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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

TESTING THE EXTENDED STIRPAT MODEL FOR LOW-CARBON ECONOMY IN THE MENA REGION*

MENA BÖLGESİNDE DÜŞÜK KARBONLU EKONOMİ İÇİN GENİŞLETİLMİŞ STIRPAT MODELİNİN TEST EDİLMESİ

Canan ŞENTÜRK **
Selin KAYA ***
Onur SUNGUR ****

Abstract

On a global scale, waste and carbon are increasing because of the reasons such as rising population, urbanization, consumption, industrial production, and energy demand etc. Moreover, according to the World Economic Forum's global risks map, environmental problems and climate change have been among the most important risks since 2011. The fact that economic growth, one of the basic components of sustainable development, is limited to linear processes (rather than closed-loop/circular systems) threatens another component, environmental quality. Therefore, the importance of growth with a low-carbon economy model emerges both on a global and national scale. In this context, the study aims to provide a more comprehensive framework for investigating the main arguments for a low-carbon economy and environmental degradation in the MENA region. The variables of trade openness and renewable energy are added to the main elements of the STIRPAT model. The extended model is tested with the ARDL

* This study is a revised version of the paper with the same title that was presented at the 20th International Conference of the Middle East Economic Association (MEEA), hosted by Istanbul Topkapı University on September 13–14, 2024, and published in the conference abstract book.

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bounds test approach for the period 1990-2020. While population, affluence, and technology variables give statistically significant results in the long term, the effect of the trade openness variable is observed in the short term. 38% of the effect of the shock is eliminated after a period from deviation from long-term equilibrium following short-term shocks.

Keywords: Sustainable Development, Environmental Degradation, Trade Openness, Renewable Energy, The MENA Region.

JEL Classification: Q01, Q5, F00.

Öz

Nüfus artışı, tüketimdeki çeşitlenme ve artış, sanayi üretiminin artması, kentleşmenin yoğunlaşması ve enerji ihtiyacının artması gibi sebeplerle yaratılan atık ve karbon miktarı küresel ölçekte gün geçtikçe artmaktadır. Öyle ki, Dünya Ekonomik Forumu'nun küresel riskler haritasına göre çevre sorunları ve iklim değişikliği 2011 yılından itibaren en önemli riskler arasında yer almaktadır. Ayrıca sürdürülebilir kalkınmanın temel bileşenlerinden biri olan ekonomik büyümenin (kapalı döngü/döngüsel sistemler yerine) doğrusal süreçlerle sınırlı kalması, bir diğer bileşen olan çevresel kaliteyi tehdit etmektedir. Dolayısıyla hem küresel hem de ulusal ölçekte düşük karbonlu ekonomi modeliyle büyümenin önemi ortaya çıkmaktadır. Bu bağlamda, çalışma Orta Doğu ve Kuzey Afrika (MENA) bölgesinde düşük karbonlu ekonomi ve çevresel bozulmaya ilişkin temel argümanların araştırılması için daha kapsamlı bir çerçeve sağlamayı amaçlamaktadır. Sürdürülebilirlik ilkesinden hareketle MENA bölgesi için 1990-2020 dönemi verileri esas alınarak, STIRPAT modelinin temel unsurları olan refah, nüfus ve teknolojiye; yenilenebilir enerji ve ticari dışa açıklık değişkenleri eklenmekte ve genişletilmiş STIRPAT modeli ARDL sınır testi yaklaşımıyla test edilmektedir. Uzun dönemde nüfus, refah ve teknoloji değişkenleri istatistiksel olarak anlamlı sonuçlar verirken; dışa açıklık değişkeninin etkisi kısa dönemde gözlenmektedir. Ayrıca kısa dönem şoklarını takiben uzun dönem dengesinde oluşacak sapmadan bir dönem sonrası, söz konusu şokun etkisinin %38'inin giderilebildiği; yani uyarlanma sürecinin yavaş olduğu sonucuna ulaşılmaktadır.

Anahtar Kelimeler: Sürdürülebilir Kalkınma, Çevresel Bozulma, Ticari Açıklık, Yenilenebilir Enerji, MENA Bölgesi

JEL Sınıflandırması: Q01, Q5, F00.

