشدة الظواهر الجوية المتطرفة، وارتفاع مستويات سطح البحر ، وتغير أنماط هطول الأمطار ، واضطرابات في النظم البيئية والتنوع البيولوجي. كما أن آثار هذه التغيرات على البشرية عميقة وتشمل أبعادا اقتصادية واجتماعية وبيئية.

ومن ناحية أخرى، يعتبر النمو الاقتصادي تطلع أساسيا لكل الدول، ويمثل معيارًا للتنمية والازدهار. غالبًا ما يغذي النموذج التقليدي للنمو الاقتصادي، القائم على استخراج واستهلاك الموارد الطبيعية، العمليات ذاتها التي تساهم في تغير المناخ. ولقد أدى التصنيع والتحضر والنمو السكاني تاريخياً إلى التوسع الاقتصادي، وانتشال الملايين من الفقر وتعزيز التقدم التكنولوجي. ومع ذلك، فقد جاء هذا النمو بتكلفة عالية، مما أدى إلى ممارسة ضغط هائل على الموارد الطبيعية، وتضخيم مستويات التلوث، ودفع انبعاثات الكربون إلى مستويات محفوفة بالمخاطر.

وكان يُنظر إلى النمو الاقتصادي في الماضي على أنه عقبة محتملة أمام التخفيف من آثار تغير المناخ بسبب طبيعته المتأصلة وكثيفة الكربون. ومع ذلك، فإن وجهة النظر التقليدية هذه تواجه تحديًا متزايدًا من خلال ظهور نموذج جديد يتصور علاقة تكافلية بين النمو الاقتصادي والعمل المناخي. وغالبًا ما وجد صناع السياسات والاقتصاديون أنفسهم ممزقين بين الازدهار الاقتصادي والحفاظ على البيئة، مفترضين أن حماية البيئة ستعيق النمو الاقتصادي لا محالة. ومع ذلك فقد تطور هذا المنظور عندما أدركت المجتمعات والحكومات أن تغير المناخ لا يمثل تحديًا بيئيًا فحسب، بل يمثل أيضًا تحديًا اقتصاديًا واجتماعيًا. ومن هذا المنظور ، أصبح تحدي معالجة تغير المناخ حافزًا للنمو الاقتصادي التحويلي بدلاً من كونه عائقًا.

ويعد فهم الروابط المعقدة بين تغير المناخ والنمو الاقتصادي أمرًا ضروريًا لابتكار استراتيجيات فعالة تضمن مستقبلًا مستدامًا ومرنًا. إن تبني مصادر الطاقة المتجددة، وتطوير التقنيات النظيفة، وتعزيز مبادئ الاقتصاد الدائري،

والاستثمار في البنية التحتية الخضراء هي مجرد أمثلة قليلة للمبادرات التي لديها القدرة على تعزيز النمو الاقتصادي مع تخفيف الآثار المترتبة عن التغير المناخي.

ويساهم هذا العمل في الأدبيات ذات الصلة من خلال دراسة العلاقة بين تغير المناخ والنمو الاقتصادي في البلدان المصدرة للنفط باستخدام أحدث تقنيات الاقتصاد القياسي. وقد تم تجميع بيانات 23 دولة مصدرة للنفط خلال الفترة الممتدة من 1995 وحتى 2020. ويفتح تحدي التغير المناخي في هذه البلدان فرصًا جديدة للتنويع الاقتصادي والابتكار وخلق فرص عمل والاستثمار المستدام. كما تمتلك القطاعات الخضراء، مثل الطاقات المتجددة وكفاءة استعمال الطاقة والزراعة الذكية مناخيًا، القدرة ليست فقط على دفع التوسع الاقتصادي، بل وتعزيز العدالة الاجتماعية والشمولية.

ولقد استخدمت العديد من الدراسات درجات الحرارة والظواهر الجوية المتطرفة كمؤشر لتغير المناخ، مما يمثل تبسيطاً شديداً لآثار التغير المناخي. ولذلك نستخدم في هذه الدراسة مجموعة موسعة من المؤشرات التي تظهر الانكشاف والجاهزية للتأقلم مع تأثيرات تغير المناخ. وتؤكد النتائج التجريبية للدراسة أن الجاهزية للتغير المناخي، وذلك من خلال نشر السياسات اللازمة وتوسيع الإصلاحات الهيكلية، لها تأثير إيجابي على النمو الاقتصادي. كما أن هذه النتائج لها أيضًا تأثير مهم آخر وهو تخفيف مواطن الضعف التي قد تؤثر على النمو الاقتصادي.

