



Examining the Relationship between Renewable Energy Consumption and Total Factor Productivity on Consumption-Based Carbon Emissions in Major Oil-Exporting Countries

## دراسة العلاقة بين استهلاك الطاقة المتجددة والإنتاجية الكلية للعوامل على انبعاثات الكربون المعتمدة على الاستهلاك في الدول الرئيسية المصدرة للنفط

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### Abstract

Carbon emissions represent a major global challenge threatening sustainability. As the energy sector is a key contributor to greenhouse gas emissions, this study examines the impact of renewable energy use and total factor productivity on consumption-based carbon emissions in 10 major oil-exporting countries during 2000–2020 using the Generalized Method of Moments (GMM). Unlike traditional measures, the study adopts consumption-based carbon emissions as the dependent variable. The independent variables include renewable energy consumption, total factor productivity (TFP), GDP, imports, and exports. The results show a statistically significant negative relationship between renewable energy use, TFP, and carbon emissions. Specifically, a 1% increase in renewable energy consumption and TFP reduces consumption-based carbon emissions by approximately 2% and 18%, respectively. The study recommends adopting incentive policies to promote renewable energy use, implementing carbon taxes, encouraging investment in clean energy, and adopting productivity-enhancing technologies.

**Keywords:** Renewable energy consumption, Total factor productivity, GMM, Oil exporting countries ..

### المستخلص:

أعد انبعاثات الكربون من أبرز التحديات العالمية التي تهدد الاستدامة، ولا سيما أن قطاع الطاقة يُعد من أكبر المساهمين في انبعاثات غازات الدفيئة. لذلك تهدف هذه الدراسة إلى تحليل أثر استخدام الطاقة المتجددة والإنتاجية الكلية لعوامل الإنتاج على انبعاثات الكربون القائمة على الاستهلاك في عشر دول رئيسية مصدرة وعلى خلاف المؤشرات (GMM) للنفط خلال المدة 2000–2020، باستخدام منهجية العزوم المعممة التقليدية، اعتمدت الدراسة انبعاثات الكربون القائمة على الاستهلاك كمتغير تابع. أما المتغيرات المستقلة، والناتج المحلي الإجمالي، (TFP) فتضمنت استهلاك الطاقة المتجددة، والإنتاجية الكلية لعوامل الإنتاج والواردات، والصادرات. وأظهرت النتائج وجود علاقة عكسية ذات دلالة إحصائية بين استخدام الطاقة المتجددة والإنتاجية الكلية من جهة، وانبعاثات الكربون من جهة أخرى. إذ إن زيادة استهلاك الطاقة المتجددة بنسبة 1% تؤدي إلى خفض الانبعاثات بنحو 2%، في حين أن زيادة الإنتاجية الكلية بنسبة 1% تخفض الانبعاثات بنحو 18%. وأوصت الدراسة بتبني سياسات تحفيزية لدعم استخدام الطاقة المتجددة، وتطبيق ضريبة الكربون، وتشجيع الاستثمار في الطاقة النظيفة واعتماد التقنيات المعززة للإنتاجية

**الكلمات المفتاحية:** استهلاك الطاقة المتجددة، الإنتاجية الكلية للعوامل، طريقة العزوم المعممة، الدول المصدرة للنفط.

## 1. Introduction

The climate has changed a lot over the last few decades. This change has impacted almost all aspects of life. Carbon production and its emission turned out to a major factor affecting environmental quality. As a result, it has taken the centre stage of the policy agenda and research program. Since human activity had the largest greenhouse gas emissions, the energy sector has become a central driver of environmental damage. As a result, policymakers, researchers, and international organizations now consider sustainably reducing carbon emission a major objective. But traditional carbon accounting, which only focuses on pollution produced, does not do justice to the harm done by consumption. Because of this, we have opted for the CBCE as a better measure for carbon emissions. CBCE assigns emissions to the end consumer, irrespective of where the good or service was produced (Davis & Caldeira, 2010), unlike productionbased ones. Energy-exporting countries are important agents in carbon emission because they are major producers of them. Many fossil fuel-producing countries are also among the highest CO<sub>2</sub> emitters in the world. But their energy imports and domestic consumption of carbon-intensive goods and services are relatively low compared with their total emissions (Hasanov et al., 2024). Because of their fossil fuel exports, which fulfil the energy needs of other countries and help the global economy grow, energy-exporting countries find themselves in a unique position in the global carbon cycle. The embedded emissions in these exports do not enter the inventory of these countries. This disconnection is creating a rift between profit and planet. Considering the CBCE is helpful in assessing the factors that imbalance it. Renewable energy consumption and total factor productivity have been considered key indicators of the transition to sustainable energy systems. People use renewable energy to cut carbon emission to the lowest level. It entails reducing fossil fuel consumption. Consequently, clean energy sources, such as solar, wind, and hydro

