COVID-19 restrictions and greenhouse gas savings in selected Islamic and MENA countries: An environmental input–output approach for climate policies

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Abstract

As addressed by many studies, greenhouse gas has a significant impact on the different aspects of life and more importantly on the whole environment. The excessive emission of green gas leads to climate change which is regarded as one of the most significant challenges of 21 century. Hence, in this regard, this paper has addressed the changing greenhouse gas (GHG) emissions in 18 countries of the MENA region. For this purpose, ten different scenarios of this disease's future status and its restrictions were considered in an input–output modelling framework. The empirical results indicated that the emission of greenhouse gas is reduced under all scenarios. However, some countries experience more reduction due to the restriction because of COVID-19 like Syria, Iran, Yemen and Lebanon. Based on the ninth scenario, Iran and Syria have the highest reduction in emission of greenhouse gas by 13.1 and 13.8 per cent, and based on the tenth scenario, Lebanon and Syria will experience the highest reduction in emission by about 13.1 and 17.9 per cent. The results show that according to scenario 10 (explosive intensification of the pandemic without the wave subsiding over a while) and scenario 9 (the pandemic worsens step by step without subsiding over a while), Syria and Iran have the highest reduction

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in greenhouse gas emissions, respectively. According to scenario 1 (rapid and complete control of disease), Bahrain, Qatar, and Kuwait have the lowest reduction in GHG emissions. Besides, the study draws several fruitful implications regarding environmental concerns as sectoral analysis such as *Hotels and Restaurants*, *Retail Trade*, *Fishing*, *Wholesale Trade*, and *Transport* sectors. Moreover, policymakers should be alert that notwithstanding all limitations, *Private Households* and *Public Administration* develop their emissions during the pandemic since quarantine intensifies the supply of these services. Surprisingly, none of the policy restrictions have a significant impact on GHG emissions from *Education*, *Health*, and *Other Services*, *Petroleum*, *Chemical*, and *Non-Metallic Mineral Products*, *Textiles and Wearing Apparel*, and *Re-export & Re-import*, demonstrating the robust and established nature of these sectors' activities. To control the emissions of the quarantine-neutral sectors, long- and mid-term structural and environmental policies should be considered. The researchers are guided by the novel implications in terms of how various industries might reduce emissions in different ways.

Graphical abstract

Keywords Input–output · Sector analysis · Greenhouse gases · COVID-19 · MENA · Environmental economics

Abbreviations

EU	European Union
NASA	National aeronautics and space administration
MENA	Middle East and North Africa
EKC	Environmental Kuznets Curve
OxCGRT	Government response tracker index

ISIC	International standard industrial classification
Btu	British thermal units
GHG	Greenhouse gas

1 Introduction

The emission of greenhouse gas has impacted the whole world so seriously, and it is regarded as the main cause for climate change (Althor et al., 2016; Hensher, 2008; Preston & Jones, 2006; Shen et al., 2020). Greenhouse gas is mostly produced due to energy production or consumption (Byravan et al., 2017; Kaygusuz, 2009; Lyeonov et al., 2019; Sarkodie & Strezov, 2019). The energy is very important component for development. Hence, one may argue that reduction in may harm the development goals. In this regard, the issue of sustainable development arises. In the framework of one of the sustainable developments we actually down only focus on the present generation but we also consider the needs of future generation (Blewitt, 2012; Chichilnisky, 1997; Elliott, 2012; Rogers et al., 2012; Sachs, 2015). Moreover, many other considerations will be considered, and one of them is the emission of greenhouse gas. In this context, to achieve the sustainable development goal, we have to use the energy more efficiently and with more considerations.

Most important effects of this virus have been on the economic sectors of countries. Due to countries' economic connection and communication and receiving input from each other, all have experienced a contraction in production. The restrictions on transportation, especially between countries, have slowed global economic activities. Most importantly, fear among consumers and firms has led to changing common consumption patterns. The financial markets have also responded to these changes, and global stock indices have fallen. In this regard, we can refer to some statistics. EU industrial production index (27 countries) in the first two months of 2020 compared to the same period in 2019, reduced by about 1.3%. During the same period, Malta's industrial production index increased by about 12.9%, and Estonia had the lowest growth, with a reduction of 6.23% among the EU countries. The growth of the industrial production index during the first two months of 2020 was positive for 8 EU member countries and negative for the remaining 19 countries. In the European Union, in February 2020, compared to February 2019, the production of capital goods reduced by 3.1%, energy by 1.7%, and intermediate goods by 0.2%, while the production of low-consumption consumer goods reduced by 0.5% and durable consumer goods increased by 1.5% (Eurostat, 2020).

In addition to the negative economic consequences, significant changes were made in environmental variables. Regarding the reduction in air traffic, the shutdown of factories, and the significant reduction in road traffic, there was a beneficial effect on air pollution. Reducing coal use by power plants, refineries, and other industries reduced CO₂ emissions by 250 million tonnes. NASA (National Aeronautics and Space Administration) and the European Space Agency reported a significant reduction in N₂O pollution across northeast China, and the lowest mean N₂O level recorded in India resulted from a nationwide travel ban at the end of March (Myllyvirta, 2020).

One of the most pressing environmental difficulties is always the reduction of emissions in parts of the world that, for various reasons, have paid less attention to pollutant emissions. One of these regions is the Middle East and North Africa (MENA). The common feature of these countries is the low mean and per capita income; at the same time, it is one of the most experienced energy production regions in the world. Therefore, it is

evident that these countries should make more efforts for rapid economic growth through energy production and consumption. Hence, the lack of attention to environmental issues and greenhouse gas emissions will be another common feature of this region. Many studies address the trend of energy consumption in detail (Aydin et al., 2012; Aydin, 2014, 2015a, 2015b, 2015c; Azadeh & Tarverdian, 2007; Köne & Büke, 2010). Energy consumption has had an increasing trend and over the past decades has been doubled. By now the fossil fuels have maintained their prominent position in world primary energy consumption.