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1. Introduction

Climate change is at the top of the policy priorities list around the world. It has been triggering significant environmental changes. Global warming and natural disasters have been causing billion of damages. It is becoming a severe threat to the global economy and financial system. Furthermore, climate change puts human lives at risk. It directly affects water resources, crops, and infrastructures. To mitigate risks and adverse impacts, Governments agreed, in 2015, on the necessity of controlling the average global temperature increase and keeping it below 2°C. Paris Agreement aims at reaching net-zero emissions by 2050. However, this goal requires massive international efforts to reduce GHG emissions (IPCC,2014).

This work investigates the relationship between climate change and economic growth, emphasizing oil-exporting countries. We are aware that such a relationship is highly complex and includes several potential transmission channels. Some of them have direct links, while others have indirect links. However, the related literature clearly distinguishes between the physical and mitigation risks. Physical risks include the physical impacts of extreme weather events and gradual global warming on economic activity. Mitigation and adaptation risks are the potential impacts of policies implemented to mitigate climate change. All these risks may affect the economy from the supply side, demand side, or both.

Table 1 provides some examples of macroeconomic risks from climate change. Climate change may have several types of adverse economic impacts. Extreme weather events like hurricanes, floods, and droughts can damage infrastructure, harm agricultural production, and disrupt international trade. In case of realization, these events will increase economic losses and disrupt the supply chain. Both public and private finance will be affected. Therefore, to deal with climate change, governments (and businesses) need to implement mitigation policies to reduce GHG emissions and adapt their plans to the impacts of climate change. Both actions have a cost and may require funding. For example, adapting to rising temperatures may require better-insulated buildings and extended use of air conditioning. With an increasing energy demand and to reach a net-zero emission target, moving toward clean energy sources is mandatory. Such a transition involves substantial investments in renewable energy infrastructures and R&D from both the public and private sectors.

Additionally, climate change may have social and political implications. It can widen social inequalities and create political instability. Many countries have witnessed civil wars because of water scarcity due to global warming and climate change. In response, governments may support the most vulnerable by providing social safety nets and ensuring emergency plans for extreme weather events. These actions will undoubtedly impact public finances and reshape priorities.

Table 1: Potential macroeconomic risks from climate change

Type of shock/impact		Physical risks		Transition and Adaptation risk
		From extreme weather events	From gradual global warming	
Demand	Physical risks	Uncertainty about climate events		'Crowding out' from climate policies
	Consumption	Increased risk of flooding to residential property		'Crowding out' from climate policies
	Trade	Disruption to import/export flows		Distortions from asymmetric climate policies
Supply	Labor supply	Loss of hours worked due to natural disasters	Loss of hours worked due to extreme heat	
	Energy, food, and other inputs	Food and other input shortages		Risks to energy supply
	Capital stock	Damage due to extreme weather	Diversion of resources from productive investment to adaptation capita	Diversion of resources from productive investment to adaptation capita
	Technology	Diversion of resources from innovation to reconstruction and replacement	Diversion of resources from innovation to adaptation capita	Uncertainty about the rate of innovation and adoption of clean energy technologies

Source: Batten (2018)

Nevertheless, there is a positive side to this challenging situation. Addressing climate change can also create economic opportunities. All the necessary investments in clean energy, sustainable infrastructure, energy efficiency, and research and development can create new jobs, boost economic growth, foster competitiveness, and offset somehow economic losses of climate change. Developing and deploying innovative technologies to reduce emissions can foster competitiveness and position countries at the forefront of emerging industries.

As discussed earlier, this paper aims to explore the relationship between climate change and the macroeconomy, focusing on oil-exporting countries. While every country is affected by climate change, the impact may be more severe in oil-rich countries. These countries depend highly on oil exports and revenues. Oil-rich nations are more vulnerable to the effects of climate change because they are located in regions already prone to extreme weather events such as hurricanes, rising sea levels, droughts, and heat waves. Many climate change results can directly affect the oil industry. Oil fields, pipelines, and refineries are sensitive to these natural events. As a result, oil production, transportation, and storage will be disrupted, leading to further volatility in the oil market. Moreover, the transition to clean energy will lead to job losses in sectors reliant on fossil fuels if the transition is not well planned.

Climate change can also indirectly impact the macro economy of oil-rich countries. For example, with higher global food prices (due to the physical impact of climate change) and reduced oil revenues (due to global mitigation and adaptation), there are high risks related to food security and an increase in the unemployment rate. Furthermore, oil-exporting countries relying on the tourism sector for diversification could be adversely affected by rising temperatures and sea levels. Nonetheless, climate change can intensify social and political instability in oil-rich countries, especially in regions where resources are scarce.