power, replace the former energy sources. The energy system alternatives make a contribution to the lowering of carbon intensity. Furthermore, they are now essential for effective decarbonization strategies (Shafiei & Salim, 2014; Vasilenko et al., 2017). Moreover, investing in renewable energy can generate longer-term benefits, including enhanced energy independence, improved energy security and the creation of new economic opportunities.

Also, TFP denotes the efficiency of capital, labor, and resource usage in producing a firm's output. Higher TFP is usually associated with technology improvements, better resource management, and innovation, which all lead to lower energy intensity and carbon emissions (Färe et al. 1994). For energy-exporting economies, TFP is particularly important because it allows them to achieve economic growth without carbon emissions. It also increases their global competitiveness. Although many researchers are writing about renewable energy and productivity, the joint impact of these on CBCE is yet to be examined, particularly in energy-exporting countries. Countries like Oman face economic dependence on fossil fuel earnings. This limited incentive towards the switch to the renewable energy and varying levels of technology development. With this in mind, this research tries to analyze the impact of renewable energy consumption as well as total factor productivity on consumption-based carbon emissions in major energy-exporting economies.

The rest of the current paper is structured as follows. Section 2. explained the review of literature, section 3. provide a deep explanation for the methodology, section 4. depicts the results of the study and section 5. concludes and showcases recommendations.

## 2. Literature Review

### 2.1. Theoretical Foundations

The base of consumption-based carbon emissions (CBCE), renewable energy consumption (REC) and total factor productivity (TFP) needs to deal with environmental economics, theory of International trade and production economics. CBCE gives a different way of thinking about how we view carbon emissions. It allows us to calculate and measure them differently than when we use a production-based approach. When production-based measures assign emissions to the country where goods are produced. Meanwhile, the CBCE reallocates along global supply chains to represent the carbon footprint of final consumption (Davis & Caldeira, 2010). This distinction is very important for energy-exporting countries, where a large part of carbon emissions does not come from domestic use, but from fossil-fuel exports. If policymakers and researchers take a consumption-based approach, they will better understand responsibilities for global emissions and design more effective decarbonization efforts. The CBCE framework has thus become important in tackling the problems faced by conventional production-based measures, especially in a globalized world with significant international trade. Countries that export energy typically have a large difference in emitted gases depending on what being used to measure it. The producing countries are fossil fuel exporters, and under standard accounting schemes, the greenhouse gas emissions scored from the transport and use of fossil fuels are assigned to the importing countries of Petersen et al. (2011). This creates a situation where accountability for environmental damage is imbalanced. Externalities thus arise when environmental damage caused by oil extraction, refining, and transport, such as oil spills, takes place outside the exporting or importing countries. CBCE gives a chance to understand the impact of carbon emissions in a

holistic way. Countries that export energy are often less accountable for emissions according to this measure, which is based on consumption. This is because much of their carbon-intensive output is exported. Meanwhile, these countries are feeling pressure to turn greener. A global switch to cleaner energy sources is taking place. The future of fossil fuel is bleak. (Chen & Li, 2020).

## 2.2. Renewable Energy Consumption and Carbon Emissions

The relationship between renewable energy consumption (REC) and carbon emissions has become one of the most extensively researched topics in environmental and energy economics over the past decade. The core theoretical expectation is straightforward: replacing fossil fuels with low- or zero-carbon renewable sources (solar, wind, hydro, geothermal, modern biomass) directly reduces the carbon intensity of energy supply and, consequently, CO<sub>2</sub> emissions.

Shafiei and Salim (2014) provided early robust evidence using a panel of 29 OECD countries over the period 1980–2011. Applying the STIRPAT framework and panel cointegration techniques (FMOLS, DOLS), they estimated long-run elasticities of  $-0.38$  for renewable energy consumption and  $+1.12$  for non-renewable energy consumption with respect to CO<sub>2</sub> emissions. Their Granger causality tests further confirmed unidirectional causality running from renewable energy to lower emissions, supporting the substitution hypothesis. The study also detected an environmental Kuznets curve, with urbanization initially increasing emissions but eventually reducing them at higher income levels when renewable penetration becomes significant.

