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# Innovations and the CO<sub>2</sub> Emissions Nexus in the MENA Region: A Spatial Analysis

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**Abstract:** Patents support technological innovations in any economy and would also support a clean environment. We investigate the effects of economic growth, patents, industrialization, and urbanization on CO<sub>2</sub> emissions in 17 Middle East and North Africa (MENA) economies by applying spatial econometrics. We substantiate the Environment Kuznets Curve (EKC) in the domestic economies and the whole MENA region as per direct and total estimates. Moreover, urbanization increases CO<sub>2</sub> emissions in local economies and reduces neighboring nations' emissions. The total effect of urbanization is found to be insignificant. Industrial value added increases CO<sub>2</sub> emissions in domestic and neighboring countries, as well as in the whole MENA region. Patents increase CO<sub>2</sub> emissions in domestic economies. However, patents reduce CO<sub>2</sub> emissions in neighboring countries and the MENA region. Thus, patents have a pleasant effect on the environment in the whole MENA region. It is suggested that the MENA economies focus more on patents to reduce CO<sub>2</sub> emissions. Moreover, urbanization and the industrial sector should be checked to protect the environment.

**Keywords:** CO<sub>2</sub> emissions; patents; urbanization; economic growth; the EKC



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## 1. Introduction

The Middle East and North Africa (MENA) countries have natural resource-rich economies. Their economic growth is mostly dependent on the oil and natural gas sectors and could have environmental concerns for the region, as most of the MENA region's emissions flow from the energy sector [1]. The Paris Agreement is continuously putting pressure on member countries to reduce pollution emissions and global warming [2]. Along the same lines, the Sustainable Development Goals (SDGs) also have the same objectives: to reduce pollution and promote sustainable development worldwide [3]. However, these pollution-reduction goals are a challenge for the MENA region because of its heavy reliance on pollution-oriented oil and natural gas production. Moreover, many MENA countries are among the world's top polluters. For instance, in the year 2020, six MENA countries were on the top 10 polluters list of per capita CO<sub>2</sub> emissions. Additionally, 8% of global CO<sub>2</sub> emissions are contributed by the whole MENA region [4]. To follow the target of the Paris Agreement, the MENA region is striving toward Renewable Energy Consumption (REC). This transformation was just followed by Morocco and Jordan, and most MENA countries have a minute contribution of REC in the energy mix [5]. To reduce pollution in these highly polluted economies, there is a need for innovation to introduce

energy-efficient and less polluting technologies. During the last two decades, the level of innovation has remained low in most MENA countries except Iran and Israel. For instance, Iran and Israel produced 8753 and 6886 patents annually on average during 2000–2019, respectively. In the same years, Egypt, Saudi Arabia, and Morocco produced on average 1781, 1229, and 1017 patents annually, respectively. However, the remaining MENA countries produced less than 1000 patents annually [4]. Thus, there is a need to test whether the level of innovation is sufficient to reduce pollution emissions or not. Moreover, innovation would help in the transformation of MENA economies from pollution-oriented oil and gas sectors to less-polluted industries and sectors. In addition, innovation may help reduce dependence on fossil fuels by providing alternative clean energy sources, and it could also increase energy and production efficiencies. Thus, less-polluted economic sectors, cleaner energy sources, and energy efficiency could help in the reduction of pollution emissions by technique and/or composition effects in the economies. On the other hand, innovation may have a dominant scale effect by increasing overall economic activities and energy consumption, which would pollute the environment consequently. Therefore, the net effect of innovation on the environment is an empirical question, and the present study is motivated to empirically investigate this question in a maximum sample of MENA countries to verify whether innovation helps in the reduction of emissions or not.

In the debate on REC, Research and Development (R&D) could play a significant role in transferring the economy from fossil fuels to cleaner energy. Moreover, it would improve the efficiency of the industrial and energy sectors [6]. Thus, technical innovations generated by R&D activities could help raise energy efficiency and reduce emissions [7]. Moreover, Murphy [8] argued that technical innovations would raise production efficiency, which would optimize the output with a lower level of energy and other inputs to maintain sustainable development in an economy. In macroeconomic pollution studies, we cannot ignore the effect of economic growth in determining emissions. A pioneering study by Grossman and Krueger [9] established a nonlinear association between economic progress and emissions. Subsequently, the Environmental Kuznets Curve (EKC) becomes a working horse in the environmental literature [10]. Economic growth may increase emissions in the first phase of the EKC due to excess energy usage, which is claimed as a scale effect. Later, technical and/or compositional effects may dominate, resulting in pleasant environmental outcomes of economic growth in the second phase of the EKC. In this phase of the EKC, technical progress and innovation can play a productive role in generating clean and productive technologies [11], which can reduce energy intensity and improve carbon productivity in production processes [12–14]. Thus, technical innovations can help shape the EKC.

Keeping in mind the role of innovation in pollution emissions, some studies have explored the influence of innovation on pollution in the MENA region. Bilal et al. [15] investigated One Belt One Road (OBOR) economies, including six countries from the MENA region, and corroborated the negative effect of innovation on CO<sub>2</sub> emissions using dynamic, seemingly unrelated regression. Alternatively, Dauda et al. [16] probed the different regions, including a small sample of seven MENA countries, and stated that innovation enhanced CO<sub>2</sub> emissions in the region by using Dynamic Ordinary Least Squares (DOLS). However, they did not corroborate this relationship by using Fully Modified Ordinary Least Squares (FMOLS). Thus, this relationship is inconclusive in the MENA region literature due to considering a limited sample of MENA countries and ignoring the possible spatial dimensions in the geographically nearby MENA economies. Thus, a literature gap exists in the MENA literature to identify the relationship between innovation and emissions, considering the spatial dimensions in a maximum sample of MENA countries. Yin et al. [17] argued that technical innovations could have spillovers that diffuse knowledge. Thus, innovations could have spatial linkages in a region [18], and this spatial dependency could help in developing a true relationship between innovations and emissions in the MENA region. In addition, Bockstael [19] strongly recommended the use of spatial econometrics in ecological studies, as CO<sub>2</sub> emissions are global emissions. Thus, the emissions from one

country can affect neighboring countries' environments as well. Moreover, Maddison [20] suggested using spatial techniques in pollution studies of a region because a region sharing the same landscape and environmental policies as the countries in the region could have spatial dimensions. Furthermore, we cannot ignore spatial analyses in a model if spatial autocorrelation is substantiated statistically in the model [21].

Following the above arguments, some literature suggests doing spatial analyses of the innovation, technology, and emissions relationships [18,22–26]. Thus, the present study uses spatial techniques to analyze the impact of innovations on CO<sub>2</sub> emissions in a maximum sample of 17 MENA countries, as per data availability. The present study contributes to the MENA literature by finding a positive effect of innovation on CO<sub>2</sub> emissions in domestic economies and a negative effect of innovation on CO<sub>2</sub> emissions in neighboring countries. Moreover, industrial value added has a positive effect on CO<sub>2</sub> emissions in both domestic and neighboring economies. Urbanization has a positive effect on CO<sub>2</sub> emissions in domestic economies and a negative effect in neighboring economies. In addition, the EKC is also substantiated by the relationship between economic growth and CO<sub>2</sub> emissions.

