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How to Mitigate Transportation Emissions in Saudi Arabia?

The Role of Energy Price Governance

Sa'd A. Shannak, Jeyhun I. Mikayilov, Rubal Dua

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Key Points

In light of Saudi Arabia's recent energy-pricing reform strategy, this paper investigates the main drivers of fuel carbon dioxide (CO_2) emissions in the transport sector. We employed a battery of econometric techniques to analyze the long-run relationships between income, fuel prices, energy share, population, and total carbon emissions in the transportation sector.

The results show a statistically significant relationship between studied drivers and CO_2 emissions in the transport sector. The numerical values, i.e., elasticities, from the different estimators are very close to each other, indicating the robustness of the findings. Numerically, the estimates for the elasticity of CO_2 emissions with respect to price, income, energy share and population fall in the interval of: (-0.15, -0.12), (0.17, 0.40), (-0.79, -0.36), and (1.08, 1.56), respectively.

The paper concludes that the ongoing price governance and efficiency improvement policies might result in reducing the country's annual growth rate of transport emissions from a historical 7% to 3% by 2030.

Based on the applied assumptions, CO_2 emissions from transport in 2030 are forecast to be 184 million tonnes.

Introduction

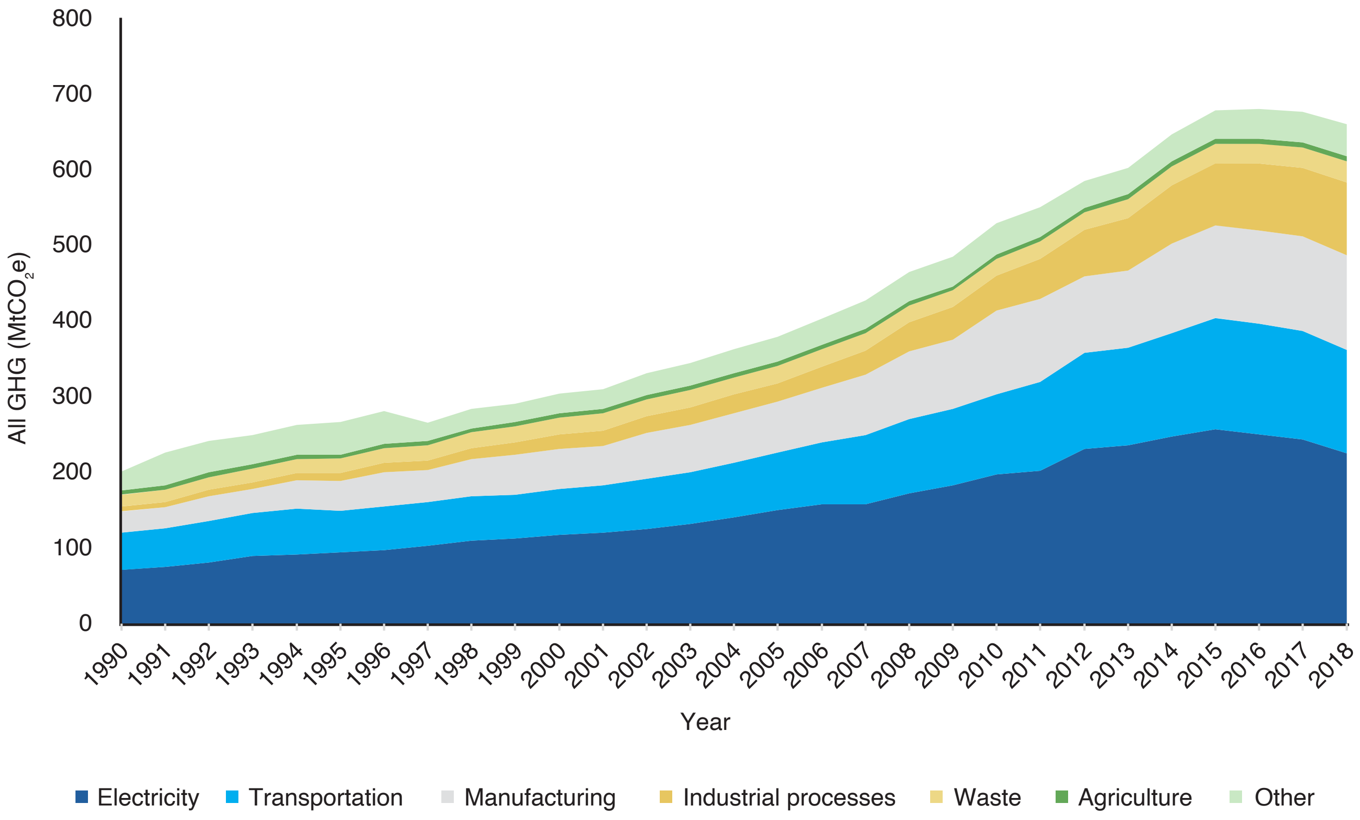
Analyzing the driving forces of carbon emissions in Saudi Arabia's transport sector is critical given its importance to the economy. One-third of total global energy consumption comes from the transportation sector, making it the second-largest energy consumer after industry (EIA 2020). According to United States (U.S.) Energy Information Administration (EIA) statistics, the average energy demand from the transportation sector increased at 2.8% annually from 1999 to 2020 (EIA 2020). The growth of Saudi Arabia's transport sector is in line with the global trend and has been driven by population growth, urbanization, income, and car ownership (Aldalbahi and Walker 2016).