In energy-exporting contexts, where fossil fuels dominate both production and consumption, the emission-reducing potential of renewables is equally pronounced, albeit starting from a very low base. Mukhtarov et al. (2023) focused on Azerbaijan – a classic oil-rich economy where renewables accounted for less than 2 % of total

final energy consumption for most of the post-Soviet period. Using ARDL bounds testing, fully modified OLS (FMOLS), dynamic OLS (DOLS), and canonical cointegrating regression (CCR) over 1993–2019, they found that a 1 % increase in renewable energy consumption reduces consumption-based CO<sub>2</sub> emissions by approximately 0.26 % in the long run. Short-run dynamics were weaker but still negative and significant. The authors stressed that Azerbaijan’s extremely high reliance on natural gas and oil for electricity generation (over 93 %) explains why even modest renewable expansion yields measurable emission reductions.

Similar results emerge from natural gas-exporting countries. Chen and Li (2020) analysed a panel of major gas exporters and documented that greater renewable energy shares significantly curb both territorial and consumption-based emissions, even after controlling for economic growth and energy intensity. Their findings suggest that renewables not only substitute domestically but also lower the carbon footprint embedded in exported natural gas when downstream combustion is reallocated under consumption-based accounting.

Broader cross-country evidence reinforces these conclusions. Vasilenko et al. (2017) examined 26 European economies and reported a strong negative correlation between renewable energy share and per capita CO<sub>2</sub> emissions, with wind and solar showing the largest marginal effects. Hasanov et al. (2024b), studying the top 40 nations ranked by Ernst & Young’s Renewable Energy Country Attractiveness Index (RECAI) between 1990 and 2018, employed second-generation panel estimators (CCE-MG, AMG, Driscoll-Kraay) that account for cross-sectional dependence, slope heterogeneity, and endogeneity. Their results indicate long-run elasticities ranging from –0.30 to –0.42: a 10 % increase in the renewable share of final energy consumption reduces CO<sub>2</sub> emissions by 3.0–4.2 %. The effect is statistically significant in 85 % of individual country regressions.

Hasanov et al. (2024a) shifted the focus explicitly to natural gas exporters and consumption-based emissions. Using the same advanced panel techniques, they confirmed that renewable energy consumption exerts a robust negative impact on CBCE, with elasticities between  $-0.32$  and  $-0.39$  across specifications. Importantly, the negative effect persists even when trade openness and export concentration are controlled for, indicating that domestic renewable deployment reduces the carbon intensity of the entire economy, including exported energy commodities.

Despite the consistent evidence, energy-exporting countries face unique barriers to scaling renewables. Mukhtarov et al. (2023) highlight heavy fossil fuel subsidies, low regulated electricity tariffs, and institutional inertia as key obstacles in Azerbaijan. Chen and Li (2020) note similar subsidy-driven distortions across gas exporters. Policy recommendations therefore converge on subsidy reform, carbon pricing, feed-in tariffs or auctions, and redirecting hydrocarbon rents toward renewable infrastructure. Overall, the literature overwhelmingly supports the conclusion that renewable energy consumption is one of the most effective and direct levers for reducing both production-based and consumption-based carbon emissions, with particularly high marginal returns in fossil-fuel-dependent economies.

### **2.3. Total Factor Productivity and Carbon Emissions**

Total factor productivity (TFP) – the efficiency with which capital, labour, and intermediate inputs are converted into output – is increasingly recognised as a critical driver of environmental performance. In the Solow-Swan growth model and its extensions, long-run economic growth is determined exclusively by technological progress, commonly measured through TFP (Färe et al., 1994). From an environmental perspective, higher TFP reduces energy and material intensity per unit of GDP, thereby decoupling economic activity from carbon emissions.

The seminal contribution linking TFP directly to emission outcomes in recent years comes from Hasanov et al. (2024b). Analysing the top 40 RECAI countries (1990–2018) with second-generation panel methods, they report long-run TFP elasticities of CO<sub>2</sub> emissions ranging from –0.44 to –0.51 across CCE-MG, augmented mean group (AMG), and Driscoll-Kraay estimators. In other words, a percentage of 1 % improvement in TFP reduces emissions by nearly half a percent – making productivity the single strongest explanatory variable in their models, outperforming even renewable energy share. The mechanism operates through multiple channels: better resource allocation, adoption of cleaner production techniques, energy-saving technological change, and innovation spillovers that lower the cost of low-carbon technologies.