## 2. Literature Review

Due to the increasing importance of using technology in combating pollution emissions, many recent studies have investigated this issue using different proxies of innovation in different economies or groups of economies. First, we discuss the studies on single-country cases, where most of the studies found were for China. For instance, Shahbaz et al. [27] investigated China by using bootstrapping Autoregressive Distributive Lag (ARDL) and found an inverted U-shaped EKC. Further, innovations reduced emissions. Moreover, public-private partnerships, exports, and Foreign Direct Investment (FDI) accelerated CO<sub>2</sub> emissions. Using data from 1991 to 2019 for China, Li et al. [28] applied nonlinear ARDL and indicated that increasing green energy technologies and energy efficiency could help reduce CO<sub>2</sub> emissions. In the same way, decreasing trends in these variables could increase emissions. Thus, they suggested that these two factors should be taken into account while trying to achieve carbon neutrality. Yang et al. [29] applied the bootstrap ARDL method to data collected for China from 1980 to 2019. Their analysis also showed that innovation could help reduce emission levels, especially in the green technology domain. Also, financial development was shown to reduce emission levels, but employment levels and energy consumption increased these levels. Nguyen et al. [30] investigated Vietnam from 1986 to 2019 by applying the ARDL technique, and found that economic growth and financial development enhanced CO<sub>2</sub> emissions. However, transportation capacity and FDI helped reduce CO<sub>2</sub> emissions. The various robustness tests also verified the results of the study. Liu et al. [31] investigated China from 1985 to 2019 and mentioned that technological innovation, as well as electricity generation, increased emissions in China in the first stage of the EKC. Afterward, economic growth reduced emissions. In their analysis of data from China using dynamic ARDL simulations, Ulucak [32] showed that energy innovation could help decrease emissions in the country and that the EKC also existed. Jiemin and Chen [33] applied the ARDL to show that private energy investments could help reduce CO<sub>2</sub> emissions, while energy consumption increased emissions on both a short- and long-term basis. They also mentioned that foreign trade in China could lead to higher emissions.

Some Chinese studies used data from cities, provinces, or sectors. For instance, Ma et al. [34] investigated Chinese provinces by using Cross-sectional Dependence (CD) techniques from 1995 to 2019 and found that technological innovation, energy investment, REC, pollution taxes, and R&D expenditures helped reduce CO<sub>2</sub> emissions. Using CD techniques, Kuang et al. [35] investigated Chinese provinces from 1990 to 2018 and indicated that REC and green technology reduced CO<sub>2</sub> emissions in China. Zhu [36] argued about the mediating role of technology and analyzed 30 Chinese provinces during 2005–2017. The results showed that technological growth and advancement in the industrial segment reduced carbon emissions and helped achieve environmental goals. Gao et al. [37] conducted a similar analysis in 30 Chinese provinces from

2008–2020 and showed that the industrial sector promoted emissions and green technology advancements decreased carbon emissions.

In the city-level analysis, Gu [38] analyzed 275 Chinese cities from 2011 to 2017 and conducted a panel data analysis. The results showed that technological innovation reduced emissions. Technological innovation was also seen to have a moderating negative effect on two widely discussed variables, including emissions and economic expansion. Liu et al. [39] performed a quasi-experiment to test the effect that innovation incentives could have on urban CO<sub>2</sub> emissions in Chinese cities and found that these incentives could help reduce CO<sub>2</sub> emissions in urban areas. You and Chen [40] investigated 282 Chinese cities from 2005–2015 and found that carbon emissions in China were reduced by technological innovations. Thus, innovation played a mediating role in reducing emissions. Li et al. [41] investigated 285 Chinese cities and showed that population density, economic growth, industrial development, and FDI increased CO<sub>2</sub> emissions. However, innovation helped reduce these emission levels. Lin and Ma [42] examined 264 Chinese cities from 2006–2017 and found that green technological innovations reduced CO<sub>2</sub> emissions after the year 2010 in the sample period. Moreover, public expenditures could not play a role in the effects of green technological innovations. However, these innovations could reduce CO<sub>2</sub> emissions in cities after they attain a mature level of human capital. In addition, these innovations upgraded the industrial structure in the cities, which consequently reduced CO<sub>2</sub> emissions. Using city-level data from 30 Chinese provinces from 2005–2019, Dong et al. [43] showed that regulations and green technologies helped reduce emissions in China.

Li et al. [44] conducted a panel analysis of 32 economic sectors from 30 provinces in China by using quantile regression. They found an EKC between emissions and patents in these sectors. In low-innovation technology fields, emissions tended to be higher, but with more advancement and patents, emissions eventually started to decline. Wang et al. [45] used data from 97 counties in China from 2000–2017 to test the effects of industrial structure and innovations on CO<sub>2</sub> emissions. An analysis showed that there were regional differences in these variables. Both innovations and industrial structures were shown to reduce emissions, and the eastern parts of the province saw more remarkable changes than the West. Yuan et al. [46] analyzed China in the first two decades of the 2000s and showed that green innovation reduced emissions. Additionally, institutional quality played a mediating role and helped improve the environment. Zheng et al. [47] investigated three Chinese regions from 2003 to 2017 and found that technological advancement improved carbon emission efficiency.

Apart from China, Adebayo et al. [48] collected data from Portugal from 1980 to 2019 by using wavelet analysis. The results showed that REC reduced CO<sub>2</sub> emissions, while trade openness and technological innovations increased CO<sub>2</sub> emissions. Their results about a positive relationship between innovation and CO<sub>2</sub> emissions were different from other studies, which corroborated a negative relationship. Xin et al. [49] examined the US from 1990 to 2016 and stated that technical innovations reduced emissions, but economic growth and trade increased emissions. Likewise, Su et al. [50] also showed that technological innovation and REC in the US could help reduce CO<sub>2</sub> emissions. The impact of REC was more significant than technological advancements, as it provided more opportunities to bring structural upgrades to energy policies. Adebayo et al. [51] investigated Brazil from 1990 to 2018 by using ARDL and found that economic growth increased emissions while technology reduced them. Jordaan et al. [52] showed a similar result for Canada, implying that more investment in innovation could reduce emissions.

Jiang and Khattak [53] showed the effect that technological advancements in marine energy could have on CO<sub>2</sub> emissions in South Korea from 1991 Q1 to 2018 Q4. There was a long-run connection between income growth, green technology development, CO<sub>2</sub> emissions, and REC. Investing more in marine energy technology and REC could help reduce CO<sub>2</sub> emissions. Raihan et al. [54] conducted a time series analysis of Malaysian data from 1990 to 2019. Using the DOLS method, they showed that economic growth could lead to almost a one-to-one increment in CO<sub>2</sub> emissions, and more REC could help



reduce these emissions by 0.3%. Technological innovation could also help reduce emissions. Udeagha and Ngepah [55] applied the quantile ARDL approach to South African data from 1960 to 2020. The purpose was to identify the type of association between emissions and technological innovation. Like a couple of studies mentioned above, more technical innovations helped reduce CO<sub>2</sub> emissions through technical effects. Moreover, the EKC was also validated in South Africa. Other factors, including higher energy consumption, industrial value added, and FDI, increased these emissions, and trade openness showed a degrading impact on the environment as well.