To summarize, this paper aims to study the impacts of climate change on economic activity in oil-exporting countries. Most studies investigating the relationship between climate change and other economic variables use changes in global temperatures or/and extreme weather events like hurricanes or floods. Are these proxies sufficient to explain climate change and its impacts? The answer is no. They may explain a portion of it but cannot do better. As discussed earlier, the relationship between climate change and economic activity is complex and multifaceted. Thus, this work uses the Notre Dame-Global Adaptation Index (ND-GAIN) Country Index. This index has multiple advantages. It describes the country's present Vulnerability to climate disruption. Moreover, it evaluates a country's readiness to implement adaptive measures to climate change (Chen et al., 2015). Furthermore, it distinguishes between different components of vulnerability and readiness measures. For example, vulnerability measure includes exposure, sensitivity, and adaptive capacity. Meanwhile, readiness measure brings in economic, governance, and social factors. Finally, the ND-GAIN score is based on over 74 variables, forming 45 core indicators, which provide us with an extended set of information about climate change's physical and mitigation risks.

The rest of the paper is organized as follows. Section 2 provides a brief literature review and examines existing studies on oil-exporting countries. Section 3 provides details about data and econometrics technics used in this work. Section 4 presents and discusses the results of the empirical analysis. Finally, Section 5 concludes the research with some policy implications and recommendations.

2. Literature Review

In his pioneering work, Nordhaus (1992) developed a global dynamic integrated assessment model, the DICE model. It incorporates different aspects of climate change[1] within the economic growth theory framework. The general idea of the model is that investing in emissions reduction will decrease current consumption while mitigating, at the same time, risks generated by climate change. As a result, consumption opportunities will increase in the future. Since 1992, the DICE model has witnessed several updates and extensions. The most recent version is DICE-2016R3, used for the Nobel lecture and article.

DICE is a global model; thus, it does not distinguish between sectors, technologies, or countries. It treats, as many studies, climate change as a single-agent problem, as discussed by Nordhaus and Yang (1996). The authors developed a regional version of DICE called the Regional Integrated Model of Climate and the Economy (RICE). The model provides disaggregated countries analysis to assess different national strategies to face climate change. One of the most important results of this model is that it confirms that international policy cooperation will ensure much higher emissions reductions. Notably, the DICE model is one of the three main integrated assessment models used by the U.S. Environmental Protection Agency (EPA). The two other models are the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) and the Policy Analysis of the Greenhouse Effect (PAGE).

However, the DICE has shown many shortcomings and has been criticized by many authors. Pindyck (2013) demonstrated that the DICE model is sensitive to the type of damage function. Furthermore, he believes most integrated assessment models suffer from serious weaknesses, including

[1] Including economic, policy, and geophysics sides.

arbitrary inputs, ad hoc descriptions of climate change impacts, and a lack of theoretical and empirical foundations.

Fankhauser and Tol (2005) suggested that most studies investigating the climate change-economic growth nexus rely on the enumerative approach. It consists of summing up several individual sectoral analyses to develop an overall assessment of social welfare change. In doing such, they ignore the effects of interlinkages among different sectors. Also, these analyses are usually static and neglect the dynamic effects between climate change and economic growth. Fankhauser and Tol (2005) proposed a theoretical framework that considers the main dynamic effects linking climate change and economic growth: capital accumulation and saving. The authors used different growth models to compare the results. However, the authors recognized that the model chosen suffered from ethical flaws. Its main objective is to maximize the aggregate social welfare, which is not the supreme quest of climate change policy.

Dell et al. (2012) examined the impact of country-level temperature variations on economic activity using a long historical data set. The findings revealed three key outcomes. Firstly, elevated temperatures have a more considerable negative impact on economic growth in developing countries. Secondly, higher temperatures may dampen both the level of economic output and its growth rate. Lastly, the increased temperatures may have several consequences, including reduced sectoral production and political instability.

Mejia et al. (2018) developed a general equilibrium model. They used data from more than 180 countries from 1950 to 2015 to estimate the causal effect of annual variation in temperature and precipitation on aggregate output and at the sectoral level in the short and long run. The empirical analysis suggested a nonlinear relationship between temperature increases and economic activity. Moreover, it revealed that the negative shock of rising temperature on per capita income is higher and long-lasting in countries with arid weather. It is the case in most low-income countries. Additionally, there is a wide range of potential transmission channels, including decreasing agricultural production and productivity, diminished capital accumulation, and increasing diseases and sicknesses.

Kahn et al. (2021) recently investigated the long-term climate change-economic activity nexus in 174 countries from 1960 to 2014 using a stochastic growth model. The model assumed that deviation of temperature and precipitation from their long-term moving average historical norms directly affects productivity. The empirical analysis revealed two distinct results. Persistent changes in the temperature negatively affect real output per capita. Meanwhile, changes in precipitation seem to have no significant effects. Furthermore, results show heterogeneous effects of temperature shocks across countries according to different specifications. The authors also discussed the potential reduction of the global real per capita income within two scenarios: the absence of mitigation policies and implementing Paris Agreement targets.

