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Statistical Analysis And Modeling Of The Atmospheric Carbon Dioxide In The Middle East And Comparisons With USA, EU And South Korea

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Abstract

Global warming is considered one of the important issues facing our planet. Global warming is the increase in average global temperatures caused mostly by increases in Carbon Dioxide CO_2. During the last two decades, the CO_2 emission in the Middle Eastern countries increased by over 200% based on The Energy Information Administration (EIA). Thus, the aim of this study is to structure a good statistical model for atmospheric CO_2 in the Middle East to identify significant attributable variables that produce the CO_2 emissions. Fossil fuel burning (gas fuel, liquid fuel, and solid fuel) cement manufacture, and gas flaring and their interactions have been identified and ranked based on their percentage of contribution to CO_2 in the atmosphere. Finally, the results of this modeling are compared to the results of the United States, European Union, and South Korea.

Keywords: global warming, Middle East, climate changes, Carbon Dioxide, CO_2 emission, fossil fuels

Background and Data

Global warming is a critical issue that is facing our planet. It is defined as the increase in average global temperatures that is caused mostly by increased carbon dioxide (CO_2). During the last two decades, CO_2 emissions in Middle Eastern countries have increased by over 200% based on The Energy Information Administration (EIA; U. AL-mulali, 2012) [1].

What is the relationship between carbon dioxide and global warming? Carbon Dioxide is present in the atmosphere in a very small amount, but it has a big impact on sustainable life on the planet. CO_2 plays a key role in trapping heat in the atmosphere and keeping our planet from freezing. However, the way that humans live, using fossil fuels and other practices that release CO_2 into the air, contributes to the amount of atmospheric carbon dioxide. As (CO_2) concentrations in Earth's atmosphere continue to increase, adding to the amount of heat trapped in the atmosphere, which raises the temperature of the planet. "The Intergovernmental Panel on Climate Change has fully documented the fact that industrial activity is responsible for the rapidly increasing levels of atmospheric carbon dioxide and other greenhouse gases. It is not surprising then that global warming can be linked directly to the observed increase in atmospheric carbon dioxide and to human industrial activity in general."(NASA GISS, Andrew Lacis, 2010)

We used monthly data spanning from 1980-2008 of 15 countries in the Middle East, namely: Bahrain, Cyprus, Israel, Iran, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen, and the Occupied Palestinian Territory. The atmospheric CO_2 (parts per million) and CO_2 Emission (thousand metric tons of carbon) were obtained from Carbon Dioxide Information Center (CDIC) [2,3]. CO_2 emissions are byproducts of burning fossil fuels (gas fuels, liquid fuels, and solid fuels) manufacturing cement, and gas flares.

We used the average of two sampling sites to gather the data of total CO_2 in the atmosphere: Negev Desert, Israel and Seychelles on Mahe Island. Israel's site is the only measurement site in the Middle East. Due to this data limitation, we included Seychelles' data as well. We used this site because of its location in the Indian Ocean and the effect of the ocean's current making the data of Mahe Island partly representative. A map of the Middle East countries (shaded green) with measurement sites (red pins) is shown in Figure 1.

In this study, an overall statistical model was proposed to represent the CO_2 in the atmosphere and all possible attributable variables, interactions and high order terms if applicable. Individual variables with significant interactions are ranked based on their percentage of contribution to CO_2 in the atmosphere and compared with those of the United States, European Union, and South Korea. Additionally, the statistical model has been evaluated by R squared (R^2), adjusted R squared (R_{adj}^2), and residual analysis.

Finally, the proposed statistical model will examine the major determinants that affect CO_2 in the atmosphere, and illustrate different combinations of various attributable variables. In addition, this model will predict the atmospheric CO_2 given the information of the explanatory variables to suggest recommendations for these countries to reduce their CO_2 emissions level.

Figure 1. Countries that constitute the Middle East

There are other possible attributable variables like contamination and deforestation. Moreover, from the economic point of view, a number of studies have indicate that there is a connection between CO_2 emissions and economic growth. For example, Farhani and Ben Rejeb (2012) [4] conducted a study to examine the relationship between energy consumption, economic growth (GDP), and CO_2 emissions. They found that an increase in energy consumption might lead to increase in the income and the CO_2 emissions.