Hasanov et al. (2024a) extended the analysis to natural gas-exporting countries using consumption-based emissions data. Their results are even more striking: TFP elasticities range from –0.41 to –0.58, with the highest values obtained under estimators that correct for cross-sectional dependence and non-stationarity. The negative relationship remains robust when controlling for trade openness, export concentration, and renewable energy consumption, confirming that productivity improvements reduce emissions independently of energy mix changes.

Chen and Li (2020) provided complementary evidence from natural gas exporters, showing that countries experiencing sustained TFP growth (e.g., Norway and Qatar in certain sub-periods) achieved absolute emission declines despite continued hydrocarbon extraction for export markets. Conversely, exporters suffering TFP stagnation or decline (e.g., Venezuela and Iran in recent decades) exhibited rising energy intensity and emissions, illustrating the environmental cost of the resource curse.

The theoretical foundation for these empirical findings lies in production economics. Higher TFP reflects technological progress, improved management practices, and better factor allocation – all of which tend to reduce energy use per unit of output. Färe et al. (1994) demonstrated that industrialised countries with rapid TFP growth also experienced substantial efficiency gains and technical progress, which naturally translate into lower emission intensity when energy is a major input.

Importantly, several studies identify strong complementarity between TFP and renewable energy consumption. Hasanov et al. (2024a, 2024b) include interaction terms and find statistically significant negative coefficients, indicating that the emission-reducing effect of renewables is amplified in high-TFP environments, and vice versa. High productivity lowers the relative price of renewable technologies through learning-by-doing and innovation, while renewable deployment stimulates demand for advanced manufacturing, digitalisation, and smart grids – all TFP-enhancing activities.

Energy-exporting economies often suffer from low or stagnant TFP growth due to Dutch disease, rent-seeking, and weak institutions. Chen and Li (2020) and Mukhtarov et al. (2023) document how heavy reliance on hydrocarbon rents crowds out human capital accumulation and diversifies economic activity, suppressing productivity. Overcoming these barriers requires deliberate policy action: investing oil and gas revenues in education, R&D, and infrastructure; improving governance and reducing corruption; and promoting economic diversification. When successful, such reforms yield a double dividend of higher growth and lower emissions.

In summary, the literature provides overwhelming evidence that total factor productivity is among the most powerful determinants of carbon emission reduction. Elasticities typically exceed those of renewable energy in absolute terms, and the two variables reinforce

each other. For energy-exporting countries seeking to reconcile continued fossil fuel production with global climate goals, productivity-enhancing reforms represent an essential and under-appreciated component of any credible decarbonisation strategy.

In addition, the summary of compiled from all the contexts is provided to easily focus on the impact of renewable energy consumption (REC) and total factor productivity (TFP) on carbon emissions (production-based or consumption-based) in table 1.

**Table 1. Summary of the relevant studies.**

| Authors (Year)                                 | Countries of Study  | Years of Study | Methodology            | Key Results (Shortened)   |
|--|---------------------|----------------|------------------------|---|
| <b>Davis &amp; Caldeira (2010)</b>             | Worldwide           | 2004           | MRIO                   | Developed countries' ↑ CBCE* (offshoring effect).   |
| <b>Peter et al. (2011)</b>                     | 68 Countries        | 1990–2008      | MRIO                   | Trade ↑ embodied carbon. Developed countries' production-based CO <sub>2</sub> ↓; CBCE ↑. |
| <b>Shafiei &amp; Salim (2014)</b>              | 29 OECD countries   | 1980–2011      | STIRPAT; Cointegration | REC** ↑ → CO <sub>2</sub> ↓ (Elasticity ≅ -0.38).   |
| <b>Vasilenko et al. (2017)</b>                 | 27 Europe countries | 1990–2014      | Panel Data             | Strong negative correlation between REC share and Wind/Solar have largest effects.        |
| <b>Kargar-Dehbidy &amp; Bakhshoudeh (2019)</b> | OPEC & Non-Oil Asia | 1995–2013      | FMOLS, ECM             | Fossil fuel ↑ → CO <sub>2</sub> ↑ (OPEC stronger effect).<br>REC ↑ → CO <sub>2</sub> .    |
| <b>Rahbar et al. (2019)</b>                    | Iran                | 1997–2015      | Panel VAR              | Energy productivity ↑ → CO <sub>2</sub> significant ↓                                     |
| <b>Masoudi et al. (2019)</b>                   | IRENA Members       | 1990–2016      | Panel data             | Innovation, Non-REC, GDP ↑ → CO <sub>2</sub> ↑ . REC ↑ → CO <sub>2</sub> ↓                |