1. Introduction

Undoubtedly, every country wants to accelerate and increase economic growth, thus trying to reach the status of a developed country. Achieving economic growth is one of the essential objectives of countries. Economic and financial development and progress are extremely important in terms of meeting the needs of society. The importance of economic growth is also evident in the literature (see Domar, 1946; Harrod, 1939; Romer, 1990; Solow, 1956). However, this situation can also lead to some environmental degradation. Particularly following the industrial revolution, the increase in production volumes also brought environmental problems. In particular, increased fossil fuel consumption leads to air pollution and, as a result, health problems. Therefore, climate degradation that occurs during economic progress is among the main concerns according to the climate perspective (Xing et al., 2023). There is a consensus that CO2 emissions have been increasing, especially since the early 2000s, and as a result, the climate has been seriously damaged and deteriorated. This poses a serious threat to the environment and life support systems (Roy et al., 2017). The global increase in greenhouse gas emissions (especially CO2), which contributes to climate warming, has become a major concern (Fu et al., 2015).

The Middle East and North Africa (MENA) is a region that stands out with its proximity to major markets and its young and educated population (OECD, 2024). However, it is known that the region is significantly affected by climate change and struggles with environmental pollution issues (World Bank Group, 2023). To become low-carbon countries, the World Bank Group (2022a) recommends the MENA countries to (i) manage agriculture and natural resources wisely; (ii) use renewable energy sources; (iii) implement climate-focused urban planning; and (iv) support green investments.

According to data from the World Development Indicators (World Bank, 2024), the MENA countries had CO2 emissions per capita of around 5.033 metric kilotons in 2020, which is about 17.3% higher than the world average. The region, however, achieved a reduction in CO2 emissions per capita of 8.75% from 2016 to 2020, better than the world average. On the other hand, it is asserted that the air pollution rate in the metropolitan cities of the MENA countries is among the top in the world (World Bank Group, 2022b). This shows that pollution is a major obstacle for the MENA countries to increase their economic growth.

In this context, achieving economic growth with minor damage to the environment is on the agenda of many countries. Many studies (Grossman and Krueger, 1995; Nordhaus, 1991) show that environmental security is essential for long-run economic growth. It is also seen that the fight against climate change and the sustainable use of the terrestrial ecosystem are also addressed within the framework of the United Nations' (2024) Sustainable Development Goals.

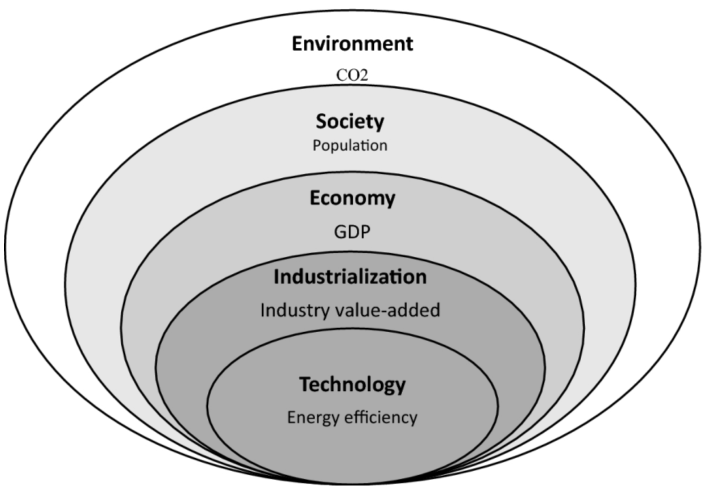


Figure 1: Strong Sustainability Principle

Source: Nasrollahi et al. (2020; 1109).

Within the framework of Cato (2012)'s green economy view and strong sustainability principle and low-carbon economy, the fact that natural capital cannot be copied gives primary importance to environmental quality. The complementary features of strong sustainability foundations are reflected in Figure 1. Therefore, the environment (CO2, GHG etc.) is the main factor that feeds, serves and hosts economy (GDP), society (Population), industrialization (industrial value-added), technology

(Cato, 2012). In this context, the study examines the environment, society and economy not as 'substituting' but as 'complementary' Nasrollahi et al. (2020; 1109). Within the three dimensions of sustainability (Economy, Society, Environment), technology connected to industry, welfare and population as well as trade and energy are also examined.

Low-carbon economy proposes the use of various methods to reduce greenhouse gas/carbon dioxide emissions by minimizing the consumption of high carbon/primary energy in the axis of green/ecological economy, circular economy and sustainable development. Therefore, the process requires a structure where economy, society, and environment develop together (Grainger and Smith, 2021).