Also, Al-Mulali (2012) [1] examined the relationship between CO_2 emission with energy consumption, economic growth, total exports and imports of goods and services, and foreign direct investment net inflows, which revealed that The total primary energy consumption, foreign direct investment net inflows, GDP, and total trade were important factors in increasing CO_2 emissions. In this study, however, we focus only on the significance of the different types of fossil fuels, cement, and gas flares contributing to atmospheric CO_2 in the Middle East.

Methodology

Natural phenomena such as atmospheric CO_2 do not follow normal distribution, which is clearly expressed in Figure 2. A p-value = 6.694e-09 from the Anderson-Darling normality test is compatible with the plot and the subject data's distribution is not Gaussian.

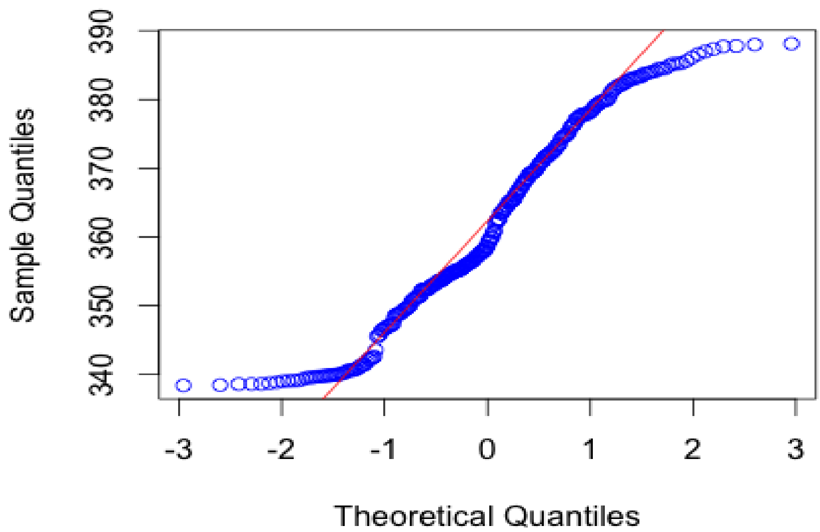

Figure 2. Q-Q plot of the CO_2 in the atmosphere

Thus, in order to know and understand the probabilistic behavior of CO_2 in the atmosphere, a parametric analysis was conducted and showed that CO_2 in the atmosphere was consistent with the Johnson SB probability distribution. Table 1 shows the result for the goodness of fit testing

H_0: data are consistent with Johnson SB

H_1: data are not consistent with Johnson SB

Table 1 Goodness of Fit Test Results

	Kolmogorov-Smirnov	Anderson-Darling
Statistic	0.05337	1.2173
Decision	Accept	Accept

The probability density function of Johnson SB distribution is given by:

$$f(x) = \frac{\delta}{\lambda\sqrt{2\pi}y(1-y)}\, exp\left\{-\frac{1}{2}\left[\gamma + \delta\left(\frac{y}{1-y}\right)^2\right]\right\}, \xi \le y = \frac{x-\xi}{\lambda} \le \xi + \lambda \ldots (1)$$

Where γ and δ are the shape parameters, ξ is the location parameter, and λ is the scale parameter. The approximate maximum likelihood estimates of the four parameters of the Johnson SB probability distribution using the atmospheric CO_2 data is given in Table 2.

Table 2 Approximate MLE of Johnson SB Parameters

$\hat{\gamma}$	$\hat{\delta}$	$\hat{\xi}$	$\hat{\lambda}$
0.1189	0.7372	335.44	55.479

To achieve the goal of this study, a statistical model of CO_2 in the atmosphere was designed considering the atmospheric CO_2 as the response variable and gas fuels (Ga), solid fuels (So), liquid fuels (Li), gas Flares (Fl) and cement (Ce) as explanatory variables. Therefore, the statistical form of the model with all possible interactions is:

$$CO_2 = \beta_O + \beta_1 Ga + \beta_2 So + \beta_3 Li + \beta_4 Fl + \beta_5 Ce + \beta_6 A_1 + \cdots + \beta_j A_j + \varepsilon \qquad (2)$$

CO_2 Indicates the atmospheric CO_2, $\beta's$ are the coefficients, $A's$ are all possible interactions and high order terms and ε is a random error. Usually we assume that the ϵ_i are independent and normally distributed with mean zero and variance σ^2,i.e.:

$$E(\varepsilon) = 0,\ var(\varepsilon) = \sigma^2\ and\ \ \varepsilon \sim N\ (0, \sigma^2) \qquad (3)$$

Thus, Figure 3 describes the increasing trend of CO_2in the atmosphere over the period of 1980-2008.