Now, considering COVID-19 pandemic in the Islamic and MENA countries and the occurrence of extensive changes in the pattern of energy production and consumption and other economic dimensions in these countries, the reduction in greenhouse gas emissions due to reduced economic activities in the MENA region is one of the most important questions of environmental researchers. This is the question that the present study intends to answer using environmental input–output data modelling and scenario design in the range from severe and complete restrictions in these countries until the complete exclusion of restrictions.

In the following, we will review studies that investigate the impact of COVID-19 on economies and the environment. Lenzen et al. (2020) estimated the economic and environmental effects of COVID-19. They considered the economic consequences of mutual government measures, resulting in reduced global production and consumption which are reinforced by global supply chains. They investigated the direct and indirect consequences of economic and social harm, as well as the effects of environmental pandemics, using a worldwide multi-regional macroeconomic model. The results show that global economic loss is \$3.8 trillion, with a pandemic 0.6 million tons of suspended particles become less than 2.5 microns and 5.1 million tons less SO₂ and NO_x emitted. Hassan et al. (2020) highlighted this pandemic's effects on renewable energy and investigated its environmental effects. According to his study, the outbreak caused severe problems in the renewable energy sector, such as supply chain delays, stock market problems, and the risk of not benefit from government incentives at the end of this year. The investors are not stable due to uncertainty in the sector. Hence, countries should show severe incentives for clean energy. A summary of the previous studies is provided in Table 1.

Besides, also many studies address the level of greenhouse gas emissions. Mitra et al. (2020) attempted to investigate the level of CO₂ emissions at 12 environmental sites in Calcutta. The results showed significant temporal changes in CO₂ levels, but no statistically significant variation was observed among sites. Interpretation of the results due to the complete closure of industries, transportation, markets, shopping malls, leisure units, and construction, which are the primary sources of CO₂ emissions, can be proven by the closure caused by COVID-19 in the city. Liberalesso et al. (2020) attempted to quantify the potential for government investment in environmentally friendly construction projects to strengthen the economy and at the same time realize the environmental achievements by reducing energy use and emitting related greenhouse gases. This analysis uses a computable general equilibrium model to investigate the macroeconomic effect of the COVID-19 crisis on a small open economy (Belgium). The proposed policy's effect is then evaluated via comparative analysis for macroeconomic parameters and CO₂ equivalent emissions for the four scenarios. The results show that the COVID-19 pandemic is significantly affecting economies. However, the reduction in emissions is less than proportionate. However, well-designed public policies can reverse this trend, leading to economic growth and a disproportionate reduction in emissions.

Moreover many other studies investigate the emission of Greenhouse gas from sectors and countries, including (Berhe et al., 2020; Ding et al., 2017; Küstermann et al., 2008;

Table 1 A summary of the previous studies

Author	Description	methodology
Lenzen et al. (2020)	Investigate the economic and environmental effects of COVID-19	A global multi-regional macroeconomic model
Hassan et al. (2020)	Investigate pandemic's effects on renewable energy	
Mitra et al. (2020)	Examine the changes in the level of CO ₂ emissions	
Liberalesso et al. (2020)	Investigate the potential for government investment in environmentally friendly construction projects	
McKibbin and Fernando (2021)	Conducted the global macroeconomic effects of COVID-19	Computable general equilibrium model
Haddad et al. (2020)	Analyse the effects of COVID-19	
Liu et al. (2020)	Investigated the effects of China's unprecedented strict measures to prevent the pandemic	A computable general equilibrium model Input–output method Statistical methods and random simulation
Ding et al., (2017)	Different versions of statistical data	
Berhe et al., (2020)	The Global Livestock Environmental Assessment interactive model	

Kyung et al., 2015; Li et al., 2021; Monteith et al., 2005; Ståhl et al., 2014). For instance (Ding et al., 2017) estimated GHG emissions of China from 1990 to 2013 using different versions of statistical data and (Berhe et al., 2020) investigated the emission in different production systems using Global Livestock Environmental Assessment interactive model.

By COVID-19 pandemic, economic studies on this disease have been expanding, which we will introduce the most critical cases in the following. McKibbin and Fernando (2021) conducted the global macroeconomic effects of COVID-19 in seven scenarios. Hence, the outbreak of a virus called COVID-19 has disrupted China's economy and spread worldwide. The pattern of the spread of this disease and its economic effect is very unclear and makes it difficult for policymakers to formulate an appropriate macroeconomic policy response. To better understand the potential economic consequences of COVID-19, this paper investigates seven different scenarios of how COVID-19 will spread next year using a modelling technique developed by L and Mc (2003). This study investigates the effects of different scenarios on macroeconomic outcomes and financial markets in a computable general equilibrium model. The scenarios studied in this paper show that even the prevalence of this disease currently can significantly affect the global economy in the short term. These scenarios show how much the disease's cost can be avoided by investing more in public health systems in all economies, especially in less developed economies with less developed healthcare systems and high population densities.