The fight against climate change and de-carbonization policies, both on a global scale and in national economies, create an important external driving force for energy transformation in the MENA region, and bring the region to a point where cooperation with other countries is mandatory. In addition, the solution of negativities such as climate change, air and water temperature increase, water scarcity, desertification, etc. constitutes the internal driving factor that directs the countries in the region to the said policy harmonization and cooperation.

Considering their economic potential, as well as their poor environmental performance, this study aims to empirically examine the pollution in the MENA countries. In this study, the main arguments regarding low-carbon economy and environmental degradation are examined for the MENA region using the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. Trade openness and renewable energy variables are added to the main elements of the STIRPAT model, which are population, welfare and technology, and the 1990-2020 period data is used for the MENA region.

The content of the study is as follows. Following the introduction, a literature review is presented, and then the data, methods and research findings are presented. The study is completed with conclusions and policy recommendations.

2. Literature Review

There are many studies in the literature that investigate the effects of economic growth on the environment using the STIRPAT model. These studies can be grouped as studies focusing on multi-country analyses and studies with single-country analyses.

Xing et al. (2023) used STIRPAT model for the middle-income countries of Asia, which are experiencing rapid growth, urbanization, and infrastructure development, which had its toll on deforestation and habitat loss. Zineb (2016) used CO2 emissions, per capita GDP, industrial activity, population growth and some control variables by using data from 176 countries and validated the STIRPAT model. Awad and Warsame (2017) verified the STIRPAT model by utilizing data from 54 nations in Africa. Anser et al. (2020), concluded that the STIRPAT model was valid for SAARC nations.

Apart from multi-country analyses, there are various studies based on single country analysis. Since China is the world's largest carbon emitter, there are many studies using the STIRPAT model for this country. Yan, Guo and Lin (2010), Huo, Yang and Tang (2012), Peng and Zhu (2010), Xu and Zhou (2011), Wang et al. (2011), Shao, Yang and Cao (2010), Ren, Gen and Xue (2012), He and Zhanf (2012) and Fu et al. (2015) used the STIRPAT model to investigate carbon emissions, urbanization and urban development patterns in various districts of China.

Studies on the countries other than China can be given as examples for India (Roy et al., 2017), Malaysia (Shahbaz et al., 2016), Taiwan (Yeh and Liao, 2017), Bangladesh, India, and Pakistan (Khan et al., 2018) and Turkey (Ibrahim et al., 2017).

In general, the population indicators positively correlated with emissions. For example, Xing et al. (2023) and Huang et al. (2021) get similar results for Asian middle-income countries and Chinese provinces, respectively. In addition, energy consumption variables seem to increase emission levels. Energy intensity in Bangladesh (Aziz & Chowdhury, 2023) and per capita energy use in emerging economies (Banday & Kocoglu, 2023) are associated with higher emission levels.

There are also studies focusing on global panels. To illustrate, Kocoglu et al. (2024) examine the effects of various factors on CO2 emissions per capita in 181 countries. Using panel threshold and dynamic panel quantile threshold regressions, they reveal that energy efficiency and forest extent lower the CO2 emissions per capita, while GDP per capita and urban growth are found to have positive impacts. Similarly, McGee et al. (2015) concentrate on 173 countries using a spatial error model. Their results show that population, GDP per capita, urban area, land area, and impervious surface area contribute to CO2 emissions.

In summary, there are few analyses based on 'the extended STIRPAT model' for the MENA region in the empirical literature. Therefore, the current study aims to contribute to the few studies addressing the subject in the international environmental economics literature by adding new ones with up-to-date data.

3. Data, Method, and Research Findings

The study aims to provide a more comprehensive framework for investigating the main arguments for a low-carbon economy and environmental degradation in the MENA region. Based on the principle of sustainability, the variables of trade openness and renewable energy are added to the main elements of the STIRPAT model (population, affluence, and technology). The extended STIRPAT model is tested with the ARDL bounds test approach using data from the MENA region for the period 1990-2020. In this context, the extended version of STIRPAT reformulated by Dietz and Rosa (1994, 1997) is used in the study. The basic equation of the model is based on the IPAT (Impacts, Population, Affluence, and Technology) model developed by Ehrlich and Holdren (1971):

$$I = P.A.T$$

$$I = \alpha . P_i^b . A_i^c . T_i^d e_i$$

α in the equation represents the constant. I represents the environmental impact; b, c, d represent the exponents of P (population), A (affluence) and T (technology), respectively, which need to be estimated. However, unlike IPAT, the STIRPAT model is a stochastic model that can be used to empirically test hypotheses (Dietz and Rosa, 1997). According to Dietz and Rosa (1997), the term technology includes not only technology as it is generally perceived, but also social organization, institutions, culture and all other factors that express the impact of humans on the environment, apart from population and welfare. Therefore, since it is important to include these factors, which are restricted within the term technology, in the model, trade openness and renewable energy are included in the model. Explanations regarding the variables of the model for the period 1990-2020 are given in Table 1 below.