Some studies focused on a group of countries to capture the impact of innovations on the environment. Du et al. [56] analyzed 71 countries from 1996 to 2012. The results of their analysis showed the opposite of many other studies, as innovation could not contribute to reducing emissions if the country was below a certain income cut-off. The EKC with an inverted U-shape was validated in these countries, and urbanization, trade openness, and industrial structure seemed to increase emissions. Yu et al. [57] showed that technological innovation could have a major impact on reducing CO<sub>2</sub> emissions in 52 countries from 1990 to 2014 as it helped improve the environmental condition in a country. Their results suggested policy implications: more investment should be made in innovation so that the environmental profile of the country could be improved. Liobikienė and Butkus [58] investigated a large panel of 147 countries from 1990 to 2012 and noticed that urbanization and trade reduced CO<sub>2</sub> emissions through the technical upshot of energy efficiency, and REC could also play a role.

Some literature tries to capture the effects of innovation in developed economies, which are supposed to produce more innovations than developing countries. For instance, Saqib [59] examined and validated the EKC in the 18 most developed countries from 1990 to 2019 by using ARDL. Moreover, increasing REC and innovations reduced CO<sub>2</sub> emissions. Economic expansion caused CO<sub>2</sub> emissions, and renewable energy could help reduce emission levels. Awan et al. [60] substantiated the EKC in 33 developed countries. They collected data from 1996 to 2014 and showed that the EKC was an N-shape in these nations in the transport sector. Moreover, urbanization increased CO<sub>2</sub> emissions. However, innovation reduced these environmentally degrading effects in the transport industry. Green technologies played a particularly important role in reducing emissions from this sector. Vitenu-Sackey and Acheampong [61] used panel data from 18 countries in the developed world from 2005 to 2018 to test the effects of energy intensity, R&D, and economic policy uncertainty on emissions. The results showed an inverted U-shaped EKC. Moreover, REC and R&D helped reduce emissions. Using data from 22 developed countries from 1990 to 2018, Rahman et al. [62] confirmed the EKC in these countries, and both renewable energy and export quality could help reduce CO<sub>2</sub> emission levels over a long period of time. Additionally, technological advancement also helped reduce emission levels.

Abid et al. [63] analyzed G8 countries from 1990 to 2019 and mentioned that technological innovation and FDI tended to reduce emission levels. Nevertheless, there was also a bidirectional relationship between emissions and several other variables like urbanization, trade openness, and financial development. The authors emphasized the role that urbanization played in lowering emission levels and mentioned that more comprehensive policies were needed to tackle the environmental degradation of urbanization. Rehman et al. [64] examined G7 countries from 1990 to 2019, and FDI and trade openness largely increased CO<sub>2</sub> emissions in Canada and Germany, while that effect was the opposite in the US and the UK. Shah et al. [65] showed that there was a dynamic association between oil prices and emissions. They also found that energy innovations helped reduce emissions. Ostadzad [66] analyzed 29 European Union (EU) countries from 2000 to 2019 and showed that innovations decreased emissions. The panel analysis also showed that innovation could help improve clean energy technology, which, in turn, contributed to emission reduction. In their panel study, Qureshi et al. [67] analyzed 17 European economies from 2010 to 2018. Eco-innovation helped reduce emissions. Khurshid et al. [68] showed that

green innovations and environmental policies reduced carbon emissions in 15 European economies and could be used to achieve sustainable development goals. Ahmed et al. [69] examined European countries from 1995 to 2019 and found that green technologies and REC reduced CO<sub>2</sub> emissions. However, economic growth raised emissions.

Some literature also examined Brazil, Russia, India, China, and South Africa (BRICS). For instance, Ma et al. [70] analyzed BRICS nations using an ARDL model. Technological innovations and patents tended to reduce emissions. However, the trademarks increased emissions. Abbas et al. [71] analyzed BRICS countries from 1990 to 2020 and mentioned that market regulation could help mediate the relationship between emissions, REC, and innovations. They also found that innovations and REC could decrease emissions. Khan et al. [72] collected data from BRICS countries from 1990 to 2019 to test the impact of information technologies on CO<sub>2</sub> emissions. The results showed that these technologies helped reduce CO<sub>2</sub> emissions. Additionally, REC and innovations reduced these emissions as well. They also validated the existence of the EKC in these countries. Zhang [73] analyzed BRICS nations from 1990 to 2019 and showed that technology helped reduce emissions. Moreover, an EKC was found except in Brazil and China.

Jiang et al. [74] analyzed BRICS nations from 1985 to 2018 to test the relationship between some variables, including coal consumption, population, Consumption-Based CO<sub>2</sub> (CBC) emissions, and environmental technologies. The analysis of the data showed that environmental technologies could help reduce CO<sub>2</sub> emissions, while coal consumption aggravated the emissions levels, resulting in environmental degradation. Meng et al. [75] analyzed BRICS and Turkey by using the CS-ARDL approach. Results showed that trade diversification, renewable energy, and green innovation could help reduce emission levels. However, economic growth increased consumption-based emissions. Jiang and Khan [76] examined the BRI economies for the period from 1995 to 2019 and found that REC and trademark applications reduced CO<sub>2</sub> emissions. Moreover, the EKC was also found. Li et al. [77] applied the ARDL model to analyze data from BRI economies from 2003–2018 and found that green innovations and exports reduced CBC emissions. However, FDI and imports increased these emissions.

Many studies also investigated the highly polluted Organization for Economic Cooperation and Development (OECD) nations. For instance, Mensah et al. [78] conducted an analysis of OECD nations and showed that patents and trademarks reduced CO<sub>2</sub> emissions while economic growth and urbanization increased these emissions. Yildirim et al. [79] analyzed 32 OECD countries from 1997 to 2018. They divided the effects of technological innovations into three regimes. The results showed that in the first regime, the effect on CO<sub>2</sub> emissions was insignificant but changed in later regimes. It tended to reduce emissions in the second regime but started to increase in the third one. There was not any extensive discussion on why this might be the case. But the results suggested that a more comprehensive and robust policy was required to test this relationship so that emissions could be reduced. Khattak and Ahmad [80] examined OECD economies, and REC and green innovations helped reduce emissions while income could increase CO<sub>2</sub> emissions. Alvarez-Herranz et al. [81] investigated 28 OECD nations from 1990 to 2014 and also showed that emissions could be reduced with innovation in OECD countries. But it took time to reach the full environmental effects of innovation in these economies. Mensah et al. [82] examined 28 OECD nations from 1990 to 2014. The results showed a valid EKC between innovation and emissions in these economies. A pollution haven was also seen in these nations, and higher income led to higher emissions before starting to decline after a cutoff. More innovation in renewable technology played the most significant role in reducing CO<sub>2</sub> emission levels, suggesting higher government investment in renewable technology. Ganda [83] examined OECD countries from 2000–2014 and indicated that R&D reduced carbon emissions. However, triadic patents increased emissions in OECD countries.

Li et al. [84] collected data from Mexico, Nigeria, Indonesia, and Turkey (MINT) countries from 2000 to 2022. FMOLS and DOLS were used to test the panel data to identify a pattern in the way technological advancement, investment in green technology, and globalization could impact CO<sub>2</sub> emissions. Non-REC led to higher emissions, but

globalization and green innovation could help reduce emissions. Moreover, technical advancements also had a moderating effect on reducing emissions. However, the EKC was not substantiated. Du et al. [85] investigated MINT economies from 1990 to 2018 and validated the EKC. Moreover, REC reduced emissions, and high-tech exports and FDI raised emissions. Chhabra et al. [86] tested 23 middle-income countries by collecting data from 1994 to 2018. They showed that the EKC was substantiated in these countries. Thus, after a certain point of income growth, emissions started to fall. There was also a spillover effect from green technologies in the results.