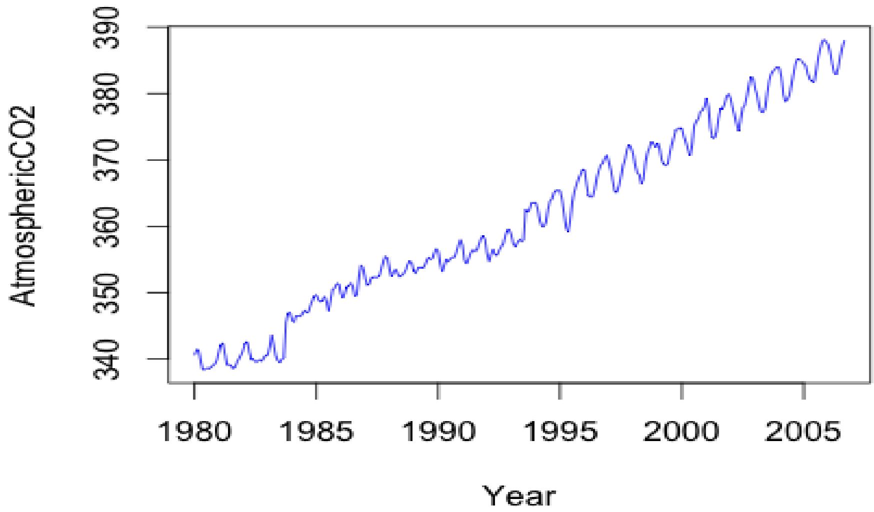

Figure3. Monthly atmospheric CO_2

To develop our statistical model, we defined the five independent variables and their interaction terms as shown in Table 3. Using backward elimination, we started with the full statistical model, which included all five attributable variables and ten possible interaction terms; i.e., total of 15 terms.

Table 3 Five Attributable Variables and their Interactions

GAS Fuels: Ga	Ga*Li	Li*Fl
Liquid Fuels: Li	Ga*So	Li*Ce
Solid Fuels: So	Ga*Fl	So*Fl
Gas Flares: Fl	Ga* Ce	So*Ce
Cement: Ce	Li* So	Fl*Ce

In the estimation process of the coefficients of the explanatory variables and all possible interactions, we found the significant contributions of both attributable variables and the interactions. Hence, in our statistical model, only 3 out of 5 explanatory variables were significantly contributing to CO_2 emissions with only 4 interaction terms. Thus, the estimated statistical model with factors that influence CO_2 in the atmosphere is given by:

$$\widehat{CO}_2 = 329.6 + 1.019 * 10^{-4}\, Ga - 5.051 * 10^{-4}\, Li + 7.856 * 10^{-3}\, Ce + 1.195 * 10^{-8}(Li)(So) + 1.512 * 10^{-8}\,(Li)(Fl) - 1.318 * 10^{-7}\,(So)(Ce) - 2.034 * 10^{-7}(Fl)(Ce) \quad (4)$$

In accordance with the proposed statistical model, gas fuels, liquid fuels, and cement are identified as key factors affecting CO_2 in the atmosphere. Furthermore, the statistical model identified the following interactions that are statistically contributing to the atmospheric CO_2 namely (Liquid Fuels*Solid Fuels), (Liquid Fuels*Gas Flares), (Solid Fuels* Cement) and (Gas Flares * Cement).