Several studies have investigated the economic impacts of climate change in developing countries and fragile states. However, none has focused on the particular characteristics of oil-exporting countries. For instance, Abidoye and Odusola (2015) explored the effects of climate change on economic growth using annual data for 34 African countries from 1961 to 2009. The authors found that a one-degree Celsius increase in temperature reduces GDP growth by 0.27 percentage points for Africa. Maino and Emrullahu (2022) explored the additional risks of climate change and rising temperatures that fragile states in Sub Saharan region have to face. The authors used ARDL-PMG and DFE estimators to evaluate the short and long-term relationship among GHG emissions, income per capita, temperature anomalies, and technology in 20 fragile states. The results showed a more pronounced impact of rising temperatures on income in Fragile states, with more than 1.8 percentage points reduction in income per capita growth.

The chosen sample is an interesting case because oil-exporting countries face unique challenges due to climate change. On the one hand, the physical adverse effects of climate change can disrupt the oil supply chain from extraction to final consumer. As a result, these countries may face weak economic activity and fiscal deficits. In some oil countries, oil windfalls represent over 90% of public revenues. On the other hand, mitigation measures at the global level will push global oil demand downward. At the local level, mitigation policies to reduce greenhouse gas emissions will force oil-exporting countries to invest heavily in renewable energy sources. Therefore, these countries will face a resource management challenge: how to provide investment to reach net-zero goals with shrinking oil revenues.

3. Data and Empirical approach

To investigate the impact of climate change on the economic growth in oil-exporting countries, we collect annual data for 23 oil-exporting[2] countries from 1995-2020. The main explanatory variables

[2] The sample includes the following countries: Algeria, Angola, Brazil, Canada, Colombia, Ecuador, Indonesia, Iran, Iraq, Kazakhstan, Kuwait, Libya, Malaysia, Mexico, Nigeria, Norway, Oman, Qatar, Russian Federation, Saudi Arabia, United Arab Emirates, United Kingdom, Venezuela.

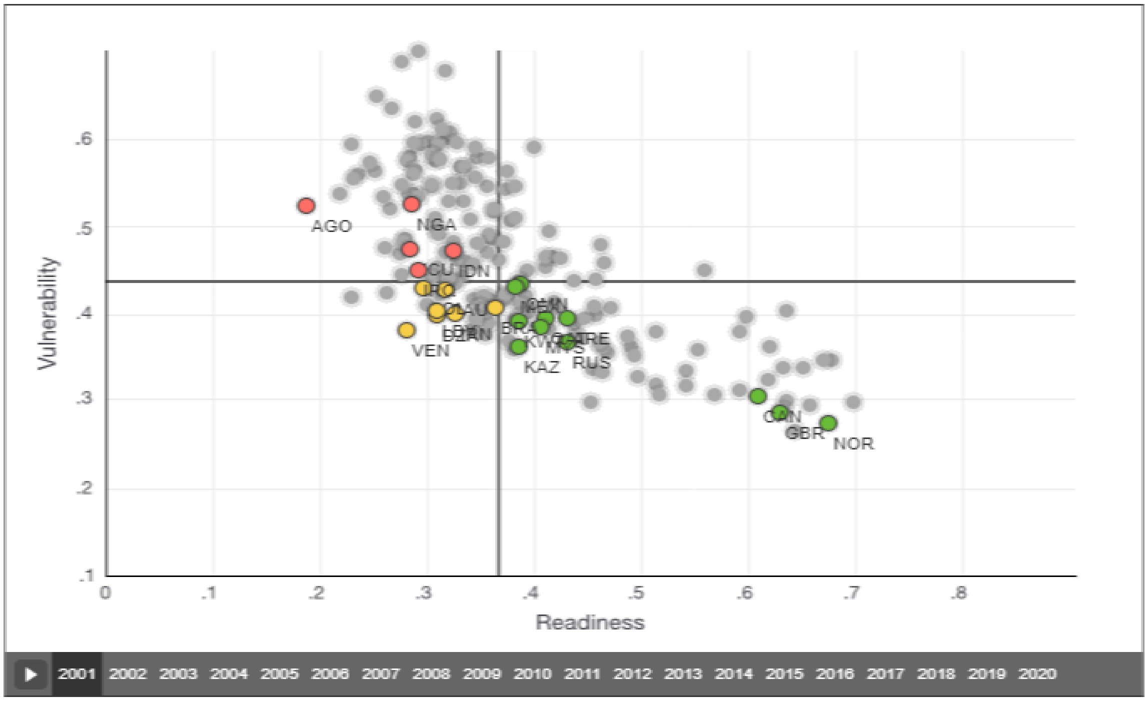
of interest constrain the choice of the study period. Specifically, the ND-GAIN Index and its two subcategories, namely the *Vulnerability* and *Readiness* indices series, start from 1995. We collect the data from different sources. Table 2 summarizes the variables' details.

Table 2: Data and sources.