More recently, Haddad et al. (2020) attempted to analyse the effects of COVID-19 using the input–output method. This report is based on the partial hypothetical extraction approach for input–output analyses. The purpose of this report is to inform regional and national governments in Brazil and Colombia about the potential economic costs of various closure strategies at the regional and sectoral levels. The results of simulating scenarios under different hypotheses about the periods and intensity of control measures can be used after the decline in the growth rate of new patients to design regional and partial policies to facilitate closure measures used against the spread of the virus. In the same line, Liu et al. (2020) investigated the effects of China's unprecedented strict measures to prevent the pandemic. Using the published data, they estimated the model parameters using statistical methods and random simulation and determined the parameters' values to obtain the simulation test's best results. At the next stage, they used their model to quantitatively predict future pandemic developments in China under different pandemic control strategies, focusing on analysing the results' sensitivity to selecting different parameters. The study results indicate that if strict quarantine measures are continued, the number of patients in the peak state will be in the range of 52,438 to 64,090, and its peak date will be from February 7 to February 19, 2020, and during March 18–30, 2020, the pandemic is under control. The complete control of the disease will occur from August 20 to September 1, 2020. Quarantine measures are the most effective technique for controlling the pandemic, according to sensitivity analysis. Long-term simulations and sensitivity analysis conducted in China revealed that this model is stable and empirically proven. It is proposed that this model be used to forecast the spread of the pandemic in other areas or nations. According to the study results in China, quarantine measures could not be reduced before the end of March 2020. The results also showed that China could completely resume production from April 2020 with appropriate measures against the pandemic. However, the government should act decisively against the disease's outbreak and take timely quarantine measures, although these measures may have negative and short-term public and economic consequences (Iqbal et al., 2021; Shahzad, et al., 2020a, 2020b, 2020c).

We intended to analyse the impact of the COVID-19 pandemic on the emission of greenhouse gas of selected Islamic and MENA countries by employing input–output

framework under different scenarios. The model that we use is the novel model to find the general equilibrium. Our results indicated that the restrictions in terms of COVID-19 have an effective impact on the reduction of greenhouse gas emission during the COVID-19 period. This paper is the first study to address the impact of COVID-19 restrictions on the greenhouse gas emission. The results indicated that the emission of greenhouse gas will decrease in terms of COVID-19 restrictions in all countries and based on every scenario. Besides, the emission greenhouse gas will also be reduced from most of the sectors except some sectors including "Private Households" and "Public Administration. In the following, a review of the theoretical framework is provided. OxCGRT index is introduced to measure governments' response to the prevalence of COVID-19 and countries' restrictions to provide the theoretical foundation for scenarios. An explanation of the material and methods is presented in Sect. 3. Besides, the scenarios used, and the MENA region's model results are reported in the fourth section. Finally, in the fifth section, the authors summarize the results and implications of modelling.

2 Theoretical support

The primary sources of economic shocks during a pandemic can be summarized in three factors: the shock caused by the diseases of the persons, the economic effects of public and private actions such as the closure of schools and factories, travel restrictions and quarantine, and the psychological effects of a disease outbreak.

COVID-19 pandemic has many effects on the world economy; consequently, on countries' economies, which will affect the economy in three ways, which we will explain below.

2.1 Supply shocks

Supply shocks are more-tangible. The direct effect on supply and human responses to the virus can be seen in cases such as the closure of schools, companies, and offices. Following sporadic reports of COVID-19 cases, many large Japanese companies have instructed their employees to continue working at home. This practice spread rapidly. From an economic point of view, these travel closures and bans directly reduce productivity, as they somehow temporarily reduce employment.

Many things today can be done remotely using digital technology and software based on cloud computing and databases. However, human presence in the workplace is vital to handling tasks requiring a direct and physical presence. A Japanese healthcare manufacturer has decided to implement remote work for all its employees, but factory workers are exempt from this requirement to meet the growing demand for medical masks. Other public health measures to reduce the prevalence of the disease—such as school closures—indirectly reduce employment because workers are forced to stay home to care for their children. Japan closed all schools for one month on February 27, 2020; Italy did the same on March 4, 2020, and the process is moving fast because child-to-child transmission is the main route of transmission for the disease. Another indirect factor in the temporary reduction in employment is the absence of those who do not go to work to care for their sick relatives. This is due to the current policy of quarantining the families of those affected and those in contact with them. The severity of these supply shocks increases when it comes to healthcare workers. For example, a hospital in one of Japan's provinces with the highest

number of COVID-19 patients was forced to reject outpatients due to the absence of nurses staying at home to care for their children.

2.2 Supply chain shocks

Till early March 2020, the COVID-19 pandemic was concentrated in China, accounting for more than 90% of all reported cases. Japan and Korea are next. These countries play an essential role in the global supply chains of many products.

As a global workshop, China is one of the global trade network centres, so disrupting its production will lead to secondary supply shocks in the manufacturing sector in almost all countries. Given the strong regional dimension of supply chains and the fact that China, Korea, and Japan are among the five countries most affected by the virus, the supply chain shock will be felt strongly in Asia.

Germany is the centre of European network and the seventh country to suffer the most virus damage in the world since March 5, 2020. It is clear that the pandemic's supply chain is most likely the main source of Europe's economic crisis pandemic. The same is true of North America. The United States ranks first in terms of mortality (delayed and limited testing in the United States means that the death rate there is much higher than the official figures compared to other countries; according to official statistics, the death rate in the United States is about twice as much as China and Italy). India, as the seventh-largest economy in the world, is less involved in supply chains and maybe somewhat protected from this kind of economic crisis pandemic. However, these network relationships seem very different for different sectors. Hence it is better not to generalize it too much and follow the sector analysis.

2.3 Demand shocks

Demand shocks due to COVID-19 can be distinguished from both practical and psychological aspects. The practical shock means that some customers refuse to enter the store, and similarly, some door-to-door services are suspended so that customers will have less access to the goods. The psychological shock is that customers and companies tend to take the "caution and patience" approach in the face of uncertainty over the COVID-19 pandemic, such as the 2008 crisis. In past crises, such as the Great Depression of 2008–2009, persons and companies refused to buy and delayed investing. This can be detrimental, significantly, when international media and individuals' communications can simultaneously and unintentionally induce such beliefs. To put it another way, the shock of "caution and patience" is sweeping the Internet. Traditional trade and bilateral finance interactions do not always follow demand shocks. These phenomena also happened during the global financial crisis of 2008–2009, when people and businesses all over the globe were impacted psychologically by the continuing financial crisis in the United States. While only a handful of countries were directly affected by high-risk loans, the US crisis's psychological shock has led persons in many countries to delay buying and investing. Thus, a financial shock in the North Atlantic became a major shock to global demand. The volume of trade and almost all productions reduced rapidly and simultaneously in all countries. Although history will not necessarily repeat this pattern in response to COVID-19 shock, this possibility cannot be ignored (Doğan et al., 2020; Shakoore et al., 2020).