Obovisa et al. [87] mentioned in their study that green technologies could reduce CO<sub>2</sub> emissions in African countries. They also showed that REC had a similar impact on the environment and that fossil fuel technology had a degrading effect. Dauda et al. [88] collected data from nine African nations from 1990 to 2016 and corroborated the EKC between technological advancement and emissions. They also showed that emissions were reduced by an increase in human capital. Habiba et al. [89] investigated and substantiated that financial development raised emissions in 12 top-emitter countries. Additionally, trade openness and non-REC raised emission levels. However, REC and innovation could help reduce CO<sub>2</sub> emissions. Hafeez et al. [90] applied the ARDL to the CO<sub>2</sub> emissions model in highly polluted countries. The results of their panel data analysis showed that renewable energy demand could help reduce emission levels to a significant level. Innovation and financial markets could also help reduce these emission levels in selected countries, including India, Japan, China, and Russia. Amin et al. [91] collected data from N-11 countries and applied the CS-ARDL model. Eco-innovations, exports, and productivity reduced emission levels, and factors contributing to higher CO<sub>2</sub> emissions were economic growth and imports.

Yunzhao [92] analyzed data from E7 countries from 1995 to 2018 to show that environmental taxes, green technology, and eco-innovation could help reduce emission levels. There was also evidence of feedback between the variables. They suggested that environmental policy needed rigorous review so that environmental issues could be tackled in a more structured way. Lingyan et al. [93] mentioned that CO<sub>2</sub> emissions could be reduced by fiscal decentralization, and environmental innovation helped achieve similar goals. Hao and Chen [94] tested E7 countries by applying the ARDL and FMOLS models. REC and innovation led to a 0.357% decline in emissions. Inflation and economic growth, however, tended to increase emissions by 0.946%. Moving to renewable energy sources significantly reduced CO<sub>2</sub> emissions in these E7 nations, and green innovation could also promote that decline. Jiang et al. [95] showed that in high-income countries, emissions tend to decline with an increase in income. Thus, the EKC hypothesis was substantiated. Moreover, innovation helped reduce emissions. Yan [96] collected data from 15 countries from 1992 to 2012 and showed that technological innovation reduced emission levels. Additionally, the role of clean and green innovative technologies was seen to be significantly notable in the reduction of emission levels.

In 10 Asian countries, Wenlong et al. [97] showed that institutional quality and trade openness could increase emissions, but technological innovation and energy efficiency could help mitigate those environmentally degrading effects. Similar to other studies mentioned above, they suggested that more investment in green technological advancement should be promoted so that environmental goals could be achieved. After collecting data from Asian countries from 2001 to 2019, Luo et al. [98] found that green technology and technological advancement, in general, led to environmental improvement by cutting down emission levels. They also validated the EKC hypothesis in the Asian countries under analysis and showed that it had an inverted U shape. The analysis also showed that FDI, population density, energy consumption, and trade increased emissions. Hao et al. [99] explored the 25 Asian economies from 1998 to 2019 and found that technological development and innovation reduced CO<sub>2</sub> emissions. Rahman and Alam [100] investigated Asian countries from 1960 to 2020 and showed that a few factors, including corruption, globalization, growth, and technical innovations, could increase emissions, and REC could

reduce these levels. Naz and Aslam [101] analyzed four South Asian economies from 1996 to 2019 and validated the EKC in the panel. Moreover, environmental innovations reduced CO<sub>2</sub> emissions, and globalization and financial development increased CO<sub>2</sub> emissions. In addition, the moderating role of governance was tested, and governance interaction with innovation helped reduce emissions. However, governance interacted with globalization and financial development to increase CO<sub>2</sub> emissions.

Some studies also care about the spatial dimensions while investigating the innovation–emissions relationship. For example, Zhong et al. [102] tested data from the power industry in China from 1997 to 2020. Clean energy technologies and technological advancements reduced SO<sub>2</sub> emissions and water and solid waste. Emissions also showed path dependencies, and fossil fuel technologies and energy-saving technologies seemed to have spatial effects on pollution. Liang et al. [25] collected data on the logistics industry in 30 Chinese provinces from 2002 to 2019. Outcomes from the panel analysis confirmed a U-shaped impact of technical innovations on emissions in the logistics industry. This rebound effect was also found in spillovers. Liu et al. [18] investigated 30 Chinese provinces from 2000 to 2019, and green innovations reduced CO<sub>2</sub> intensity in China. There was also a spillover effect, which explained that innovation in one part of a country could help generate innovations in other surrounding areas and reduce emissions.

Cai et al. [22] examined 30 Chinese provinces from 2006 to 2019 and indicated in their panel data analysis that green technology led to environmental improvement, but the effect was not as obvious and straightforward. Thus, the results could vary on a regional basis. Emissions also seem to have a spatial and regional effect, and green technologies also showed spillovers in other regions. Factors such as energy consumption, economic development, and the industrial structure of a country increased emissions, leading to environmental degradation. Sheng et al. [23] analyzed data from 48 Chinese cities located in different regions from 2001 to 2015 and showed that urbanization and emissions had different shapes of association across the country. For instance, it was U-shaped, N-shaped, and inverted N-shaped in different regions. Urbanization also depended on innovation, which tended to improve environmental quality. CO<sub>2</sub> emissions from urban areas also seemed to have a spillover effect, which negatively impacted their surrounding regions.

Chen et al. [24] examined 30 Chinese provinces from 2007–2019 and found the EKC between carbon intensity and green technological innovations in spatial analyses. It means that as more growth in green technology innovation took place, carbon intensity first increased before starting to fall after a certain cutoff. The same relationship was seen in neighboring regions. With low levels of green technology innovation, carbon emissions were high. Once technology started to grow, emissions gradually started to decline. The results had crucial policy implications and suggested that governments and companies invest more in green technologies to tackle environmental degradation. In the relationship between emissions and growth, Zhang and Chen [26] investigated 37 Chinese cities and found an N-shaped EKC in spatial analyses. Moreover, the EKC was also found between technological innovation and emissions.

In the MENA literature, Bilal et al. [15] conducted a panel data analysis on OBOR countries and divided OBOR countries into different regions, including six MENA countries from 1991 to 2019. Innovation could reduce emissions rates in these regions, including the MENA region, while globalization tended to increase emissions. There were some regional differences seen across countries as well. The analysis implied that investing more in technological innovation could moderate the effect of globalization on emissions and reduce environmental degradation. Dauda et al. [16] examined 18 countries from different regions, including seven MENA countries, BRICS, and G6 regions, from 1990 to 2016. The authors corroborated that innovations decreased emissions in G6 and raised them in the MENA and BRICS. Moreover, the EKC was validated in the BRICS nations. Salehi et al. [103] investigated six automobile companies in Iran from 2018 to 2019 using dynamic panel techniques and found that CO<sub>2</sub> emissions reduced the stock prices, returns,



and market value of automobile companies. Moreover, a unidirectional causality was also reported from CO<sub>2</sub> emissions to stock returns.