The recommended statistical model has been assessed using R squared (R^2) and adjusted R squared (R^2_{adj}) which are the key criteria to evaluate the model fitting. They provide an overall measurement of how well the model fits. The regression sum of squares (SSR), is the variation that is explained by the proposed model. The sum of squared errors (SSE), known as the residual sum of squares, is the variation that is left unexplained. The total sum of squares (SST) is proportional to the sample variance and equals the sum of SSR and SSE [5]. The coefficient of determination (R^2) represents the proportion of total variation in the response that is explained by the proposed statistical model and is given by:

$$R^2 = 1 - \frac{SEE}{SST} \qquad (5)$$

As (R^2) always increases with every explanatory variable added to statistical model, adjusted R squared (R^2_{adj}) has been adjusted for the number of predictors in the model as follows: it increases only if more variables are added and improve the model. On the other hand, it decreases when we add more useless predictors to the model. It is preferred when we work with several parameters and is given by:

$$R^2_{adj} = 1 - \frac{SEE/_{df_{error}}}{SST/_{df_{total}}} \qquad (6)$$

For our suggested statistical model, R^2 is 0.9848 and R^2_{adj} is 0.9844. That is, our statistical model explains 98.48% of the variation in the response variable; equivalently, the significant attributable variables and the interactions estimate about 98% of the total CO_2 emissions in the atmosphere. Both $R^2$and $R^2_{adj}$are very high (more than 90%) and very close to each other. These results illustrate that the increase of the value of R^2 is not due to the increase in the number of the predictors but to the good quality of the proposed statistical model.

Additionally, we performed a residual analysis that calculated the actual value of CO_2 in the atmosphere (response) minus the estimated value of CO_2 in the atmosphere using the proposed statistical model, and it attests the quality of the developed statistical model. The residual analysis also justified model assumptions of normality, linearity, and constant error variance. For the developed statistical model, the mean residual was very small ($\bar{r} = \frac{1}{n}\sum r_i = 3.58 \times 10^{-18}$), and it indicates that the predictions from our statistical model are good. Moreover, the residual plots are used to assess the model assumptions such as: Q-Q plots in Figure 4 and scatter plot in Figure 5. In Q-Q plot, we see an approximate normality distributed residual and the scatter plot illustrates an approximate zero mean and no clear pattern or trend in the residuals.