Each of these demand shocks in the first round is likely to intensify under the Keynesian multiplier influence. Not working means not making money for many people and

companies worldwide, which will be a significant obstacle to meeting their needs. Globally, countries' economies are interconnected by the cross-border circulation of goods, services, knowledge, persons, financial capital, foreign direct investment, international banking, and exchange rate (Baldwin & Di Mauro, 2020).

2.4 Greenhouse gases

Conventionally, the relationship among different indicators of environmental degradation and economic development is expressed via the environmental Kuznets curve (EKC). In this regard, environmental pollution through economic development has caused damage by combining factors such as economic growth, population growth, energy use, and industrial activities (Fatima et al., 2021; Guo et al., 2021; Rafique et al., 2021). According to Grossman and Kruger studies, the relationship between environment and per capita income is inverted in the form of U (Bhattacharyya, 2019; Shahzad et al., 2020a), which means that environmental vulnerability to the development of economic activities is based on static assumptions about technology and environmental investment, because as income increases, so will the demand for environmental quality improvement. In other words, in the early stages of economic growth, awareness and knowledge of environmental problems are low, not crucial. At the early stages of economic growth, environmental damage increases with income growth (Fatima et al., 2021; Shahzad et al., 2020b; Talbi et al., 2020), partly an upward trend in per capita income. Then, by increasing awareness and enforcement of environmental laws, the level of degradation reduces (Ghazouani et al., 2020, 2021; Shahzad, 2020c).

Following COVID-19 pandemic and imposing severe restrictions in various countries worldwide, the debate over the environmental effects and emissions due to the pandemic is still new and insufficiently studied. However, some argue that the COVID-19 pandemic reduces environmental pollution, and some mention another significant damage to the environment. Hence, we try to mention some of them.

2.4.1 Negative environmental impacts of COVID-19

The COVID-19 pandemic has led to an increase in hospital activity and increasing medical waste. Some studies show that during the peak period of the disease in Wuhan, an average of 240 tons of medical waste was generated daily in hospitals, which is six times the average amount (Zuo, 2020). Moreover, plastic-based medical masks used worldwide are another environmental problem. "Masks are made of polypropylene and are very difficult to break down in nature," said Tracey Read, founder of the Environmental Protection Agency, Seas without Plastic (CDP, 2020).

2.4.2 Positive environmental effects of COVID-19

One of the most important positive effects of COVID-19 pandemic is the significant reduction in greenhouse gas emissions in the world plan. According to studies, the reduction in traffic due to the closure of many industrial, scientific, and tourist centres has led to a reduction in greenhouse gas emissions. This reduction was observed in countries such as China and Italy (CDP, 2020). Furthermore, a 25% reduction in carbon emissions was reported in China (Myllyvirta, 2020). A significant reduction was observed in France and Italy's nitrogen dioxide, imaged by the Copernicus Sentinel-5P satellite during the

Table 2 OxCGRT Indicators. *Source:* <https://covidtracker.bsg.ox.ac.uk>

ID	Name	Type	Targeted/General
<i>Containment and closure</i>			
C1	School closing	Ordinal	Geographic
C2	Workplace closing	Ordinal	Geographic
C3	Cancel public events	Ordinal	Geographic
C4	Restrictions on gathering size	Ordinal	Geographic
C5	Close public transport	Ordinal	Geographic
C6	Stay at home requirements	Ordinal	Geographic
C7	Restrictions on internal movement	Ordinal	Geographic
C8	Restrictions on international travel	Ordinal	No
<i>Economic response</i>			
E1	Income support	Ordinal	Sectoral
E2	Debt/contract relief for households	Ordinal	No
E3	Fiscal measures	Numeric	No
E4	Giving international support	Numeric	No
<i>Health systems</i>			
H1	Public information campaign	Ordinal	Geographic
H2	Testing policy	Ordinal	No
H3	Contact tracing	Ordinal	No
H4	Emergency investment in healthcare	Numeric	No
H5	Investment in COVID-19 vaccines	Numeric	No
<i>Miscellaneous</i>			
M1	Other responses	Text	No

pandemic and a year earlier (ESA, 2020). During the pandemic, air pollution has reduced. There are also many other studies on reducing pollution in different countries.

2.5 Government response tracker index (OxCGRT)

To combat the COVID-19 epidemic, countries have taken considerable efforts. Measuring governments' success against the coronavirus throughout the globe and looking into their experiences may help manage and combat the virus. Based on OxCGRT, the data are collected by large groups of researchers from publicly available sources such as newspapers, press releases, and government meetings and recorded according to a specific standard. The collected data are reported in the form of 18 indicators, which can be seen in Table 2 (Hale, Petherick, et al., 2020; Hale, Webster et al., 2020):

2.6 Research scenarios

Using Government Response Tracker Index (OxCGRT) for 18 countries in the MENA region and one period of time (in this article, based on the nature of Input–Output tables, one year is considered) is considered the initial shocks to these economies, and their effects on the economic sectors of these countries will be studied. To calculate the effects of these shocks by considering the types of direct, indirect, and total relationships in economies, the

Table 3 Selected countries of the MENA region. *Source:* World Bank, MENA Region countries

Country	Code	Country	Code
Azerbaijan	AZE	Libya	LBY
Bahrain	BHR	Morocco	MAR
Algeria	DZA	Oman	OMN
Egypt	EGY	Qatar	QAT
Iran	IRN	Saudi Arabia	SAU
Iraq	IRQ	Syria	SYR
Jordan	JOR	Turkey	TUR
Kuwait	KWT	Tunisia	TZA
Lebanon	LBN	Yemen	YEM