	Variable name	Source
1	Final consumption expenditure (real)	National Accounts. United Nations Statistics Division (UNSD)
2	Gross fixed capital formation (real)	
3	GDP at constant (2015) prices - USD	
4	Oil production	U.S. Energy Administration
5	Vulnerability index	Notre Dame Global Adaptation Initiative
6	Readiness index	

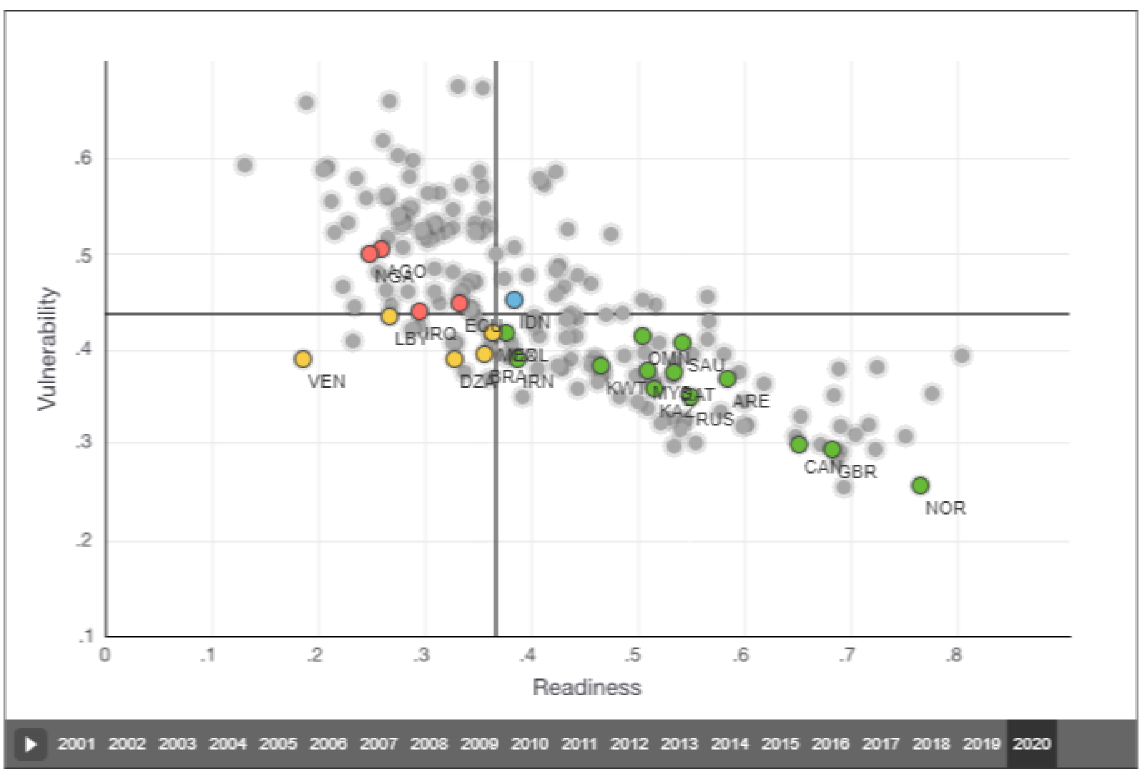
ND-GAIN Country Index assesses countries' exposure and their abilities to mitigate risks emerging from climate change and their capacities to adapt to different scenarios. Therefore, ND-GAIN evaluates both the *Vulnerability* and *Readiness* of countries to climate change. To optimize the outcomes of this quest, ND-GAIN uses 45 indicators. It uses 36 variables to assess vulnerabilities, which include the country's exposure, sensitivity, and capacity to adapt to climate change. Furthermore, it uses 9 variables to measure a country's economic, governance, and social readiness to face climate change challenges. Graphs 1 and 2 provide us with the evolution of Vulnerability and Readiness indicators in oil-exporting countries between 2 points, namely 2001 and 2020. One can notice a valuable positive development in terms of Readiness. It explains countries' pro-activity to face climate change challenges by embarking on necessary structural reforms and supporting transition steps. However, little change is observed in the Vulnerability index. It may be explained by the fact that countries cannot do much about physical exposure, like the geographical situation, quality of crops, and water sources.