The reviewed literature shows the importance of innovation and technological progress in reducing emissions in most studies. However, some studies also corroborated that innovation increased emissions [31,48,100]. These studies exposed the scale of the effect of innovation on emissions. For instance, increasing innovation can lead to higher economic activities and energy consumption, which can be responsible for higher pollution emissions. Thus, innovation had a positive effect on emissions. Moreover, Liang et al. [25] found a U-shaped impact of innovation on emissions. This study confirmed that innovation had a technique effect and initially reduced emissions. Later, the scale effect of innovation was found to be dominant over the technique effect, and innovation enhanced emissions through increasing economic activities. On the other hand, some studies also reported an inverted U-shaped impact of innovation on emissions [26,44,82,88]. These studies confirmed that innovation had a scale effect in the first stage and increased emissions. Later, innovation generated a more dominant technique effect over the scale effect and helped reduce emissions. The different results may also be claimed because of different countries' samples, econometric techniques, and ways of modeling this relationship. Thus, the exact effect of innovation on emissions is an empirical question, which is explored in the MENA region [15,16]. However, both studies found the opposite results. For instance, Bilal et al. [15] reported a negative effect of innovation in six MENA countries, and Dauda et al. [16] reported a positive impact of innovation on emissions in seven MENA countries. Thus, the effect of innovation on emissions is inconclusive in the MENA literature, which needs further attention by using a maximum sample of countries from the MENA region. Moreover, MENA countries have nearby economies. Therefore, spatial dimensions are expected in the relationship between innovation and emissions, which are ignored by Bilal et al. [15] and Dauda et al. [16]. Therefore, the present study applies spatial econometrics to a sample of 17 MENA countries from 2000 to 2019 and re-investigates this relationship in spatial dimensions to claim an empirical contribution to the MENA literature.

### 3. Methods

Grossman and Krueger [9] suggested a nonlinear impact of economic growth on pollution, which is termed the EKC. This nonlinear relationship between economic growth and pollution is suggested because economic growth may increase the scale of economic activities and energy consumption. Thus, economic growth can be responsible for higher emissions in the first phase of economic growth [9]. However, economic growth may generate the technique and composition effects in the second stage of the EKC [10]. Thus, the present study also hypothesizes a nonlinear, inverted U-shaped relationship between economic growth and CO<sub>2</sub> emissions to test the EKC hypothesis. Moreover, innovations can play a role in shaping the EKC. For instance, innovations can generate technologies that can increase overall economic activity and pollute the environment by having a scale effect. However, technical innovation would generate low-energy consumption technologies, which could enhance production with a lesser use of energy [8]. Moreover, technical innovation can also generate clean technologies [11] and may decrease energy intensity and emissions [12–14]. Thus, innovation can help generate technique and/or composition effects in an economy and reduce emissions. Thus, we hypothesize a negative effect of innovation on CO<sub>2</sub> emissions. However, industrialization may increase energy consumption and pollute the environment [22,37,41,55,56]. Therefore, we hypothesize the positive effect of industrial value added on CO<sub>2</sub> emissions. On the consumption side, urbanization can increase the demand for consumables, which can increase energy consumption and pollution emissions [23,37,63,78]. Thus, we hypothesize a positive effect of urbanization on CO<sub>2</sub> emissions. Based on the above theoretical discussions, we hypothesize the following model:

$$CO2_{it} = f(GDPC_{it}, GDPC_{it}^2, PAT_{it}, IVA_{it}, URB_{it}) \quad (1)$$

$CO2_{it}$  shows the natural log of  $CO_2$  per capita.  $GDPC_{it}$  shows a natural logarithm of Gross Domestic Product (GDP) per capita (constant 2015 USD).  $GDPC_{it}^2$  is the square of  $GDPC_{it}$  to analyze the EKC hypothesis in Equation (1).  $IVA_{it}$  and  $URB_{it}$  are the percentages of industrial value added and urban population in GDP and total population, respectively.  $PAT_{it}$  shows the total number of applied resident and nonresident patents in thousands, which is a proxy for innovation.  $URB_{it}$  and  $IVA_{it}$  are in percentages. Thus, these variables are not taken in logarithms. Patent data carries zero in some years. So, patents' data is also not taken in logarithm. The period 2000–2019 is utilized for 17 MENA economies, and data on all variables are taken from the World Bank [4]. Table 1 shows the description of the variables.

**Table 1.** Description of variables.

Variable	Variable Construction	Sample Period	Data Source
$CO2_{it}$	Natural logarithm of $CO_2$ per capita. $CO_2$ emissions per capita are measured as $CO_2$ emissions in metric tons divided by the total population.	2000–2019	World Bank [4]
$GDPC_{it}$	Natural logarithm of GDP per capita. GDP per capita is measured as GDP in constant 2015 US dollars divided by the total population.	2000–2019	World Bank [4]
$GDPC_{it}^2$	Square of the $GDPC_{it}$ .	2000–2019	World Bank [4]
$PAT_{it}$	The total number of applied patents by residents and nonresidents in all categories is in the thousands.	2000–2019	World Bank [4]
$IVA_{it}$	The percentage of the total industrial value added, including construction (outputs minus intermediate inputs), in the total GDP.	2000–2019	World Bank [4]
$URB_{it}$	The percentage of the urban population in the total population.	2000–2019	World Bank [4]

Equation (1) can be tested by using Fixed Effects (FE) with different country and time effects. The FE is regressed with FE-time, FE-country, and FE-both to verify which specification is superior to pooled Ordinary Least Square (OLS). The valid specification will be chosen by applying the Likelihood Ratio (LR) test. Moreover, the spatial autocorrelation may be expected in Equation (1) due to geographically nearby MENA economies, as Bockstael [19] argued for its importance in pollution studies. In a particular relationship between innovation and emissions, the literature suggests doing spatial analyses [18,22–26]. Thus, it seems pertinent to check the spatial autocorrelation in Equation (1) by using Lagrange Multiplier (LM) and LM robust tests as proposed by Debarsy and Ertur [104]. If we can find a statistically significant spatial autocorrelation, then we need to apply any spatial specification to have robust results. Thus, we apply the Spatial Durbin Model (SDM) to Equation (1), which is suggested by Elhorst [105], in the following way:

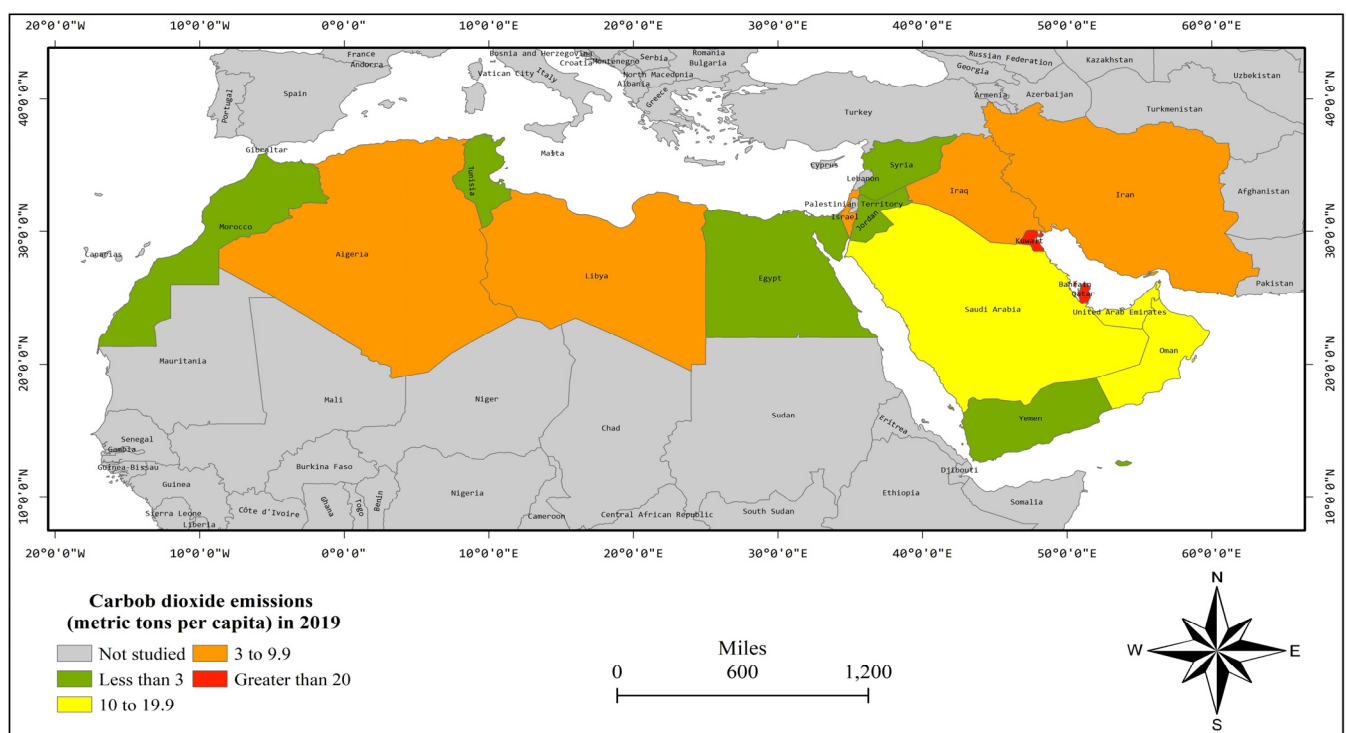
$$\begin{aligned}
 CO2_{it} = & \alpha_0 + \alpha_1 GDPC_{it} + \alpha_2 GDPC_{it}^2 + \alpha_3 PAT_{it} + \alpha_4 IVA_{it} + \alpha_5 URB_{it} \\
 & + \beta_1 \sum_{j=1}^n w_{ij} GDPC_{jt} + \beta_2 \sum_{j=1}^n w_{ij} PAT_{jt} + \beta_3 \sum_{j=1}^n w_{ij} IVA_{jt} \\
 & + \beta_4 \sum_{j=1}^n w_{ij} URB_{jt} + \delta \sum_{j=1}^n w_{ij} CO2_{jt} + v_i + u_t + \varepsilon_{it}
 \end{aligned} \quad (2)$$

Equation (2) is the SDM specification and has been added to a weight matrix  $w_{ij}$  of  $17 \times 17$  dimensions. Each element of the weight matrix carries the inverse of the distance ( $1/\text{distance}$ ) between the capital cities of 17 MENA countries. The distance is calculated from one country ( $i$ ) located in the MENA region to the other MENA countries ( $j$ ) in

kilometers. Zero is placed in the case of  $i = i$ . Later, the weight matrix is normalized with a procedure proposed by Kelejian and Prucha [106]. Moreover, it is pertinent to check the suitability of SDM over other spatial specifications to choose the best spatial specification for Equation (2). Thus, we will use the Wald test suggested by Elhorst [107]. The Wald test can be applied to the null hypotheses of  $\beta = 0$  and  $\beta + \delta \cdot \alpha = 0$ . The rejection of  $\beta = 0$  will suggest that SDM is better than Spatial Autoregressive (SAR). The rejection of  $\beta + \delta \cdot \alpha = 0$  may recommend that SDM is better than Spatial Error Model (SEM). In addition, the LR test will be used to verify the conclusions from the Wald test. The Stata 14.2 software is used for data estimations, and commands for estimation are taken from Belotti et al. [108].

#### 4. Data Analysis

Figure 1 shows the spatial distribution of CO<sub>2</sub> emissions per capita in the year 2019. Egypt, Morocco, and Tunisia are located in North Africa and are nearby countries with CO<sub>2</sub> emissions less than 3. Jordan and Syria are also nearby countries in the same range. Algeria and Libya are neighboring countries and have emissions between 3 and 9.9. In the same emission bands, Iran and Iraq are neighboring countries, and Israel is also located near these countries. Oman, the UAE, and Saudi Arabia are neighboring countries and have CO<sub>2</sub> emissions between 10 and 19.9. Moreover, Bahrain, Kuwait, and Qatar are nearby countries and have CO<sub>2</sub> emissions of more than 20. Thus, Figure 1 displays the spatial connections between CO<sub>2</sub> emissions in 17 MENA countries.



**Figure 1.** Geographical distribution of CO<sub>2</sub> emissions per capita in the year 2019. Source: Data were sourced from the World Bank [4] to develop this figure.

Before starting regression analysis, we perform Variance Inflation Factor (VIF) to test multicollinearity among the independent variables of the model. Table 2 shows that all VIF values are less than 5. Thus, we may conclude that independent variables do not carry the problem of multicollinearity.

At first, pooled regression is applied to Equation (1) and then tested using FE models in Table 3. Later, we use the LR test to verify that FE models are better than pooled regression. The LR test rejects the null hypothesis for the FE-country and FE-both effects. Thus, these models are preferable to pooled regression. These models confirm the EKC. Patents could

not determine emissions, and industrial value added and urbanization have negative effects on emissions. Then, we apply LM and LM-robust tests to verify the spatial autocorrelation in the estimates. The results substantiate the spatial lag and error effects in all models, which is also proven by Figure 1. Thus, the non-spatial results in Table 3 are biased, and we shift our analyses toward spatial models.

**Table 2.** Variance Inflation Factor (VIF).

Variable	GDPC <sub>it</sub>	GDPC <sub>it</sub> <sup>2</sup>	PAT <sub>it</sub>	IVA <sub>it</sub>	URB <sub>it</sub>
GDPC <sub>it</sub>	-				
GDPC <sub>it</sub> <sup>2</sup>	3.18	-			
PAT <sub>it</sub>	1.02	1.01	-		
IVA <sub>it</sub>	1.06	1.02	1.00	-	
URB <sub>it</sub>	3.16	1.02	1.00	1.00	-

**Table 3.** Non-spatial results.

Variable	Pooled Regression	FE-Country	FE-Time	FE-Both
GDPC <sub>it</sub>	0.5179 (0.168)	3.7187 (0.000)	0.4007 (0.298)	3.5906 (0.000)
GDPC <sub>it</sub> <sup>2</sup>	0.0076 (0.704)	−0.1672 (0.000)	0.0130 (0.524)	−0.1599 (0.000)
PAT <sub>it</sub>	−0.0080 (0.285)	0.0039 (0.344)	0.0039 (0.614)	0.0068 (0.100)
IVA <sub>it</sub>	0.0035 (0.004)	−0.0021 (0.000)	0.0041 (0.001)	−0.0019 (0.000)
URB <sub>it</sub>	0.0170 (0.000)	−0.0044 (0.062)	0.0183 (0.000)	0.0064 (0.060)
Diagnostic tests				
LM Spatial Lag	797.350 (0.000)	401.011 (0.000)	780.669 (0.000)	374.212 (0.000)
Robust LM Spatial Lag	21.458 (0.000)	90.634 (0.000)	27.322 (0.000)	93.808 (0.000)
LM Spatial Error	808.140 (0.000)	321.346 (0.000)	787.886 (0.000)	293.192 (0.000)
Robust LM Spatial Error	32.249 (0.000)	10.969 (0.001)	34.539 (0.000)	12.789 (0.000)
$\sigma^2$	0.1436	0.0105	0.1485	0.0099
R <sup>2</sup>	0.8862	0.9921	0.8890	0.9929
LR test		905.61 (0.000)	8.61 (0.979)	944.41 (0.000)
No. of Observations	340	340	340	340

Note: ( ) carries probability values. The LR test is the Likelihood-Ratio (LR) test, which is utilized to verify the suitability of FE models over pooled regression.