Table 4 26 parts of input–output tables of the studied countries

Sector name	Symbol	Sector name	Symbol
Agriculture	Sector 01	Construction	Sector 14
Fishing	Sector 02	Maintenance and repair	Sector 15
Mining and quarrying	Sector 03	Wholesale trade	Sector 16
Food and beverages	Sector 04	Retail trade	Sector 17
Textiles and Wearing apparel	Sector 05	Hotels and Restaurants	Sector 18
Wood and paper	Sector 06	Transport	Sector 19
Petroleum, Chemical, and non-metallic mineral products	Sector 07	Post and Telecommunications	Sector 20
Metal products	Sector 08	Financial intermediation and business activities	Sector 21
Electrical and machinery	Sector 09	Public administration	Sector 22
Transport equipment	Sector 10	Education, health and other services	Sector 23
Other manufacturing	Sector 11	Private households	Sector 24
Recycling	Sector 12	Others	Sector 25
Electricity, gas, and water	Sector 13	Re-export and Re-import	Sector 26

symmetric input–output Table of industry–industry in 2015 is used, which is grouped into 26 sections (Table 4). The input–output table is based on the fourth version of ISIC classification. Therefore, to establish the relationship between the input–output pattern and the types of gases, multiplier coefficients of pollution and energy footprint index published by the KGM Institute were used. The selected countries in the MENA region studied in this study are shown in Table 3.

To compare input–output tables with each other, it is necessary to have tables with the same dimensions. In other words, the studied tables should be matched in terms of the number and nature of parts. The following equation is used for this purpose:

$$H_{ixj} \times Y_{jxi} \times H'_{jxi} = Y^*_{ixi} \quad (1)$$

Y is the initial matrix, and Y^* is the matched matrix. Matrix H acts as a converter whose number of rows is equal to the number of rows of the matched matrix, and the number of columns is equal to the number of entries of the initial matrix. As a result, a matched

matrix is obtained by reducing the number of entries of the initial matrix from j to i . As the case may be, the elements of the conversion matrix H and its transposition H' , as the case may be, consist of zero and one. (Table 4).

To convert the n -part input–output Table to an m -part Table, first, the conversion matrix H is pre-multiplied by the principal matrix Y , and then its transposition is multiplied by the product of the matrix H in the matrix Y . Therefore:

$$[H]_{n \times 7} \times [Y_{ij}]_{m \times m} \times [H]_{m \times n} = [Y_{ij}^*]_{n \times n} \quad (2)$$

Like other modelling models in different sciences, in this study, hypotheses have also been considered that can be classified into three categories. The first category is related to input–output modelling hypotheses which were mentioned in various books and papers such as Raa, (2006), Miller and Blair (2009), and Ciaschini (1988). The second group of hypotheses points out that since 2015, the technologies for the production of economic activities in the MENA region have not changed, and in other words, the technical coefficients of the sectors are the same since 2015 to date. The third category of hypotheses is related to the coronavirus and government decisions, as it is assumed that with the intensification of the pandemic, social restrictions and bans on activity are intensified. With the reduction, the severity of the restrictions reduces. The first category of hypotheses, such as homogeneity, final exogenous demand, linear production function, etc., provides the leading platform for implementing input–output models for the model maker. The second group is considered because the MENA region countries' statistical input–output tables after 2015 are not available. The third category of hypotheses also allows the quantification of shock based on the OxCGRT index in supply and demand.

3 Data and methodology

In a general classification, environmental input–output modelling is divided into "hybrid sector methods" and "ecological-economic inputs and products."

According to the first type, the "hybrid sector" method analyses the environmental sector (in this study, greenhouse gases) using the input–output table. In this method, energy data in terms of British thermal units (Btu) and non-energy data in terms of currency are included in the Table. For this purpose, first the necessary matrices for this analysis are defined. Z matrix is an interdepartmental matrix that consists of two parts: energy carriers and non-energy materials. In this matrix, the unit of measurement for Btu energy carriers and non-energy materials is the monetary unit.

$$Z = \begin{cases} E_z(\text{Btu}) \text{ energy carriers} \\ Z_j(\$) \text{ non-energy materials} \end{cases}$$

For example, for a two-sector economy, we would have:

$$Z = \begin{bmatrix} \text{Btu} & \text{Btu} \\ \$ & \$ \end{bmatrix}$$

The total output of X in the energy input–output matrix is defined as follows:

$$X = \begin{cases} E_x(\text{Btu}) \text{ energy carriers} \\ X_j(\$) \text{ non-energy materials} \end{cases}$$

For example, for a two-sector economy that has an energy sector, we have:

$$X^* = \begin{bmatrix} \text{Btu} \\ \$ \end{bmatrix}_{2 \times 1} \quad (3)$$

The final demand in the energy input–output matrix also includes two parts: monetary and btu.

$$Y = \begin{cases} E_y(\text{Btu}) \text{ energy carriers} \\ Y_j(\$) \text{ non-energy materials} \end{cases}$$

Matrix F represents the sum of direct and indirect energy use.

$F^* = \text{Intersectoral energy use} + \text{final energy use}$

$$F = \begin{cases} F_k(\text{Btu}) \text{ energy carriers} \\ 0(\$) \text{ non-energy materials} \end{cases}$$

For example, for a two-sector economy, this matrix is as follows:

$$F^* = \begin{bmatrix} \text{Btu} \\ 0 \end{bmatrix}_{2 \times 1} \quad (4)$$

Now, we calculate the matrix of Leontief A^* coefficients for the energy input–output matrix using the above definitions as follows:

$$A^* = Z^* (\hat{X}^*)^{-1} \quad (5)$$

$\hat{X}^*$ matrix is a diagonal matrix in which each element of the diameter is the total output of one of the economic sectors. For example, for a two-sector economy, the matrix of Leontief coefficients would be as follows:

$$A^* = \begin{bmatrix} \frac{\text{Btu}}{\$} & \frac{\text{Btu}}{\$} \\ \frac{\$}{\text{Btu}} & \frac{\$}{\$} \end{bmatrix}_{2 \times 2} \quad (6)$$

Nevertheless, the properties of this matrix are different from the conventional Leontief matrix. For example, the sum of each column in matrix A^* may not be less than one. Direct energy use is the amount of energy input that each sector receives directly from the energy sector. Direct energy use coefficients per production unit can be obtained from the following equation.

$$\delta = F^* \cdot (X^*)^{-1} \cdot A^* \quad (7)$$

The coefficients of total energy use, including direct and indirect use, are as follows:

$$\alpha = F^* \cdot (X^*)^{-1} \cdot (I - A^*)^{-1} \quad (8)$$

Finally, according to the emission coefficients, changes in gas emissions can be calculated.