|  |                        |           |               |  |
|--|------------------------|-----------|---------------|--|
| <b>Arefian et al. (2020)</b>   | OECD                   | 1990–2014 | Panel-VAR     | Non-REC ↑ → CO2↑.<br>REC, Trade openness ↑ → CO2 ↓                         |
| <b>Chen &amp; Li (2020)</b>  | Natural Gas Exporters  | N/A       | Panel data    | REC ↑ → CO2 ↓.<br>Sustained TFP*** ↑ → CO2 ↓                               |
| <b>Zabihi et al. (2023)</b>  | G7                     | 2019–2021 | Quantile Reg. | Wind/Solar ↑ significantly constrains CO2, effect varies by firm/quantile. |
| <b>Mohammadi et al. (2023)</b>   | Developing Nations     | 2000–2019 | GMM           | REC and Economic complexity ↑ → CO2 ↓.<br>Trade openness ↑ → CO2↑.         |
| <b>Mukhtarov (2023)</b>  | Turkey                 | 1990–2019 | ARDL          | REC, TFP ↑ → CO2 ↓.<br>Income and Imports ↑ → CO2↑.                        |
| <b>Mukhtarov et al. (2023)</b>   | Azerbaijan             | 1993–2019 | ARDL, FMOLS   | 1% REC ↑ → CBCE ↓ 0.26%  |
| <b>Mukhtarov et al. (2024)</b>   | Oil-Rich Countries     | 1993–2019 | DOLS          | REC ↑ → CO2 ↓ (1% REC → 0.26% ↓). GDP ↑ → CO2↑.                            |
| <b>Hasanov et al. (2024a)</b>  | Natural Gas Exporters  | 1990–2020 | Panel data    | REC, TFP ↑ → CBCE ↓. Significantly.  |
| <b>Hasanov et al. (2024b)</b>  | Top 40 RECAI Countries | 1990–2018 | Panel data    | TFP ↑ is strongest variable → CO2 ↓. REC ↑ → CO2 ↓                         |
| <b>Hasanov et al. (2025)</b>   | Renewable Dependent    | 1990–2025 | Panel data    | TFP in energy sectors ↑ → CO2 ↓.   |
| * CBCE: Consumption-Based Carbon Emissions<br>** REC: Renewable Energy Consumption<br>*** TFP: Total Factor Productivity |                        |           |               |  |

## 4. Methodology

Studying the impact of Renewable Energy Consumption (REC) and Total Factor Productivity (TFP) on emissions is vital because they represent the key policy levers for achieving decoupling sustaining economic growth while mitigating climate change. Therefore, this study investigates the impact of renewable energy consumption and total factor productivity (TFP) on carbon emissions in the ten major oil-exporting countries, based on the International Energy Agency (IEA) reports and data availability, over the period 2000–2020.

Hence, the hypotheses of the study are as follows:

H1: Using more renewable energy decreases CO<sub>2</sub> emissions.

H2: Incse in total factor productivity decrease CO<sub>2</sub> emissions.

### 4.1. Model Specification and Data Description

This study investigates the impact of renewable energy consumption and total factor productivity (TFP) on carbon emissions in the ten major oil-exporting countries<sup>1</sup>, based on the International Energy Agency (IEA) reports and data availability, over the period 2000–2020. The empirical model applied in this study follows Hasanov et al. (2024a) and is specified as follows:

$$CCO2_{it} = \alpha_0 + \alpha_1 IM_{it} + \alpha_2 EX_{it} + \alpha_3 REN_{it} + \alpha_4 GDP_{it} + \alpha_5 TFP_{it} + u_{it} \quad (1)$$

In this equation, all variables are transformed into their natural logarithmic forms to avoid multicollinearity issues. CCO<sub>2</sub> represents consumption-based carbon emissions, while IM, EX, REN, GDP, and TFP denote imports, exports, renewable energy consumption, income (proxied by GDP), and total factor productivity, respectively. The term  $u$  denotes the error component. The variables of the study include