Table 4 shows the spatial results. At first, we estimate SDM with both FE and Random Effects (RE) and apply the Wald test. The null hypotheses  $\beta = 0$  and  $\beta + \delta \cdot \alpha = 0$  are rejected in both the FE and RE estimates. Thus, SDM cannot condense to SAR or SEM in both FE and RE estimates. Thus, SDM is proven to be the most appropriate spatial model in both estimates. Then, we apply the LR test to confirm the results of the Wald test and find the same evidence that SDM is preferred. However, the SAR results are also presented to verify the robustness of the SDM results, and the signs of the effects remain the same in both SAR and SDM estimations. Moreover, the Hausman test is applied to compare the FE and RE effects. The null hypothesis is accepted, which explains that RE is superior to FE. Thus, we continue the interpretation of SDM with RE.



Table 4. Spatial results.

	SDM FE Parameter ( <i>p</i> -Value)	SDM RE Parameter ( <i>p</i> -Value)	SAR FE Parameter ( <i>p</i> -Value)	SAR RE Parameter ( <i>p</i> -Value)
Coefficient Estimates				
GDPC <sub>it</sub>	3.4577 (0.000)	3.3227 (0.000)	3.4693 (0.000)	3.6977 (0.000)
GDPC <sub>it</sub> <sup>2</sup>	−0.1524 (0.000)	−0.1446 (0.000)	−0.1545 (0.000)	−0.1661 (0.000)
PAT <sub>it</sub>	0.0086 (0.060)	0.0054 (0.183)	0.0082 (0.031)	0.0045 (0.267)
IVA <sub>it</sub>	−0.1836 (0.000)	−0.1249 (0.002)	−0.1663 (0.000)	−0.1941 (0.000)
URB <sub>it</sub>	0.3942 (0.282)	0.8219 (0.002)	0.5689 (0.066)	0.4135 (0.069)
Direct Estimates				
GDPC <sub>it</sub>	3.4955 (0.000)	3.3593 (0.000)	3.5057 (0.000)	3.7127 (0.000)
GDPC <sub>it</sub> <sup>2</sup>	−0.1549 (0.000)	−0.1467 (0.000)	−0.1563 (0.000)	−0.1669 (0.000)
PAT <sub>it</sub>	0.0083 (0.035)	0.0071 (0.067)	0.0087 (0.019)	0.0049 (0.205)
IVA <sub>it</sub>	0.1815 (0.000)	0.1359 (0.000)	0.1678 (0.000)	0.1947 (0.000)
URB <sub>it</sub>	0.4773 (0.144)	0.8513 (0.001)	0.5677 (0.058)	0.4212 (0.050)
Indirect Estimates				
GDPC <sub>it</sub>	−0.5894 (0.213)	−0.7484 (0.004)	−0.8371 (0.010)	−0.3301 (0.317)
GDPC <sub>it</sub> <sup>2</sup>	0.0420 (0.047)	0.0380 (0.013)	0.0373 (0.011)	0.0148 (0.319)
PAT <sub>it</sub>	0.0267 (0.564)	−0.0391 (0.042)	−0.0213 (0.101)	−0.0477 (0.712)
IVA <sub>it</sub>	−0.0551 (0.798)	0.3469 (0.001)	0.3941 (0.023)	0.1612 (0.360)
URB <sub>it</sub>	−3.2234 (0.301)	−1.0494 (0.031)	−1.3488 (0.123)	−3.4988 (0.444)
Total Estimates				
GDPC <sub>it</sub>	2.9061 (0.000)	2.6109 (0.000)	2.6686 (0.000)	3.3827 (0.000)
GDPC <sub>it</sub> <sup>2</sup>	−0.1129 (0.000)	−0.1087 (0.000)	−0.1190 (0.000)	−0.1522 (0.000)
PAT <sub>it</sub>	0.0349 (0.459)	−0.0320 (0.099)	−0.0126 (0.021)	−0.0428 (0.296)
IVA <sub>it</sub>	−0.2366 (0.303)	0.4828 (0.056)	0.5619 (0.000)	0.1785 (0.000)
URB <sub>it</sub>	−2.7461 (0.395)	−0.1981 (0.651)	−0.7811 (0.726)	−3.0776 (0.633)
Weights				
W × GDPC <sub>it</sub>	0.4771 (0.200)	0.1951 (0.332)		
W × PAT <sub>it</sub>	0.0337 (0.565)	−0.0503 (0.039)		
W × IVA <sub>it</sub>	−0.1384 (0.673)	0.4009 (0.004)		
W × URB <sub>it</sub>	−4.1771 (0.308)	−1.0745 (0.059)		
W × CO <sub>2it</sub>	−0.3819 (0.077)	−0.3637 (0.037)	−0.3294 (0.026)	−0.1107 (0.272)
Diagnostic tests				
R <sup>2</sup>	0.8723	0.8749	0.8673	0.8159
σ <sup>2</sup>	0.0083 (0.000)	0.0093 (0.000)	0.0083 (0.000)	0.0097 (0.000)
Spatial Lag-Wald Test	47.96 (0.000)	42.09 (0.000)		
Spatial Error-Wald Test	41.65 (0.000)	31.37 (0.000)		
Spatial Lag-LR Test	45.36 (0.000)	39.28 (0.000)		
Spatial Error-LR Test	51.23 (0.000)	40.14 (0.000)		
Hausman Test	9.01 (0.531)		3.89 (0.761)	
No. of Observations	340	340	340	340

The results of coefficient estimates are ignored as they do not carry spatial effects. The direct estimates show the positive and negative effects of GDPC<sub>it</sub> and GDPC<sub>it</sub><sup>2</sup>, respectively. Thus, the EKC is substantiated in the domestic economies of the investigated MENA region with an inverted U-shaped relationship. The indirect estimates display an inverse situation, and economic expansion shows a U-shaped impact on CO<sub>2</sub> emissions in neighboring MENA countries. However, the net effect of economic expansion is inverted U-shaped in the total estimates. Accordingly, the EKC is proven in the spatial analysis of the whole MENA region, and our hypothesis of an inverted U-shaped relationship between economic growth and CO<sub>2</sub> emissions is validated. Patents have a positive impact on emissions in direct estimates. In contrast, the spillover effect of patents is negative. On the whole, the

net effect of patents is negative in the total estimates. Thus, the hypothesized negative effect of innovation on CO<sub>2</sub> emissions in the whole region is validated. Industrial value added has a positive effect on direct and indirect estimates. Moreover, the indirect impact is found to be larger in magnitude than the direct impact. The total effect of industrial value added is positive, and industrialization is responsible for higher CO<sub>2</sub> emissions. Hence, our hypothesized positive effect of industrial value added on CO<sub>2</sub> emissions is validated in the whole region. Urbanization has a positive impact on direct estimates. However, our results show a negative effect of urbanization in indirect estimates, and urbanization has pleasant environmental spillovers in neighboring economies. Even so, the indirect impact is larger in magnitude than the direct impact. However, the total effect of urbanization is insignificant, and the hypothesis of a positive effect of urbanization is not validated in the whole region.