Table 1: Definition of Variables

CO	CO2 Emissions (kg per 2015 US$ of GDP)	World Bank
POP	Population	World Bank
AFF	Affluence (Gross Domestic Product, annual %)	World Bank
TEC	Technology (Patent applications, residents)	World Bank
OPEN	Trade (% of GDP)	World Bank
RE	Renewable Energy Consumption (% of total final energy consumption)	World Bank

The expanded version of the STIRPAT model is presented in the following equation:

$$co = \alpha + b(pop) + c(aff) + d(tec) + d(open) + d(re) + e$$

Firstly, the unit root tests developed by Phillips and Perron (1988) and Dickey and Fuller (1981) are used to test the stationary of the variables, and then the diagnostic tests are presented by giving the ARDL long-term estimation results, ARDL bounds test and error correction model findings, respectively.

Table 2: Unit Root Tests

	I (0)				**I (I)**			
Variables	**Augmented Dickey-Fuller (ADF)**		**Phillips-Perron (PP)**		**Augmented Dickey-Fuller (ADF)**		**Phillips-Perron (PP)**	
CO	-2.2277	0.2012	-2.3050	0.1770	-4.5802	0.0011*	-4.5802	0.0011*
POP	0.2697	0.9722	-1.3687	0.5840	-4.6314	0.0010*	-3.1655	0.0327**
AFF	-4.1860	0.0028*	-4.2478	0.0024*	-8.9669	0.0000*	-11.1259	0.0000
TEC	-0.2720	0.9150	-1.1983	0.6619	-3.4648	0.0188**	-10.0026	0.0000
OPEN	-1.2681	0.6309	-1.2681	0.6309	-3.8560	0.0065*	-3.9151	0.0056*
RE	-1.8030	0.3717	-1.7981	0.3742	-2.9411	0.0429**	-2.9781	0.0489**

Note: *, **, signs indicate that the variables are significant at 1% and 5% significance levels, respectively.

According to the ADF and PP unit root test results presented in Table 2, it can be said that the variables have become stationary at the first difference (I(I)). For the next stage, ARDL, it is important not to have the series become cointegrated at the same level, but to examine whether there are variables that have become stationary at the second degree, and the results are deemed appropriate for this condition. In cases where the variables are stationary at the same degree [I(I)] or some variables are stationary at the level [I(0)], in other words, regardless of the degrees of integration of the series, the Autoregressive Distributed Lag Model (ARDL) developed by Pesaran and Pesaran (1997), Pesaran, Shin and Smith (2001) is used to test the long-term relationship between the series. In addition, if cointegration is detected between the variables in the model, the Error Correction Model is estimated to investigate the correctability of the imbalance that will occur in the short term in the long term. Accordingly, the optimal lag length is determined by taking into account the AIC information criterion and the appropriate model is determined as ARDL (1,0,0,0,2,0).

Table 3: Long-Run Regression, ARDL (1, 0, 0, 0, 2, 0)

Dependent Variable: CO				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
POP	0.127088	0.042770	2.971438	0.0075*
AFF	-0.014206	0.005758	-2.467131	0.0228**
TEC	-3.15E-06	1.39E-06	-2.257264	0.0353**
OPEN	0.001304	0.000892	1.461078	0.1595
RE	-0.023493	0.023344	-1.006413	0.3262
EC = CO – (0.1271*POP – 0.0142*AFF – 0.0000*TEC + 0.0013*OPEN – 0.0235*RE)				

Note: * p-value incompatible with t-Bounds distribution. * and ** signs indicate that the variables are significant at 1% and 5% significance levels, respectively.