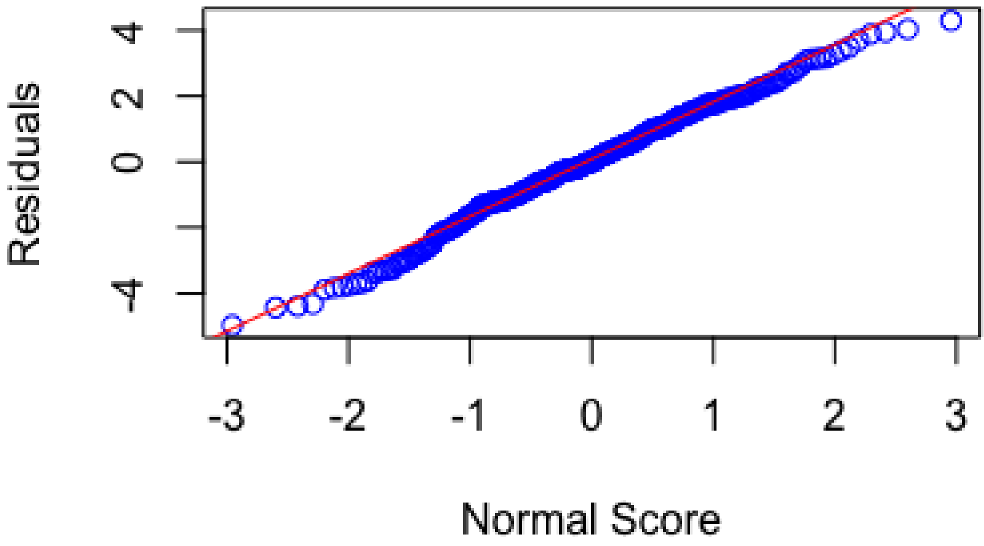

Figure 4. Residual's Q-Q plot

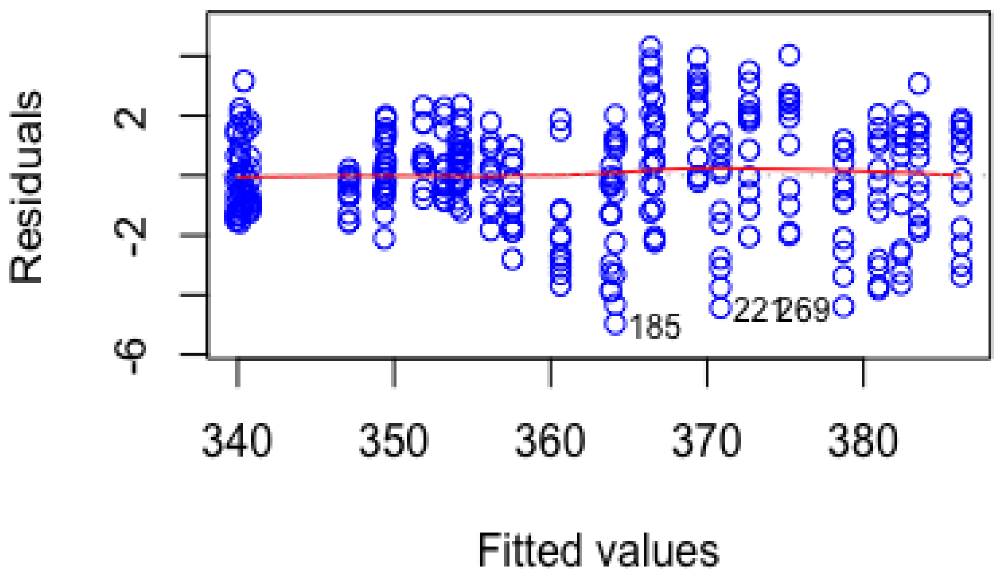

Figure 5. Residual's scatter plot

Results and Discussion

After obtaining the proper statistical model and evaluating the quality of the model using different criteria, which are stated above, we can infer useful pieces of information from the subject model. First, we will identify the significant attributable variables and their interaction terms. That is, we can identify as fuels, liquid fuels, cement and the interactions of (Liquid Fuels*Solid Fuels), (Liquid Fuels*Gas Flares), (Solid Fuels* Cement) and (Gas Flares * Cement) as the key factors affecting CO_2 in the atmosphere. Second, we can use the model to predict the atmospheric CO_2 given the information of the attributable variables and pose recommendations for these countries to reduce their CO_2 emissions level.

Third, one of the advantages of the proposed statistical model is to rank the variables and their significant interactions based on their percentage of contribution to CO_2 in the atmosphere. Therefore, when we built our statistical model, backward elimination and forward selection were considered but the ranking of the attributable variables and the significant interactions was based on the maximum increase in R^2[6,7]. As seen in Table 4, cement manufacturing is ranked as the 3rd contributing predictor to CO_2 in the atmosphere. An increase in R^2 of the model and the percentage means that cement explains about 0.23% of the remaining variation given that gas fuels and the interaction between gas flares and cement are also in the model. Equivalently, we can say that cement estimates about 0.23% more of the total CO_2 emissions in the atmosphere than gas fuels and the interaction between gas flares and cement. Also, gas fuels have the largest contribution to the CO_2 emissions in the Middle East, which contributes to bout 95% of the CO_2 emissions. In Figure 6, we ranked these factors and their interaction terms by their percentage of contribution to the CO_2 in the atmosphere.

Fourth, we can perform a surface response analysis to identify the value of each contributable variable to minimize the CO_2 emissions in the atmosphere. Finally, we can calculate the confidence limit, which will be useful in controlling CO_2 emissions.

Table 4 Ranking the Variables Based on their Contribution

Rank	Variables	R^2	Percentage (%)
1	Gas Fuels	0.9564	95.64
2	Gas Flares * Cement	0.9605	0.41
3	Cement	0.9628	0.23
4	Solid Fuels* Cement	0.9640	0.12
5	Liquid Fuels*Solid Fuels	0.9652	0.12
6	Liquid Fuels	0.9819	01.67
7	Liquid Fuels*Gas Flares	0.9848	0.29