A closer look at transportation fuel demand in the Kingdom revealed growing consumption between 2000 and 2018 (IEA 2020). One contributing factor was the high economic growth rate that the country witnessed during that period. Demand in the Kingdom for gasoline and diesel for use in transport increased at an annual rate of 4.7% and 4.6%, respectively, between 2000 and 2018 (IEA 2020). In 2000, demand for gasoline alone was 10.9 million tonnes of oil equivalent. In 2018, total gasoline demand had increased to 26.1 million tonnes of oil equivalent (IEA 2020). Likewise, diesel demand for transportation had grown from 8.8 million tonnes of oil equivalent in 2000 to 20.9 million tonnes of oil equivalent in 2018 (IEA 2020). Demand growth for kerosene for use in transportation averaged 1.8% between 2000 and 2018 (IEA 2020).

Associated greenhouse gasses in Saudi Arabia also increased between 2000 and 2015 across many sectors, including transportation (Figure 1). The growing trend in emissions changed at the beginning of 2015. Fuel emissions were 146.94 million tonnes of carbon dioxide equivalent ($MtCO_2e$), before dropping to 142.9 $MtCO_2e$ in 2017 (Figure 1). In 2017, total CO_2 emissions in the country were estimated at 656.31 $MtCO_2e$, 36% of which were from electricity generation, 22% from the transportation sector, and 19% from the manufacturing/construction sector (WRI 2020) (Figure 2).

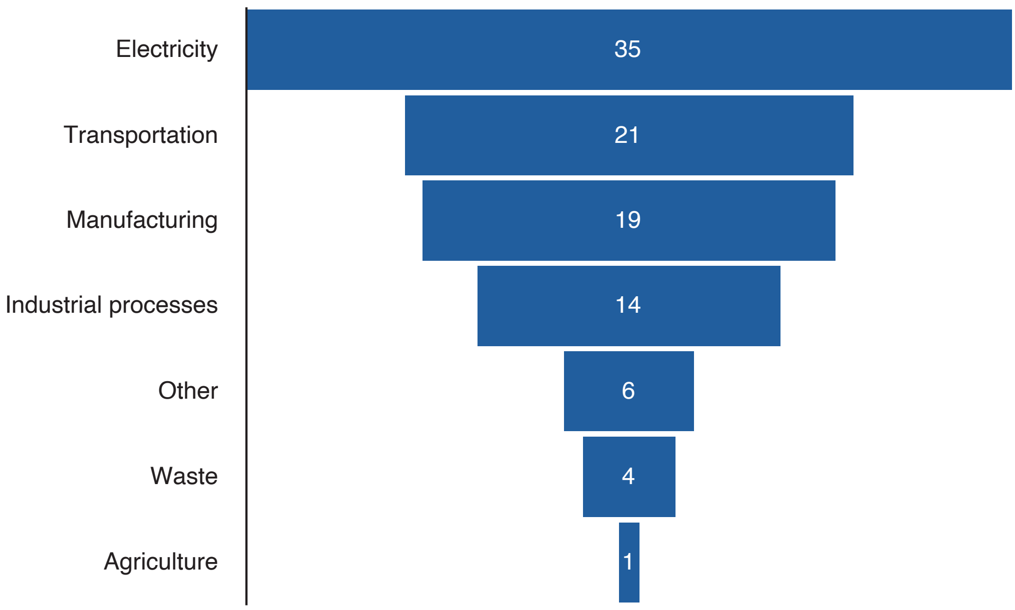
Notably, Saudi Arabia has taken major steps toward lowering emissions and rationalizing energy demand. For example, since 2015 the Kingdom has implemented domestic energy price reform (EPR) and fiscal reform under the Fiscal Balance Program (SV2030 2019). EPR aims to make energy consumption more sustainable and increase government revenues by raising energy prices (SV2030 2019). The Saudi government has been gradually raising fuel prices. This includes 91-octane gasoline, which it raised from 0.375 Saudi riyals (SAR) per liter (l) ($0.38 per gallon) in 2014 to 0.45 SAR/l ($0.45 per gallon) in 2015, then to 0.75 SAR/l ($0.76 per gallon) in 2016, 1.37 SAR/l ($1.38 per gallon) in 2018 (Sheldon and Dua 2021), and 1.99 SAR/l ($2.00 per gallon) in 2021. This policy has affected several sectors in many ways, including the transport sector. For example, motor vehicle sales were affected during the period following the implementation of the EPR (OPEC 2018). Saudi Arabia's motor vehicle sales were almost steady between 2005 and 2008 (540,000 vehicles), dropping slightly in 2009 to 520,000. Sales picked up and started increasing gradually until 2015 when they reached 828,200 vehicles sold. In 2016, right after gasoline prices started to rise, recorded vehicle sales dropped to 655,500 and continued dropping until 2018, when 403,857 vehicle sales were recorded (CEIC Data 2021). At the time of writing this paper, this drop has continued. This can be explained by the lower population growth rate that the country has witnessed compared with 2015. Furthermore, consumer behavior might also have changed, with vehicle owners possibly retaining their vehicles for a longer period.