## 5. Discussion

The results show that the EKC is corroborated by an inverted U-shaped relationship between economic growth and CO<sub>2</sub> emissions. Thus, economic growth after a certain threshold point could have pleasant environmental effects. Likewise, Zhang and Chen [26] also corroborated the EKC in spatial analyses of Chinese cities. Innovation has a positive effect on CO<sub>2</sub> emissions in the direct estimates. Thus, innovation has a scale effect on CO<sub>2</sub> emissions in the local economies of innovation producers. It means that innovation is responsible for increasing economic activities, energy consumption, and CO<sub>2</sub> emissions. Some literature has also shared the same finding that innovation increased emissions [31,48,100]. Moreover, a few other studies reported the U-shaped effect [25] and the inverted U-shaped effect [24,44,88] of innovation on emissions. However, our results indicate that increasing innovation is increasing CO<sub>2</sub> emissions, which may be due to the increasing overall energy consumption of economic activities. It seems that the level of innovation is still low in MENA countries, and the scale effect of innovation is dominant over the technique effect. Hence, increasing innovation could not generate sufficient clean technologies, and energy efficiency could not be achieved at a level to support a clean environment. So, innovation contributes to emissions by increasing aggregate energy consumption in innovation-generating domestic economies.

The indirect estimates show a negative effect of innovation on CO<sub>2</sub> emissions. Thus, increasing patents is helping to reduce emissions in neighboring MENA countries and has positive environmental consequences for neighboring economies. This finding is matched with the theoretical arguments of Yin et al. [17] that innovation diffuses knowledge through spillover effects. In the empirical analyses, a few studies also corroborated the spillovers of regional innovation and green technologies on the emissions of neighboring regions in China [18,22,102]. Moreover, the total effect of innovation is negative. Thus, increasing innovation reduces CO<sub>2</sub> emissions and has pleasant environmental outcomes in the whole MENA region. The most reviewed literature also substantiated the negative impact of innovation on emissions. Particularly in the MENA literature, Bilal et al. [15] reported a negative impact of innovation on CO<sub>2</sub> emissions in six MENA countries, and Dauda et al. [16] stated a positive impact of innovation on CO<sub>2</sub> emissions in seven MENA countries. Thus, the MENA literature is inconclusive regarding the exact relationship between innovation and emissions due to a limited sample of MENA countries. However, we find a negative indirect effect and a positive direct effect of innovations on CO<sub>2</sub> emissions in MENA countries. Thus, innovations are damaging the environment of the patent producers' MENA economies. However, patents are improving the environment of neighboring nations, with spillover effects across the whole MENA region. Thus, the results of the present study provide some new insights into this relationship by applying a spatial model and exploring a large sample of 17 MENA countries.

The results show the positive direct and indirect effects of industrial value added on CO<sub>2</sub> emissions. Thus, the industrial sector shows a scale effect and is increasing CO<sub>2</sub> emissions in domestic and neighboring economies. So, industrialization has environmental

concerns for both domestic and neighboring countries. Moreover, the indirect effect is found to be greater than the direct effect. Therefore, neighboring countries are affected on a larger scale by the industrial activities of their domestic economies. Along the same line, many studies corroborated the positive effect of industrialization on emissions [22,37,41,55,56]. In contrast, Zhu [36] reported a negative impact of industrialization on emissions [36]. Urbanization has a positive impact on direct estimates. Thus, urbanization has a scale effect on domestic economies. Along the same line, many studies have substantiated the positive impact of urbanization on emissions [23,56,60,63,78]. However, our results show a negative effect of urbanization in indirect estimates. Thus, increasing urbanization increases CO<sub>2</sub> emissions in domestic economies but has pleasant environmental spillovers in neighboring economies. Even so, the indirect impact is larger in magnitude than the direct impact. Sheng et al. [23] also corroborated the negative spillover effect of urbanization on emissions. However, the total effect of urbanization is found to be statistically insignificant in our estimates.

## 6. Conclusions

Technological innovations can reduce pollution if the technique effect of innovation surpasses the scale effect. We examine the effects of economic growth, patents, industrialization, and urbanization on CO<sub>2</sub> emissions in 17 MENA economies by doing spatial analyses. The results substantiate the EKC's impact on local economies and the whole MENA region. Nevertheless, the spillover effect of economic growth is U-shaped in indirect estimates. Patents increase CO<sub>2</sub> emissions in direct estimates and have environmental concerns for local economies through the scale effect of innovation. However, patents reduce CO<sub>2</sub> emissions with an indirect effect, and patents are reducing CO<sub>2</sub> emissions in neighboring MENA countries. Moreover, the indirect impact of patents is found to be greater than the direct impact. Thus, the net effect of patents is negative in total estimates, and innovation helps decrease CO<sub>2</sub> emissions in the whole MENA region. In prior studies, Dauda et al. [16] found a positive impact of innovation on emissions in seven MENA countries. However, Bilal et al. [15] substantiated the negative effect of innovation on emissions in six MENA countries. Both studies used a limited sample of MENA countries and also ignored the possible spatial dimensions in analyses of geographically nearby economies in the MENA region. Therefore, the present study tests and substantiates the spatial autocorrelation in the non-spatial models. Then, spatial techniques are utilized to conclude the results. The study finds a positive effect of innovation on CO<sub>2</sub> emissions in domestic economies and a negative spillover effect of innovation on CO<sub>2</sub> emissions in neighboring economies. Thus, the present study contributes to the MENA literature by reporting the positive direct and negative indirect effects of innovation on CO<sub>2</sub> emissions. Industrial value added in a country increases CO<sub>2</sub> emissions in domestic and neighboring MENA countries. Additionally, the net effect of industrialization on emissions is also positive in the whole MENA region, which shows that the industrial sector has environmental concerns for the MENA region. Urbanization increases CO<sub>2</sub> emissions in domestic economies but reduces emissions in neighboring MENA economies through its spillover effects. Thus, urbanization is harmful to the domestic environment but has pleasant environmental effects in neighboring MENA economies. The total effect of urbanization is statistically insignificant, and urbanization has neutral environmental effects for the whole MENA region.

The results specify that innovation increases CO<sub>2</sub> emissions in domestic economies. It means that the scale effect of innovation is dominant over the technique effect of innovation in domestic economies. Thus, MENA countries are suggested to finance the innovations, which could promote the technique effect and reduce CO<sub>2</sub> emissions in their domestic economies. However, innovation has a negative effect on CO<sub>2</sub> emissions in the whole MENA region, and innovation is supporting a clean environment in the whole MENA region as well. We suggest MENA countries develop a common innovation fund in the region to finance patents and technological innovation activities in any country in this region. Moreover, the results show that the industrial sector has environmental concerns in

both domestic and neighboring economies. It means that the scale effect of industrialization is dominant over the technique effect. To promote the technique effect in the industrial sector, MENA countries are advised to give tax concessions and financial support for the use of clean technologies and renewable energy sources in industries. In this way, the negative environmental effects of industrial value added may turn into positive environmental effects, which could be helpful in protecting the environment from industrial activities. Moreover, the composition of the industry should be changed. For this purpose, the government should tax the dirty industries with high pollution levels and may use this revenue to subsidize the industries with low levels of pollution. Urbanization increases emissions in domestic economies. So, low-energy-consumption vehicles and urban items should be subsidized. Moreover, items with high energy consumption should be taxed. So, the negative environmental effects of urbanization can be reduced in domestic economies.

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