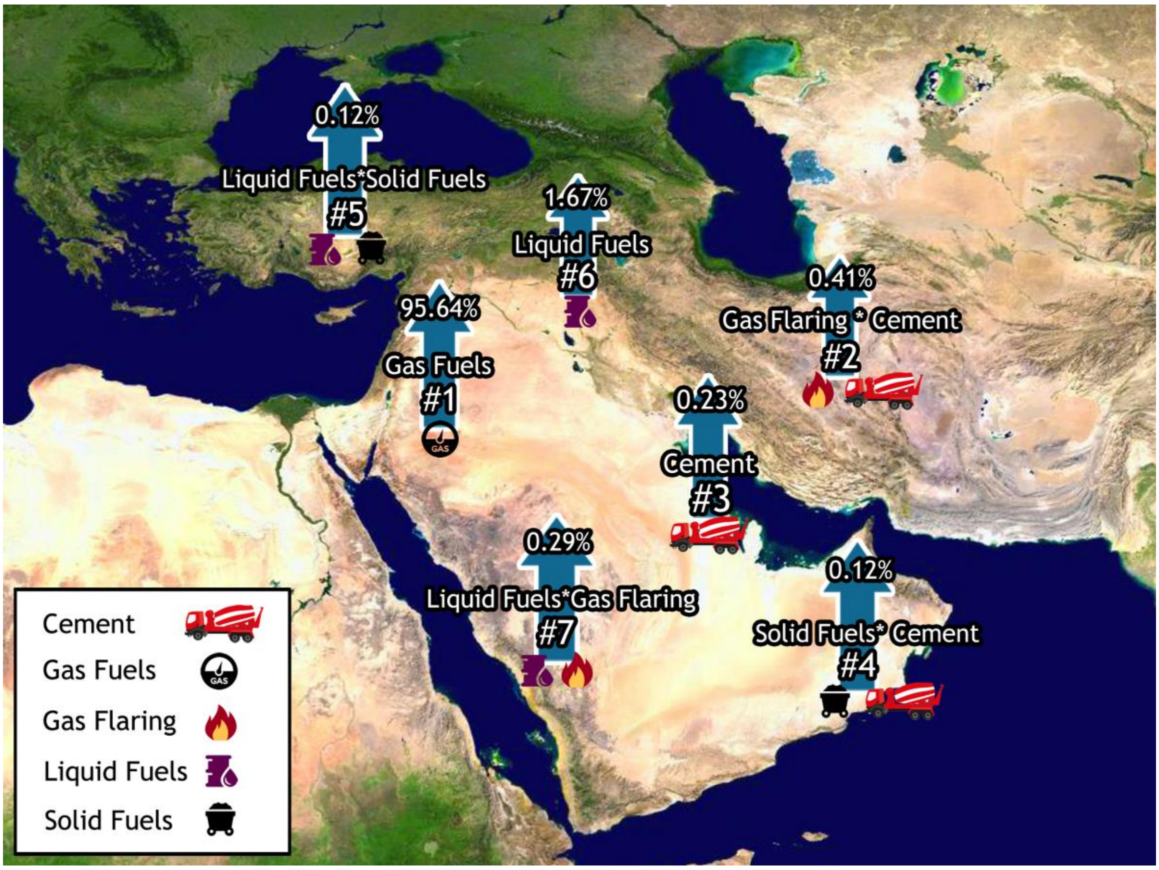

Figure 6. Ranking the attributing variables of the atmospheric CO_2

Comparison between USA, EU, South Korea, and the Middle East

Since world leaders agree that global warming is a serious problem, there is more international consensus to establish a global policy to control the factors of global warming. To support this idea, we will do comparison analysis of the atmospheric carbon dioxide between the USA, EU, South Korea, and the Middle East.

Xu and Tsokos (2013) [7,8] built a statistical model that identified the significant risk factors and their interactions that contribute to the CO_2 in the atmosphere in United States. These variables and interactions contributed to about 98.98% of CO_2 emissions in United States. The ranks of the contributing variables with the rate of contribution of CO_2 in the atmosphere are listed in Table 5.

Table 5 Ranking the Attributing Variables of USA

Rank	Variables	Contribution (%)
1	Liquid-Fuels (Li)	17.59
2	Li & Ce	16.36
3	Ce & Bu	15.73
4	Bunker-Fuels (Bu)	15.06
5	Cement (Ce)	10.77
6	Gas-Flares (Fl)	8.95
7	Gas-Fuels (Ga)	6.82
8	Ga & Fl	5.43
9	Li & Ga	2.25
10	Li & Bu	0.02

Similarly, Teodorescu and Tsokos (2013) [9] structured a statistical model using CO_2 emissions data for countries within the European Union (EU). They found that gas-fuels create about 48.72% of overall CO_2 emissions in the EU. The significant risk factors and their interactions along with their ranking are presented in Table 6 below.