Graph 1: Vulnerability and Readiness in oil-exporting countries in 2001



Source: Author calculation from ND-GAIN

Graph 2: Vulnerability and Readiness in oil-exporting countries in 2020



Source: Author calculation from ND-GAIN

Using the NG-GAIN indices as a proxy of climate change and some control variables, we construct the general function in equation (1):

$$RGDP_t = f(Vul_t, Ready_t, Cons_t, GFCF_t, Oilp_t) \quad (1)$$

Then, we analyze the impact of climate change on economic growth in oil-exporting countries using the econometric model in equation (2):

$$LnRGDP_t = \beta_0 + \beta_1 LnVul_t + \beta_2 LnReady_t + \beta_3 LnCons_t + \beta_4 LnGFCF_t + \beta_5 LnOilp_t + \varepsilon_t \quad (2)$$

where *RGDP* is the real income, *Vul* is the vulnerability index, *Ready* is the readiness index, *Cons* is the real total consumption, *GFCF* is the real gross fixed capital formation, and *Oilp* is the oil production. All the variables are expressed in natural logarithm. β_0 denotes the constant term, while β_1 to β_5 denote long-term elasticities. Finally, ε_t represents the error term.

Our empirical strategy follows several steps. We test for cross-sectional dependence and slope homogeneity/heterogeneity in the first step. In the second step, we assess the integration order of the variables. If there is cross-sectional dependence, we use the second-generation unit root tests, which consider crosse sectional dependence. In the third step, we investigate the long-run relationship among variables. Finally, considering some important control variables, we use several estimators to analyze the relationship between climate change and economic growth in oil-exporting countries. Section 4 will provide further details.

3.1 Cross-section dependence and slope heterogeneity tests

With globalization, countries have become highly interrelated and connected. It is especially true between oil-exporting countries due to their relationship with the global oil market. Al Rousan *et al.*, (2018) illustrated the dynamic network structure of major oil-producing countries. The authors investigate the oil production coordination between OPEC and non-OPEC countries. They find that both parties' decisions may affect each other. Consequently, neglecting cross-section dependence between these countries in our panel analysis is risky. Grossman and Krueger (1995) and Westerlund and Edgerton (2007) suggested that it may lead to inconsistent and biased results.

Oil-exporting countries share many characteristics. However, they are also heterogeneous in many fields. Hence, mechanically assuming a homogenous slope coefficient between cross-sections may also lead to biased results (Breitung, 2005; Jalil, 2014).

Therefore, we test for cross-sectional dependence using multiple tests[3] and slope heterogeneity using Pesaran and *Yamagata* (2008) and Blomquist and Westerlund (2013) to avoid misleading information and biased results. Both tests should precede unit root tests. It is a necessary step to choose the most appropriate panel unit root tests.

Pesaran and Yamagata's (2008) test is an upgraded version of Swamy's (1970) test. It suggests two "Delta" statistics:

$$\tilde{\Delta}= \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{\sqrt{2k}}\right) \sim X_k^2 \tag{3}$$

$$\tilde{\Delta}_{adj}= \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{v(T,k)}\right) \sim N(0,1) \tag{4}$$

where N represents the number of cross-sections unit, S represents the Swamy test statistic, and k represents the number of independent variables. The null hypothesis suggests that slope coefficients are homogenous. The adjusted "Delta" is a mean-variance bias-adjusted version of the regular "Delta"

The Blomquist and Westerlund (2013) test considers the presence of cross-sectional dependence. It is worth mentioning that this test relaxes homoscedasticity and serial independence. Nevertheless, It is consistent with heteroscedasticity and autocorrelation consistent (HAC) and also suggests two delta test statistics:

$$\Delta_{HAC}= \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{\sqrt{2k}}\right) \sim X_k^2 \tag{5}$$

$$(\Delta_{HAC})_{adj} = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{v(T,k)}\right) \sim N(0,1) \tag{6}$$

The null hypothesis is the same as in Pesaran and Yamagata (2008).

[3] Pesaran (2015, 2021), Juodis, Reese (2021), Fan *et. al*. (2015), and Pesaran, Xie (2021).

3.2 Unit Root and Cointegration Tests

We employ a panel unit root test to investigate the stationarity and level of integration of the variables used in this work. However, if the cross-sectional dependence is confirmed, the first-generation panel unit root tests are inconsistent. Consequently, we will employ the second-generation unit root test, the CIPS test, suggested by Pesaran (2007) according to the following equation:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i \ (N,T) \quad (7)$$

After identifying the order of integration, we will proceed with panel cointegration tests. We apply the four most used panel cointegration tests. Specifically, Kao (1999), Pedroni (2005), Westerlund (2005), and Westerlund and Edgerton (2007) tests to investigate the existence of a long-run equilibrium relationship between the variables.

4. Empirical results

As discussed, the first step is the check for the exitance of cross-sectional between oil exporting countries and slopes properties in these countries. According to Table 3, the four CSD tests reject the null hypothesis of weak cross-sectional dependence and confirm a strong one (except CD* for consumption and vulnerability index). Therefore, we employ a second-generation unit root to test the stochastic properties of the variables while considering cross-sectional dependency between countries of our sample.