CO<sub>2</sub> emissions (in million tons) due to consumption (CCO<sub>2</sub>), total factor productivity index (TFP), real GDP per capita in constant 2015 US dollars (GDP), exports of goods and services (EX) as % of GDP, imports of goods and services (IM) as % of GDP and share of renewable energy (REN) in total energy consumption. The Global Carbon Atlas, Penn World Table (PWT), and the World Bank's World Development Indicators (WDI) database provided the data, respectively. Using CO<sub>2</sub> emissions to quantify carbon emissions offers various benefits. This captures all carbon emissions embodied in domestic consumption as well as imports, and the international trade aspect allows for the analysis of the distinction between production-based and consumption-based emissions (Wiebe & Yamano, 2016; Peters et al., 2012; Hasanov et al., 2024a). Incorporating trade indicators such as exports and imports enables the differentiation between these two dimensions: exports represent goods produced domestically but consumed abroad implying a negative relationship with consumption-based carbon emissions whereas imports represent goods produced abroad but consumed domestically, which are expected to have a positive impact on consumption-based emissions (Hasanov et al., 2018). Furthermore, renewable energy consumption is expected to exert an inverse effect on CO<sub>2</sub> emissions, while GDP representing a country's level of income and economic activity is anticipated to have a positive effect. Finally, total factor productivity (TFP), as a measure of technological progress and innovation, is hypothesized to reduce carbon emissions. Summary information about the data and their expected sign is shown in Tables (2) and (3).

Table 2. Description of Variables and Data Sources

| <b>Variable</b> | <b>Definition</b>                  | <b>Unit of Measurement</b>    | <b>Source</b>       | <b>Reference Papers</b>                     |
|-----------------|------------------------------------|-------------------------------|---------------------|---|
| <b>CCO2</b>     | Consumption-based carbon emissions | Million tons                  | Global Carbon Atlas | Hasanov et al. 2024.; Mukhtarov et al. 2023 |
| <b>TFP</b>      | Total factor productivity index    | 2017 = 100                    | PWT                 | Hasanov et al. 2024                         |
| <b>REN</b>      | Renewable energy consumption       | Share of total energy use (%) | WDI                 | Hasanov et al. 2024.; Mukhtarov et al. 2023 |
| <b>EX</b>       | Exports of goods and services      | Share of GDP (%)              | WDI                 | Mukhtarov et al. 2023                       |
| <b>IM</b>       | Imports of goods and services      | Share of GDP (%)              | WDI                 | Hasanov et al. 2024.; Mukhtarov et al. 2023 |
| <b>GDP</b>      | GDP per capita                     | Constant 2015 USD             | WDI                 | Hasanov et al. 2024.; Mukhtarov et al. 2023 |

Table 3. Expected Signs of Variables

| <b>Variable</b> | <b>Definition</b>                  | <b>Expected Sign</b> |
|-----------------|------------------------------------|----------------------|
| <b>CCO2</b>     | Consumption-based carbon emissions | —                    |
| <b>TFP</b>      | Total factor productivity          | Negative (-)         |
| <b>REN</b>      | Renewable energy consumption       | Negative (-)         |
| <b>EX</b>       | Exports of goods and services      | Negative (-)         |
| <b>IM</b>       | Imports of goods and services      | Positive (+)         |
| <b>GDP</b>      | GDP per capita                     | Positive (+)         |

The descriptive statistics of the main variables of the research model for the countries under study are shown in Table (4). As is clear from the table, the highest consumption-based carbon emissions are related to the United States with an average of approximately 6035 million tons per year. After that, the Russian country is in second place with an average of 1297 million tons. In contrast, the lowest emissions are related to Qatar with an average of 45 and Norway with an average of 47 million tons per year. Also, Iran, Russia, Saudi Arabia and the United States have very high standard deviations, which indicates that the carbon emissions in these countries have been very scattered in the years under study. The lowest standard deviation is related to Norway, which indicates stability in carbon emissions in different years.

Table 4. Descriptive Statistics of Consumption-Based Carbon Emissions in Selected Countries (Million Tons)

| Country       | Minimum  | Maximum  | Mean     | Standard Deviation |
|---------------|----------|----------|----------|--------------------|
| Canada        | 480.2638 | 607.7214 | 564.7733 | 33.21035           |
| Iran          | 290.5976 | 690.1095 | 492.2631 | 113.8637           |
| Kazakhstan    | 103.0586 | 195.8848 | 150.6114 | 25.04291           |
| Kuwait        | 33.2868  | 107.4039 | 74.80908 | 22.07506           |
| Mexico        | 441.5031 | 562.0422 | 504.3453 | 37.51478           |
| Norway        | 31.98871 | 55.13340 | 47.04230 | 5.932476           |
| Qatar         | 17.28550 | 76.49350 | 45.11750 | 19.96922           |
| Russia        | 996.2989 | 1471.615 | 1297.305 | 125.3261           |
| Saudi Arabia  | 210.4451 | 652.9513 | 478.8393 | 148.2505           |
| United States | 5186.863 | 6722.182 | 6034.911 | 429.4765           |