Table 5 Schematic model of symmetric input–output table with ecological inputs and outputs

Eco- logical product		Total produc- tion	Final demand	Inter-section exchange					
				Consuming sector					
CO ₂	SO ₂					Industry	Mining	Agriculture	
n ₁₂	n ₁₁	x ₁	f ₁	a ₁₃	a ₁₂	a ₁₁	Agriculture	Producing sector	
n ₂₂	n ₂₁	x ₂	f ₂	a ₂₃	a ₂₂	a ₂₁	Mining		
n ₃₂	n ₃₁	x ₃	f ₃	a ₃₃	a ₃₂	a ₃₁	Industry		
				m ₁₃	m ₁₂	m ₁₁	Oil, gas, and	Ecological input	
				m ₂₃	m ₂₂	m ₂₁	land		

The second type of environmental input–output modelling related to various gas emissions is ecological-economic inputs and products. This method is used in this study.

Modelling environmental issues distinguish among factors used as input in the production process, such as primary energy, land, water, and factors produced in this process, such as pollution, waste, and greenhouse gases.

These environmental factors can be used as inputs and outputs. We consider a set of ecological inputs (such as crude oil, gas, solar energy, wind energy, biomass, water, land, etc.) and show its value with $M = (m_{kj})$ matrix. Each M matrix element reflects the value of environmental input of type k used in Sector J production.

We also consider a set of environmental outputs, such as the amount of air pollution caused by SO₂, and denote it by the matrix $N = [n_{ik}]$. Each N matrix element represents the value of the ecological output of type k generated by the output of Sector i . In this case, the Table is generalized as follows (assuming the Table has three parts, two ecological inputs, including oil and gas and land, and two ecological products):

According to Table 5, the matrix of Leontief technical coefficients can be defined.

$$A_{n \times n} = Z_{n \times n} \hat{X}_{n \times n}^{-1} \quad (9)$$

where $Z_{n \times n}$ is the inter-section exchange matrix, and $\hat{X}_{n \times n}$ is the diameter matrix whose diameter elements are the total product of each section.

Then, we define the matrix of ecological input coefficients $R = [r_{kj}]$, which is the value of ecological commodity k used for one dollar of production in industry j .

$$R_{k \times n} = M_{k \times n} (\hat{X}_{n \times n}^{-1}) \quad (10)$$

$M_{2 \times 3}$ shows the inter-section exchange matrix between the two ecological goods of land and oil and gas and industry, agriculture, and mining sectors. The matrix of ecological output coefficients is defined in the same way. The elements of the matrix of ecological output coefficients $Q = [q_{ki}]$ represent the ecological output of k , which is produced for one dollar of the product of j .

$$Q_{k \times n} = N'_{k \times n} (\hat{X}_{n \times n})^{-1} \quad (11)$$

In this case, $N_{n \times k}$ is the matrix of the final production of ecological goods produced by each economic sector. Then, the matrix of the coefficients of the total inputs and outputs of the ecological goods is calculated as a function of the final demand. First, we express the coefficient matrix of the effects of all the inputs:

$$Q_{k \times n}^* = Q_{k \times n} (I - A)_{n \times n}^{-1} \quad (12)$$

$$R_{k \times n}^* = R_{k \times n} (I - A_{n \times n})^{-1} \quad (13)$$

Matrix $Q^*=[q_{ij}]$ elements show the amount of i -type pollution produced directly and indirectly in exchange for one \$ of final demand for section j . The elements of the $R_{2 \times 3}^*=[r_{ij}^*]$ matrix indicate how much ecological input is directly and indirectly needed to meet the final demand for a product of Section j . Because of the social restrictions imposed, it is necessary to consider changes in production, relationships among sectors, and the resulting shock. The total output changes and relationships among sectors are modelled via the hypothetical partial extraction method (Miller & Blair, 2009). The partial hypothetical extraction method, which is part of the generalized hypothetical extraction method, was introduced by Dietzenbacher and Lahr (2013), pioneers of input–output modelling. As mentioned earlier, the general hypothetical extraction method has significant drawbacks. In this method, these drawbacks and problems were answered so that, first, in this method, it is assumed that α per cent of the intermediate input of sectors of the economy are removed for various reasons than with what is occurs in the economy, has higher compliance. Second, according to this method, there is no absolute emphasis on the matrix of intermediate effects, and the value-added vector and its changes are considered. Third, according to the partial hypothetical extraction method, it is unnecessary to reduce α per cent of a sector's input. However, it can be assumed that α per cent increases in the sectors for various reasons such as natural factors, exploration of mines and reservoirs, economic policy, etc. Fourth, in this method, supply will not be extracted; consequently, the intermediate exchange matrix will not be smaller. It should be noted that we used PyIO which is a module for Input–Output analysis, written in Python. The data has been extracted from the Eora global supply chain database which is made up of a multi-region input–output table (MRIO) model that provides a time series of high-resolution IO tables for 190 countries, along with matching environmental and social satellite accounts.