Table 3: Weak Cross-Sectional Dependence Tests (CSD)

	CD	CDw	CDw+	CD*
Lrgdp	80.96***	9.27***	1297.06***	-1.70*
Lcons	80.90***	9.27***	1296.03***	0.94
Lgfcf	79.71***	9.28***	1277.13***	-2.34**
Lvuln	81.08***	9.30***	1298.91***	-1.30
Lready	80.12***	9.31***	1283.77***	3.52***
Loilp	80.98***	9.28***	1297.40***	5.89***

Note: CD: Pesaran (2015, 2021), CDw: Juodis, Reese (2021), CDw+: Fan et. al. (2015), and CD*: Pesaran, Xie (2021). ***, **, * indicate significance level of 1%, 5%, 10%, respectively.

Moreover, Table 4 reveals that both tests reject the null hypothesis of slope homogeneity. These results confirm that slopes in oil-exporting countries are heterogeneous. Therefore, the right way to suggest tailored country-level policy recommendations is to run estimations at the country level, as the slopes are heterogeneous. Deriving policy recommendations based on panel analysis may be misleading because of heterogeneous slopes.

Table 4: Slope heterogeneity test

Delta	20.506***
Delta_Adjusted	23.987***
Delta_HAC	84.650 ***
Delta_ HAC_Adjusted	99.023 ***

Note: *** indicates a significance level of 1%. We implement HAC robust option to consider potential autocorrelation and heteroscedasticity.

Table 5 describes the level of integration of the variables. With the presence of cross-sectional dependence, a second-generation panel unit root test is necessary. The test confirmed that all the data have a unit root in level. All series became stationary when applying the CIPS test on the first difference at 1% significance level. The statement is similar with both configurations, namely with and without trends. All variables are integrated of order one: I(1).

Table 5: Panel unit root tests.

Variables	**CIPS with trend**		**CIPS without trend**	
	Level	**First difference**	**Level**	**First difference**
Lrgdp	0.386	-8.099***	0.109	-9.639***
Lcons	0.078	-8.678***	-0.199	-9.609***
Lgfcf	-0.925	-11.257***	0.091	-12.551***
Lvuln	-0.880	-10.104***	-0.225	-12.991***
Lready	0.058	-10.746***	1.236	-12.464***
Loilp	3.089	-6.545***	1.006	-7.952***

Note: *** indicates a significance level of 1%.

The next step is to investigate the long-run equilibrium between variables. We employed four tests, namely Pedroni (1999, 2004), Kao (1999), Westerlund (2007), and Westerlund (2007) with Bootstrap, to check whether our variables are cointegrated or not. Table 6 provides the results of all four tests. The null hypothesis H0 is: no cointegration, and the alternative is: All panels are cointegrated. The results of the four tests are represented in Table 6

All Pedroni (1999, 2004) test statistics rejected the null hypothesis at a 5% minimum. It confirms strong cointegration between variables. Four of five Kao(1999) test statistics approved cointegration between variables except for the Augmented Dicky-Fuller. The significance varies from 1% to 10%. We can conclude that the Kao test also confirmed the cointegration between variables. Only two of four statistics in Westerlund's (2007) test confirm the cointegration. However, when we ran the test with Bootstrap, three of four proved the cointegration at a very high significance level. We conclude that all variables are cointegrated using several tests.

Table 6: Cointegration tests.

Pedroni (1999, 2004) with constant and trend					
Statistics	Modified Phillips-Perron t	Phillips-Perron t	Augmented Dickey-Fuller t		
Sample value	1.923**	-2.950***	-2.240**		
Kao (1999) with constant					
Statistics	Modified Dickey-Fuller t	Dickey-Fuller t	Augmented Dickey-Fuller t	Unadjusted modified Dickey-Fuller t	Unadjusted Dickey-Fuller t
Sample value	-1.3635*	-1.5455*	-0.1124	-2.5334***	-2.1878**
Westerlund (2007) without Bootstrap					
Statistics	Gt	Ga	Pt	Pa	
Sample value	-2.493*	-7.001	-12.024***	-8.650	
Westerlund (2007) with Bootstrap					
Statistics	Gt	Ga	Pt	Pa	
Sample value	-2.493***	-7.001	-12.024**	-8.650**	

Notes: *, **, and *** indicate rejection of the null hypothesis of no cointegration at the 1%, 5%, and 10% significance levels, respectively.

Table 7 describes long-run estimation results from both 1st and 2nd generation estimation methods. Our choice of using the 1st generation methods is motivated by having a benchmark for comparison between 1st and 2nd generation methods' results. Moreover, it demonstrates how it is crucial to consider the cross-sectional dependency effect when investigating the relationship between climate change and economic growth in oil-exporting countries. The results confirm the expected sign and significance in most cases, except for the Vulnerability index. The following discussion will explain the possible interpretations.

Rows 2 to 4 reveal the estimation results from three different estimators: Fixed-effect, Between-effects, and Mean Group. These methods ignore the potential CD effect. While rows 5 to 7 reveal estimation results from Common Correlated Effects Mean Group, Augmented Mean Group, and Regularized Common Correlated Effects Mean Group, all considering the CD effect.