Source: Research Findings

#### 4.2. Model Estimation Results

To estimate the model, the lagged form of the dependent variable was included as an explanatory variable to capture the dynamic process of carbon emission behavior (Jiang & Ma, 2019). To tackle the potential endogeneity due to the lagged dependent variable being correlated with the error term, the dynamic panel generalized method of moment was applied. When the dependent variable at level is non-stationary,

use of GMM will be valid as per the dynamic property of the process. The panel unit root tests results based on Levin, Lin, and Chu (LLC) are presented in Table 5.

Table 5. Panel Unit Root Test Results

| Variable    | Level     |             | First Difference |             |
|-------------|-----------|-------------|------------------|-------------|
|             | Statistic | Probability | Statistic        | Probability |
| <b>CCO2</b> | -1.6245   | 0.0674      | -4.69286         | 0.0001      |
| <b>TFP</b>  | -1.76896  | 0.0385      | -5.83440         | 0.0000      |
| <b>REN</b>  | -1.33260  | 0.0913      | -5.81844         | 0.0000      |
| <b>EX</b>   | -1.07755  | 0.1406      | -6.05204         | 0.0000      |
| <b>IM</b>   | -1.91651  | 0.0277      | -4.59014         | 0.0000      |
| <b>GDP</b>  | -3.90131  | 0.0000      | -2.01496         | 0.0220      |

Source: Research Findings

In the results of the unit root test, GDP variables are at level stationary, and the other variables are stationary at first order difference. To examine the cointegration of the variables, the Pedroni test was used, which is shown in Table (6). According to the results, the existence of a long-term cointegration relationship between the research variables is confirmed and the model estimator will be free of spurious regression.

Table 6. Pedroni Panel Cointegration Test Results

|   | Test   | Statistic     | Probability | Weighted<br>Statistic | Probability |
|---|--|---------------|-------------|-----------------------|-------------|
| <b>Within-<br/>Dimension<br/>Tests</b>  | Panel  | 1.75182       | 0.0399      | 0.826877              | 0.2042      |
|   | Panel p<br>Phillips-<br>Perron (PP)<br>test  | 1.722516      | 0.9575      | 1.999390              | 0.9772      |
|   | Panel t<br>Phillips-<br>Perron (PP)<br>test  | -<br>4.621685 | 0.0000      | -4.296216             | 0.0000      |
|   | Augmented<br>Dickey-<br>Fuller (ADF)<br>test | -<br>3.969165 | 0.0000      | -4.048936             | 0.0000      |
| <b>Between-<br/>Dimension<br/>Tests</b> | Panel p<br>Phillips-<br>Perron (PP)<br>test  | 3.112881      | 0.9991      | —                     | —           |
|   | Panel t<br>Phillips-<br>Perron (PP)<br>test  | -<br>7.202754 | 0.0000      | —                     | —           |
|   | Augmented<br>Dickey-<br>Fuller (ADF)<br>test | -<br>4.753865 | 0.0000      | —                     | —           |

Source: Research Findings

The estimation results obtained using the GMM method are summarized in Table 7. As shown, the lagged CO<sub>2</sub> emission variable has a positive and statistically significant coefficient of 0.26, suggesting that a 1% increase in past emissions leads to a 0.26%

increase in current emissions. Furthermore, total factor productivity (TFP) exhibits a significant negative coefficient of  $-0.18$ , implying that improvements in productivity reduce carbon emissions. This finding is consistent with the results reported by Hasanov et al. (2024a)

Table 7. Estimation Results of the Model Using the GMM Method

| Variable                  | Coefficient | Probability |
|---------------------------|-------------|-------------|
| <b>CO<sub>2</sub>(-1)</b> | 0.2564      | 0.0106      |
| <b>TFP</b>                | -0.1795     | 0.0134      |
| <b>REN</b>                | -0.0241     | 0.0365      |
| <b>EX</b>                 | -0.2802     | 0.0076      |
| <b>IM</b>                 | 0.1882      | 0.0103      |
| <b>GDP</b>                | 0.3665      | 0.0009      |
| <b>Sargan Test</b>        | 82.626625   | 0.000014    |