4 Empirical results

In this section, modelling the changes in the greenhouse gas emissions in ten scenarios in 18 countries in the MENA region are presented.¹ Since the situation facing countries around the world concerning COVID-19 pandemic and the resulting restrictions is not absolute, ten different scenarios will be investigated in this paper (Table 6), and the emission status of greenhouse gases in each case was modelled. The study flow diagrams are illustrated in Fig. 1.

The modelling results are performed for all 18 countries, and the results are specified. Table 7 shows the total changes in the greenhouse gas emissions in these 18 countries. Moreover, Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 (10 heatmaps) show the reduction or increase in greenhouse gas emissions in 26 sectors and the final demand of selected Islamic and MENA countries:

¹ The countries in MENA region which studied in this paper are as follows: Algeria, Azerbaijan, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, and Yemen.

Table 6 Ten scenarios

Num.	Description	figure
Scenario 1	Rapid and complete control of disease	<p>Scenario 1</p>
Scenario 2	Gradual but complete control of the epidemic over a while	<p>Scenario 2</p>
Scenario 3	Gradual control of the epidemic by severe reduction in contagion at the end of a period	<p>Scenario 3</p>
Scenario 4	Gradual control of the epidemic by a modest reduction in contagion at the end of a period	<p>Scenario 4</p>
Scenario 5	Two identical waves of disease	<p>Scenario 5</p>
Scenario 6	Two dissimilar waves of disease	<p>Scenario 6</p>
Scenario 7	A sustained wave of disease and a sensible declining trend at the end of a period	<p>Scenario 7</p>
Scenario 8	A sustained wave of disease with a mild declining trend at the end of a period	<p>Scenario 8</p>
Scenario 9	The epidemic worsens step by step without subsiding over a while	<p>Scenario 9</p>
Scenario 10	Explosive intensification of the epidemic without the wave subsiding over a while	<p>Scenario 10</p>

Fig. 1 Flowchart of study

Table 7 Total changes in greenhouse gas emissions in the countries of MENA region under ten scenarios of COVID-19 pandemic

Country	Scenario 01 (%)	Scenario 02 (%)	Scenario 03 (%)	Scenario 04 (%)	Scenario 05 (%)	Scenario 06 (%)	Scenario 07 (%)	Scenario 08 (%)	Scenario 09 (%)	Scenario 10 (%)
<i>Azerbaijan</i>	-0.05	-0.20	-0.25	-0.25	-0.41	-0.74	-1.40	-1.63	-8.73	-12.18
<i>Bahrain</i>	-0.01	-0.13	-0.20	-0.20	-0.33	-0.60	-1.12	-1.31	-6.61	-9.07
<i>Algeria</i>	-0.03	-0.15	-0.20	-0.20	-0.33	-0.60	-1.14	-1.33	-7.21	-10.10
<i>Egypt</i>	-0.05	-0.19	-0.24	-0.24	-0.38	-0.67	-1.25	-1.45	-7.67	-10.71
<i>Iran</i>	-0.07	-0.24	-0.30	-0.30	-0.48	-0.84	-1.59	-1.85	-13.85	-9.08
<i>Iraq</i>	-0.04	-0.17	-0.22	-0.22	-0.36	-0.65	-1.25	-1.46	-7.87	-11.00
<i>Jordan</i>	-0.04	-0.19	-0.26	-0.26	-0.42	-0.77	-1.45	-1.69	-8.78	-12.15
<i>Kuwait</i>	-0.01	-0.12	-0.16	-0.17	-0.28	-0.51	-0.98	-1.14	-5.81	-7.95
<i>Lebanon</i>	-0.04	-0.20	-0.27	-0.27	-0.44	-0.81	-1.53	-1.78	-9.48	-13.16
<i>Libya</i>	-0.03	-0.16	-0.21	-0.22	-0.36	-0.67	-1.29	-1.51	-8.28	-11.59
<i>Morocco</i>	-0.04	-0.18	-0.23	-0.23	-0.37	-0.66	-1.24	-1.44	-7.61	-10.62
<i>Oman</i>	-0.02	-0.13	-0.18	-0.18	-0.30	-0.56	-1.07	-1.25	-6.85	-9.60
<i>Qatar</i>	-0.01	-0.08	-0.11	-0.11	-0.17	-0.31	-0.59	-0.68	-3.57	-5.02
<i>Saudi Arabia</i>	-0.02	-0.14	-0.18	-0.18	-0.30	-0.55	-1.05	-1.23	-6.65	-9.33
<i>Syria</i>	-0.03	-0.24	-0.33	-0.34	-0.57	-1.10	-2.13	-2.48	-13.10	-17.94
<i>Turkey</i>	-0.03	-0.14	-0.18	-0.18	-0.30	-0.55	-1.05	-1.23	-6.70	-9.40
<i>Tunisia</i>	-0.04	-0.18	-0.24	-0.24	-0.39	-0.69	-1.30	-1.51	-7.96	-11.06
<i>Yemen</i>	-0.05	-0.20	-0.25	-0.25	-0.40	-0.72	-1.36	-1.58	-8.31	-11.55

Source: Authors' calculations

Fig. 2 Changes GHG emissions in each sector based on scenario 1. *Source:* Authors' calculations

Fig. 3 Changes GHG emissions in each sector based on scenario 2. *Source:* Authors' calculations

At this stage, it is better to examine the results separately for each sector and compare the situation of each sector in ten scenarios, as indicated in Figs. 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38.

Fig. 8 Changes GHG emissions in each sector based on scenario 7. *Source:* Authors' calculations

Fig. 9 Changes GHG emissions in each sector based on scenario 8. *Source:* Authors' calculations

Fig. 12 GHG emission in sector 1. *Source:* Authors' calculations

4.1 Discussion

Regarding the economic shocks resulting from COVID-19 pandemic and in the framework of input–output modelling, and considering the lack of change in production technology in countries affected by the disease, its effects on each of the production and service activities of economies were measured, besides in ten scenarios the trend of changes in greenhouse gas emissions was investigated in 18 countries in the MENA region.