According to the long-term estimation results (Table 3), as a result of the analysis carried out based on the extended STIRPAT model, it is observed that the POP, AFF, and TEC variables representing the population, welfare, and technology variables are statistically significant. The coefficient sign of the POP variable is positive, meaning that population growth has a negative effect on carbon emissions. On the contrary, it can be said that the coefficient signs of the welfare and technology indicators are negative, indicating that both variables have a reducing effect on carbon emissions (and therefore environmental degradation). Although the coefficient signs of the trade openness and renewable energy variables are as expected, the variables do not have statistical significance in the long term. At this stage, the ARDL bounds test is important. When the critical values are taken as basis, if the F statistic value is greater than the upper limit, there is a cointegrated relationship. However, if the F statistic value is smaller than the lower limit at the critical values, there is no cointegrated relationship between the variables.

Table 4: Bounds Test ARDL (1, 0, 0, 0, 2, 0)

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	**9.436164**	10%	2.578	3.858
k	5	5%	3.125	4.608
		1%	**4.537**	**6.37**

According to the bounds test results for the cointegrated relationship in Table 4, since the calculated F-statistic is higher than the upper critical value at the 0.01 significance level (9.436164 > 6.37). It is decided that there is a long-term relationship between the variables and the long-term equation is expressed as follows:

EC = CO – (0.1271*POP – 0.0142*AFF – 0.0000*TEC + 0.0013*OPEN – 0.0235*RE)

Table 5: ECM Regression ARDL (1, 0, 0, 0, 2, 0)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.201194	0.023857	8.433304	0.0000*
D(OPEN)	0.000752	0.000463	1.625365	0.1197
D(OPEN(-1))	-0.001134	0.000490	-2.314314	0.0314**
CointEq(-1)*	-0.384147	0.045663	-8.412564	0.0000*
R-squared	0.744170			
Adjusted R-squared	0.713470			

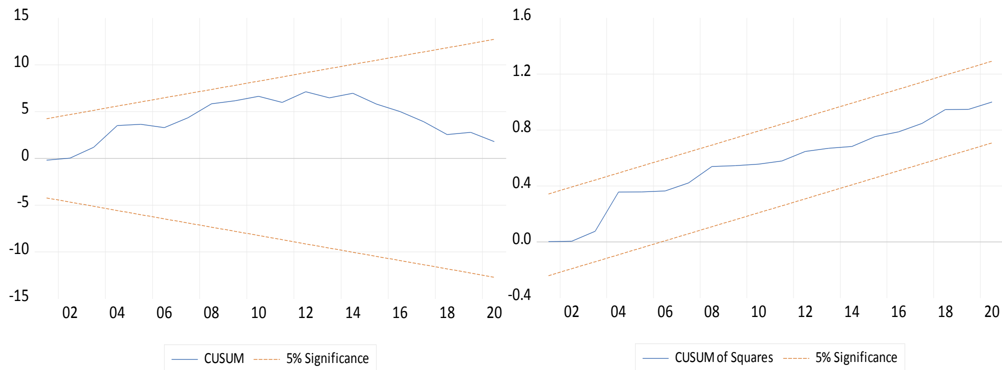
Note: * p-value incompatible with t-Bounds distribution. * and ** signs indicate that the variables are significant at 1% and 5% significance levels, respectively.

The error correction model results are given in Table 5. Accordingly, it is observed that there is a statistically significant relationship between CO and trade openness with a lag of 1 in the short term. The direction of the relationship between OPEN and the dependent variable is negative and its coefficient is 0.001134. The error correction term coefficient (CointEq(-1)) is determined as –0.384147; its sign is negative as expected and it is observed to be statistically significant. In this case, it can be interpreted that a deviation from the balance that will occur in the short term will be corrected after 2.6 periods (years) and converge to the long-term balance. 38% of the effect of the shock is eliminated after a period from deviation from long-term equilibrium following short-term shocks. In other words, it is concluded that the adaptation process is slow.

Table 6: Diagnostic Tests

Breusch-Godfrey Serial Correlation LM Test	0.198198 (0.8220)
Jarque-Bera Normality Test	0.304694 (0.858690)
Breusch-Pagan-Godfrey Heteroskedasticity Test	0.509912 (0.8348)
Ramsey RESET Test	0.150836 (0.7021)
CUSUM Tests	Stable

According to the diagnostic test results of the model in Table 6, Graph 1, and 2, it can be said that there is not autocorrelation (Breusch-Godfrey LM Test) and heteroscedasticity problem (Breusch-Pagan-Godfrey Test) in the model. And the error term is normally distributed (Jarque-Bera Test), the model is established with the correct specifications (Ramsey Reset Test) and the estimated parameters are stable (CUSUM Tests). Therefore, these results support the reliability of the obtained estimation results.