Source: Research Findings

An increase in factor productivity reduces carbon emissions by 18%. In fact, TFP is an indicator and measure of the level of technology and efficiency, it can be said that technological progress reduces the emission of pollutants (carbon dioxide). Since newer technologies are cleaner and have fewer emissions than older technologies and bring greater efficiency and productivity, they reduce the field of carbon emissions. Given that the oil-exporting countries studied in the study have a great diversity in their economic structures, the level of technology, technology and knowledge at their disposal is also different, and this has caused the coefficient obtained to be relatively small. Whereas, if the selected countries have homogeneous

structures, the TFP coefficient is expected to be larger and its effect on reducing pollution will be greater. The use of renewable energy has a -0.02 and has a negative and significant effect on reducing carbon emissions and is in line with the results of Masoudi et al. (2010), Mukhtarov (2023) and Vaslinko et al. (2017). Renewable energies or reversible energies that are obtained from sources other than fossil fuels do not directly cause pollution and, as a result, reduce the level of pollutants and especially carbon emissions. As before, the obtained coefficient is small due to the differences in the countries. For example, among the selected countries and in the period under study, the share of renewable energies in total energy consumption in Saudi Arabia and Kuwait is very small, but it is significant in Canada and Norway, and the obtained coefficient does not show this difference. If countries used renewable energies in consumption in almost similar proportions, the REN coefficient would be much higher. Similar to Peter et al. (2011), exports also have a negative and significant coefficient of -0.28 and imports have a positive and significant coefficient of 0.18, as expected. When the absolute value of the elasticity of exports is greater than that of imports, it shows that exports reduce carbon emissions from consumption more than imports increase them. According to the research of Mukhtarov et al. (2023), the coefficient of GDP per capita of 0.37 has a positive and significant effect on carbon emissions. In fact, every 1% increase in income leads to a 37% increase in carbon dioxide from consumption. An increase in per capita income causes demand and consumption of goods and services, which results in an increase in carbon emissions.

## 5. Conclusion and Recommendations

This study investigates how renewable energy consumption and total factor productivity (TFP) influence consumption-based carbon emissions from 2000 to 2020, using the Generalized Method of Moments (GMM). Because fossil-fuel exporters generate substantial pollution through fuel trade and transport, the analysis focuses on ten major oil-exporting countries: Canada, Iran, Kazakhstan, Kuwait, Mexico, Norway, Qatar, Russia, Saudi Arabia, and the United States. Although these countries differ considerably in energy use, technological capacity, and income levels, such variations are unlikely to significantly affect the study's results.

The findings indicate that higher renewable energy use and greater productivity both help reduce carbon emissions. Shifting toward sustainable energy sources—such as solar and wind—plays a crucial role in curbing emissions. TFP improvements contribute through two main channels:

Technological advancement, which enables cleaner production methods and supports the transition from fossil fuels to renewable energy.

Efficiency gains in both production and consumption, which reduce environmental degradation and consequently lower greenhouse gas emissions, including CO<sub>2</sub>.

Other model variables, such as exports and imports, also significantly affect emissions. Exports are associated with lower carbon emissions, whereas imports contribute to higher emissions, reflecting the broader environmental implications of trade and globalization. Additionally, GDP per capita positively impacts emissions, suggesting that rising income levels increase production and consumption, thereby raising emission levels.

These results highlight the importance of replacing fossil fuels with renewable energy sources. Policies such as financial incentives, tax exemptions, and subsidies can encourage renewable energy adoption and improve production efficiency. Implementing a carbon tax on fossil-fuel-related production, consumption, and trade can further reduce fossil-fuel demand while generating revenue that can be reinvested in advanced, efficient energy technologies—such as hydrogen-based systems.

The study's findings offer several important policy directions for governments, especially in oil-exporting nations. First, policymakers should prioritize the expansion of renewable energy infrastructure by creating stable regulatory frameworks, long-term investment strategies, and public-private partnership opportunities. Second, governments should support innovation systems that strengthen technological capability, such as investing in research and development, promoting clean technology transfer, and enhancing workforce skills. Third, carbon pricing mechanisms—including carbon taxes or emissions trading systems—should be designed to balance economic growth with environmental sustainability, ensuring that polluters face clear incentives to transition toward cleaner production. Finally, trade policies should integrate environmental considerations by encouraging low-carbon exports and reducing dependence on carbon-intensive imports. Together, these policy actions can accelerate the shift toward a low-carbon economy while supporting productivity-driven economic growth.

In conclusion, future research should explore country-specific analyses to better understand how renewable energy use and productivity influence carbon emissions and to facilitate meaningful comparisons across countries.

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