Thus, the trend of changes in greenhouse gas emissions in these 18 countries under various conditions of COVID-19 pandemic that will occur in the future can be summarized as follows: If the first scenario (rapid and complete control of disease) occurs, we will see a tiny amount of reduction in gas emissions. Under these circumstances, Iran will have the highest reduction in GHG emissions, and the three countries of Kuwait, Bahrain, and Qatar will see the least changes in the emissions. The most optimistic scenario for this disease in a given period is scenario one. Based on the second scenario (gradual but complete control of the pandemic over a while), Syria and Iran will see the most considerable reduction in greenhouse gas emissions, while the three countries of Oman, Kuwait, and Qatar will see

The results of fourth scenario (i.e., gradual control of the pandemic by a modest reduction in contagion at the end of a period) are very similar to the third scenario, and the situation of countries is not different from each other, and we will only see a further reduction in the emissions. The rate of change in greenhouse gas emissions from the fifth scenario (two identical waves of disease) will be more noticeable than before. Syria, Iran, Lebanon, Jordan, and Azerbaijan will be the leaders to reduce the greenhouse gas emissions, and Turkey, Kuwait, and Qatar have the least change.

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The seventh scenario (a sustained wave of disease and a sensitive declining trend at the end of a period) is almost similar to the sixth scenario, except that greenhouse gas emissions decreased by one more per cent on average. In scenario eight (a sustained wave of disease with a mild declining trend at the end of a period), the only country that will see very little change in reducing greenhouse gas emissions is Qatar. In contrast, Syria is witnessing a significant reduction in gas emissions. The other 16 countries, namely Iran, Lebanon, Jordan, Azerbaijan, Yemen, Tunisia, Libya, Iraq, Egypt, Morocco, Algeria, Bahrain, Oman, Turkey, Saudi Arabia, Kuwait, will see a decrease in gas emissions.

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Fig. 15 GHG emission in sector 4. *Source:* Authors' calculations

by step without subsiding over a while), Iran and Syria are two countries that will face a significant difference in reducing greenhouse gas emissions. After these two, the five countries of Lebanon, Jordan, Azerbaijan, Yemen, and Libya are witnessing relatively large greenhouse gas emissions reductions. Nine countries, Tunisia, Iraq, Egypt, Morocco, Algeria, Oman, Turkey, Saudi Arabia, Bahrain, are in the middle. Moreover, at the end of the list are Kuwait and Qatar.

The tenth scenario (explosive intensification of the pandemic without the wave subsiding over a while), which can be called the most pessimistic scenario, like scenario 9, changes all countries in the region in greenhouse gas emissions. Thus, these reductions will be due to the restrictions imposed and not changes in production technology. However, the tenth scenario for 17 of the 18 countries achieves the highest reduction in greenhouse gas emissions, in contrast to Iran, which has the highest reduction in the ninth scenario.

As it is clear from the comparison of Figs. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, the most massive reduction in pollution in these countries was related to the reduction in the activities of the sectors "Hotels and Restaurants," "Retail Trade" and "Fishing."

COVID-19 pandemic began deep in China's Hebei Province and is spreading rapidly. The high rate of the virus has now been reported from East Asia to the Middle East, Europe, and the Americas, and in several countries, the death rate has surpassed that of China. Coronavirus 2019, or COVID-19, also known as nCoV acute respiratory disease 2019, is an infectious disease caused by the new coronavirus, a virus very similar to SARS. The economic consequences of outbreak could include the United States, the Eurozone, the Middle East, and the Far East, and as health policies are adopted, rulers are thinking about the economic consequences.

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Diseases, pandemics, and pandemics have exogenous shock nature in the economy since their entering mechanism to economic interactions, and relations is developing from external factors. Hence, the channels of this phenomenon to the economy should be identified. In this type of modelling, the economic effects and loss are modelled in the short term because experiences have shown that the discovery of vaccines and drugs for diseases will not be long-term. Hence, it can be considered that the production technology will not change during this period, and input–output tables of recent years can be used. The two main channels of a shock to the economy are affected by supply and demand. Reducing

Fig. 18 GHG emission in sector 7. *Source:* Authors' calculations

firms' activity, staffing of economic activities, and the demand of the private and public sectors will finally enter the global economy's supply chain and affect all countries, even if they are immune to this disease.

Regarding the economic shocks resulting from the COVID-19 pandemic and in the framework of input–output modelling, and considering the lack of change in production technology in countries affected by the disease, its effects on each of the production and service activities of economies were measured, besides in ten scenarios the trend of changes in greenhouse gas emissions was investigated in 18 countries in the MENA region.

In general, the result indicated the significant impact of COVID-19 restrictions on the emission of greenhouse gas from all the sectors, particularly Hotels and Restaurants,"

Future studies can focus on finding the impact of OCID-19 restriction in other countries in other regions around the world using more advanced and comprehensive methods and approaches.

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Fig. 25 GHG emission in sector 14. *Source:* Authors' calculations

Fig. 26 GHG emission in sector 15. *Source:* Authors' calculations

Fig. 27 GHG emission in sector 16. Source: Authors' calculations

Fig. 30 GHG emission in sector 19. *Source:* Authors' calculations

Fig. 31 GHG emission in sector 20. *Source:* Authors' calculations

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Authors' contribution MGA contributed to conceptualization, methodology, data curation, software, writing—original draft preparation. SR contributed to validation, writing—original draft preparation, writing—reviewing, and editing. MI contributed to validation, writing—original draft preparation, writing—reviewing, and editing. RR contributed to methodology, data curation, validation, and software. MGD contributed to visualization, writing—reviewing and editing, supervision.

Data availability The datasets used during the current study are available from the corresponding or first author on reasonable request, <https://doi.org/10.6084/m9.figshare.14128715.v3>.

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