Table 6 Ranking of Attributable Variables of EU

Rank	Variables	Contribution (%)
1	Gas-Fuels (Ga)	48.72
2	Li & Bu	12.41
3	Li2	11.79
4	Bu2	7.78
5	Gas-Flares (Fl)	6.66
6	Li & Fl	5.06
7	Li & Bu	4.71
8	Liquid-Fuels (Li)	2.86

Recently, Kim and Tsokos (2015) [10] have identified the individual attributable variables along with significant interactions terms that contribute to atmospheric CO_2 in South Korea. Their proposed statistical model explained 99.41% of the CO_2 in the atmosphere. The ranking of the explanatory variables and significant interactions with their percentages of overall contribution are presented in Table 7.

Table 7 Ranking of the Attributable Variables of South Korea

Rank	Variables	Contribution (%)
1	Liquid-Fuels (Li)	75.37
2	Solid-Fuels (So)	18.61
3	So & Bu	2.008
4	Ga & Bu	1.534
5	Li & Bu	0.912
6	Bunker-Fuels (Bu)	0.47
7	Gas-Fuels (Ga)	0.224
8	Li & So	0.207
9	Li & Ga	0.062
10	Li & So & Bu	0.004

Table 8 also gives an interesting comparison of what contributes to the CO_2 emissions in the atmosphere in the United States, European Union, South Korea and Middle East.

Table 8 Comparison between USA, EU, South Korea, and ME

Rank	USA	South Korea	EU	Middle East
1	Li	Li	Ga	Ga
2	Li & Ce	So	Li & Bu	Fl & Ce
3	Ce & Bu	So & Bu	Li^2	Ce
4	Bu	Ga & Bu	Bu^2	So & Ce
5	Ce	Li & Bu	Fl	Li & So
6	Fl	Bu	Li & Fl	Li
7	Ga	Ga	Li & Bu	Li & Fl
8	Ga & Fl	Li & So	Li	
9	Li & Ga	Li & Ga	-	
10	Li & Bu	Li & So & Bu	-	

A significant fact we get from this comparison is that 95% of the CO_2 emissions in the Middle East and 48% in EU are caused by gas-fuels, whereas in the US and South Korea gas-fuels contribute to only 7% and 0.224% of emissions, respectively. Moreover, liquid fuels are ranked as the number one attributable variable in the US and South Korea; however, it is the 5th in the Middle East with 15% contribution and only 3% contribution in the EU.

In addition, the Middle East has only four significant interactions of the risk factors while US and South Korea have five, and EU has only 3 contributing interactions to CO_2 emissions. These comparisons support the idea that each country should form their own policy to regulate this issue individually.

Conclusion

First**,** we performed parametric analysis of the response variable (CO_2 in the atmosphere) and presented that the Johnson SB probability distribution best characterizes the probabilistic behavior of the natural phenomenon. Second, we developed a statistical model that identifies the risk factors and their interaction terms that affect the atmospheric CO_2 in the Middle East. We have found that gas-fuels, liquid fuels, cement, and only 4 interaction terms namely (Liquid Fuels*Solid Fuels), (Liquid Fuels*Gas Flares), (Solid Fuels* Cement) and (Gas Flares * Cement) are significantly contributing to atmospheric CO_2. The proposed statistical model was evaluated using R squared (R^2), adjusted R squared (R^2_{adj}) and residual analysis. All the results supported the high quality of our proposed statistical model.

Several significant points can be obtained from our proposed statistical model. First, this model can be used to get an accurate estimate of CO_2 in the atmosphere. Second, it can be used to identify the significant attributable variables and their interaction terms and to rank them based on their percentage of contribution to CO_2 in the atmosphere. Finally, we can utilize surface response analysis to identify the value of the contributable variables and interaction that will help to develop a strategic policy to control or minimize CO_2 emissions in the Middle East.

Moreover, we have compared the predictors of the atmospheric CO_2 of the Middle East with those of the United States, European Union countries, and South Korea. Some of the interesting comparisons are: gas-fuels are the number one factor of the CO_2 emissions in the Middle East and EU. It contributes about 95% in the Middle East and 48% in EU, where in the US and South Korea it contributes only 7% and 0.224%, respectively. Also, liquid fuels ranked as the number one attributable variable in the US and South Korea; however, it is the 5th in the Middle East with 15% contribution and the last in EU with only 3% contribution to CO_2 emissions.

The results of this study leads us to conclude that there is no need for a global policy to control global warming, but each country should establish their own policy to regulate this issue individually.

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