The estimated coefficients from the Fixed-effect and Between-effects are pretty distinct from those in the last three rows, particularly the magnitude and significance of *Vul*, *Consum*, and *GFCF*. The CD effect may explain this. In other words, neglecting the CD effect may provide misleading results of those variables on the real gross domestic product.

The Common Correlated Mean group and its regularized version results provide the optimal statistical significance and expected sign. We will use the results of the former for interpretation purposes. We begin with our main variables of interest, namely the Vulnerability and Readiness indices. A 1% increase in readiness will boost the real GDP by 0.07%. The result is statistically significant at 5%. Adapting policies and business environments to mitigate climate change will support economic activities. However, a 1% increase in vulnerabilities will reduce real GDP by 0.28%. If governments do not implement the necessary reforms, the effects of climate change will dampen economic growth. Nevertheless, the variable is not significant in the long run. This means that efforts to enhance readiness will offset the adverse effects of vulnerabilities on the real GDP. In the estimation, we added three important control variables that may affect the economic growth of oil-exporting countries in the long run: total consumption, gross fixed capital formation, and oil-exporting nations. The empirical results suggest that all variables positively affect economic growth, and the results are statistically very significant, i.e., 1%.

A 1% rise in total consumption, gross fixed capital formation, and oil production will increase real GDP by 0.3%, 0.1%, and 0.23%, respectively. We notice that oil will keep playing an important role in shaping economic activity in these countries. Also, high liquidity and oil windfalls will support private and public consumption. Moreover, investment in infrastructure technologies will also support economic growth and energy transition toward more clean energy.

Table 7: Estimations

Regressor	*Consum*	*Gfcf*	*Vul*	*Ready*	*oilp*	*D.C.*
FE	0. .477*** (0.097)	0.086* (0.045)	-2.137** (0. 966)	0.000 (0.105)	0.256* (0.069)	*t*
BE	0. 663*** (0. 056)	0. 210*** (0. 064)	0. 117 (0. 222)	0. 312** (0. 123)	0. 071 (0. 030)	*c*
MG	0. 518*** (0. 072)	0. 129*** (0. 036)	-0. 488 (0. 412)	0. 116* (0. 064)	0. 260*** (0. 056)	*c*
CCE-MG	0.300*** (0. 067)	0. 102*** (0. 0156)	-0. 275 (0. 267)	0. 075** (0. 036)	0. 230*** (0. 047)	*c*
AUG-MG	0.335*** (0. 073)	0. 104*** (0. 026)	0. 134 (0. 297)	0. 012 (0. 044)	0. 228*** (0. 043)	*c*
RCCE	0. 350*** (0. 063)	0.099*** (0.166)	-0.029 (0.334)	0.108** (0.046)	0.248** (0. 041)	*c*

Notes: Dependent variable is *rgdp*. *, **, and *** indicate rejection of the null hypothesis at the 1%, 5%, and 10% significance levels, respectively. F.E., B.E., and M.G. stand for Fixed-effects, Between-effects, and Mean Groups, respectively. CCE, AUG, and RCCE denote Common Correlated Effect, Augmented mean group, and regularized Common Correlated Effect. *D.C.* stands for deterministic components. It can be constant (c) only or constant and trend (t) depending on its statistical significance. We did not exclude constant if it is statistically insignificant because it is hard to assume that the rgdp initial level is zero during the period under consideration. The number of observations = 26 (Time series observations) x 23 (Number of countries) = 598.

5. Empirical results

This work aimed to investigate the impact of climate change on economic growth in oil-exporting countries. The novelty of this paper is to use variables that consider several effects of climate change, including both physical and mitigation risks. Furthermore, this work considers a set of countries, where pollutant energy source is the main source of revenues and of energy.

As discussed, the relationship between climate change and the economic activity is complex and can be treated from different angles. Mitigating and adapting to climate change require coordinated efforts from governments, businesses, and individuals to minimize the negative economic impacts while maximizing the potential benefits of a sustainable and resilient future. Firstly, mitigation policies to reduce gas emissions to slow down climate change. It may include Carbon pricing in form of carbon tax or cap-and-trade system. It will incentivize emitters to reduce their emissions. Secondly, supporting renewable energy production and use and ensure smooth energy transition from oil to cleaner energy sources. Solar, wind and hydropower are good alternatives. Thirdly, implementing energy efficiency standards to reduce energy demand. It can be integrated in construction, transportation, and several kind of appliances. While adaptation policies which aim to prepare for and respond adequately to the effects of climate change are also very important. It mainly concern investment in infrastructure to protect the economy from extrem weather events like floods and rising sea levels i.e. flood protection systems, sea walls, sewage and water management systems.

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