Graph 1: Cusum and Cusum of Squares Tests

4. Conclusion

The world is an isolated place where constant change is experienced; and everything that happens on it is part of a cycle. In connection with this structure, it can be said that every change that consumes something creates the need for another change that enables the re-feeding of those things. Within the framework of industrial ecology and environmental quality in a growing economy, it can be said that the linear economy, which is a subset of all possible discourses and objects in the world, is open to three important structures consisting of matter, energy and information. With Boulding's (1966) emphasis on cowboy / spaceship economies, which describes the thermodynamics of a closed loop / circular economy; the need for a closed loop economic system arises, considering that systems in today's economy can be open or 'closed' according to a series of input and output classes. Therefore, this issue, which is of vital importance for climate stability in the new economy, covers an extremely challenging area and necessitates the systematic design of near-zero-carbon-neutral-low-carbon economies for the new economy.

The study aims to provide a more comprehensive framework for investigating the main arguments for a low-carbon economy and environmental degradation in the MENA region. With Cato's (2012) emphasis on green economy view and strong sustainability principle and low-carbon economy, the fact that natural capital cannot be copied gives primary importance to environmental quality. Therefore, the environment (CO_2, GHG etc.) is the main factor that feeds, serves and hosts economy (GDP), society (population), industrialization (industrial value-added), technology (Cato, 2012). Within the three dimensions of sustainability (economy, society, environment), technology connected to industry, affluence and population as well as trade and energy are also examined. Based on the principle of sustainability, the extended STIRPAT model is tested with the ARDL bounds test approach using data from the MENA region for the period 1990-2020.

According to the long-term estimation results, it is observed that the POP, AFF, and TEC variables representing the population, affluence and technology variables are statistically significant. The coefficient sign of the POP variable is positive, meaning that population growth has a negative effect on carbon emissions. On the contrary, it can be said that the coefficient signs of the welfare and technology indicators are negative, indicating that both variables have a reducing effect on carbon emissions (and therefore environmental degradation). According to error correction model results, it is observed that there is a statistically significant relationship between CO and trade openness with a lag of 1 in the short term. The direction of the relationship between OPEN and the dependent variable is negative and its coefficient is 0.001134. The error correction term coefficient (CointEq(-1)) is determined as – 0.384147; its sign is negative as expected and it is observed to be statistically significant. In this case, it can be interpreted that a deviation from the balance that will occur in the short term will be corrected after 2.6 periods (years) and converge to the long-term balance. 38% of the effect of the shock is eliminated after a period from deviation from long-term equilibrium following short-term shocks. In other words, it is concluded that the adaptation process is slowly.

The transformation in the energy system that supports the transition to low-carbon energy on a global scale has led to different speeds of adaptation to change, especially in the energy sector, due to internal difficulties in the MENA countries. This situation varies depending on the lack of homogeneity among the countries in the region and whether the countries have hydrocarbon resources. In light of these results, sectors based on primary energy resources such as oil and natural gas account for more than half of both exports and GDP in most countries in the region. For example, in Saudi Arabia, it covers 70% of exports and 50% of GDP in 2019. For this reason, it can be said that economic diversification is of great importance for the countries in the region in terms of both carbon reduction and sustainability. On the other hand, it is thought that with technological solutions, the MENA countries can contribute to overall de-carbonization by creating more job opportunities both in the production of blue and green hydrogen and in its supply to other countries. In particular, the competitive advantage of the MENA countries, which are rich in hydrocarbon/primary energy resources, is based on low-cost reserves and long-term and excellent knowledge in the industry. Therefore, the long-term sustainability of the hydro-carbon industry depends on increasing investments in capital-intensive carbon capture, utilization and storage (CCUS) technology, as it will enable the de-carbonization of petroleum products. Although the study findings do not find a statistically significant relationship between renewable energy and carbon emissions, the existence of significant wind and solar energy potential in the countries of the region suggests that investments in the development of renewable energy will contribute to environmental quality by enabling the diversification of energy sources. In summary, it is thought that a road map that includes plans and targets in this direction at the MENA region scale, as well as national policies, will be more efficient for the development of sectors such as energy, industry, transportation, construction and agriculture, which are primarily attributed as the source of emissions in economies, towards a low-carbon economy.

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