Figure 1. Greenhouse gas (GHG) emissions ($MtCO_2e$) across different sectors in Saudi Arabia (1990-2018).



Source: WRI (2020).

Figure 2. The percentage share of CO2e emissions in Saudi Arabia by sector in 2018.

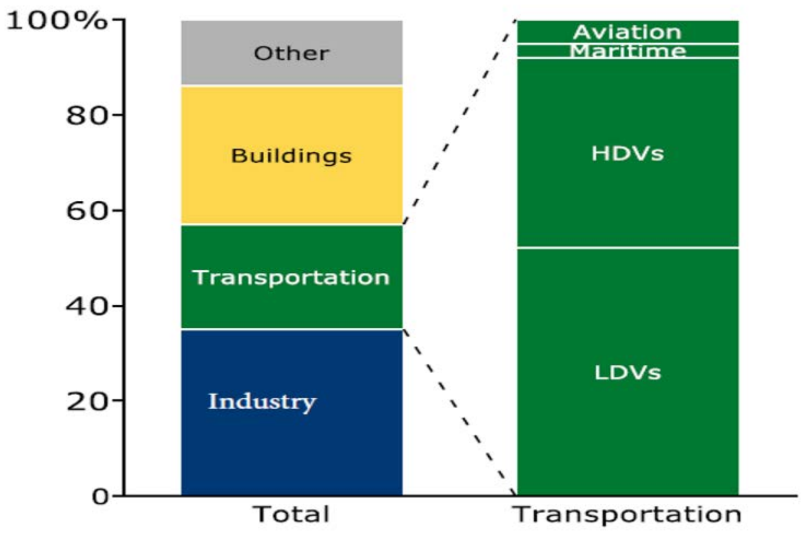


Source: WRI (2020).

Another policy intervention the Kingdom has taken was to improve fuel economy standards by setting sales-weighted average fleet fuel economy targets for automakers. In 2016, the Saudi government applied light-duty vehicle Corporate Average Fuel Economy (CAFE) standards (equivalent to the U.S. 2012 I standards) to set fuel consumption standards for light-duty engines and define optimum travel distance per liter of fuel consumption (liter of gasoline per distance traveled in kilometers [km]). This has led to a 10% improvement in the fuel economy of the new fleet (Howarth et al. 2020). It is worth noting that most of the transportation sector's energy consumption in Saudi Arabia is driven by light-duty and high-duty vehicles. Light-duty vehicles represent 52% of the country's vehicle fleet, while heavy-duty vehicles represent 40% (IEF, 2021) (Figure 3).

Additional educational and awareness programs were created to educate car owners on engine fuel efficiency through mandatory fuel efficiency labels (SEEC 2018). Strict measures were also developed to ensure imported used vehicles complied with Saudi Arabia's minimum energy performance standards. It is anticipated that this program will lower fuel consumption by 3% on average (SEEC 2017). The government has also launched several energy efficiency standards targeting heavy-duty vehicles, including a fuel efficiency improvement program, fuel efficiency labeling, and a tire resistance and grip initiative launched by the Saudi Energy Efficiency Program in 2014 and applied in November 2019. In 2019, a heavy-duty vehicle aerodynamic initiative was launched. It is anticipated that this initiative will achieve fuel savings of 5%-9% (Howarth et al. 2020).

Figure 3. Energy consumption in Saudi Arabia's transportation sector.



Source: IEF (2021).
Notes: LDV = light-duty vehicles and includes sedan cars, sport utility vehicles (SUVs), minivans, and any other road vehicles that weigh less than 3,500 kilograms (kg); HDV = heavy-duty vehicles (also called commercial vehicles, i.e., trucks, buses, and other road vehicles that weigh more than 3,500 kg).

Although analyzing energy demand across sectors is an area of growing research interest among a wide range of policymakers, some research considers the associated greenhouse gases from transportation fuel in developing countries such as Saudi Arabia. Hence, studying the factors driving transport fuel emissions in Saudi Arabia is an important step forward in helping to control carbon emissions. In this paper, we investigate the main drivers affecting carbon emissions in Saudi Arabia's transportation sector. In particular, we explore the impact of income, fuel prices, energy share, and population growth. Different econometric estimation techniques have been employed to study the long-run relationships among variables. In addition, this study aims to make forecasts for transport CO_2 emissions using estimated models for different policy options.

Literature Review

In this section, we review studies relevant to our research objective and employ econometric models to analyze the factors influencing transportation fuel emissions.

With time-series data, econometric models can be effective in analyzing variables and relationships. For example, Wei et al. (2013) studied the carbon emissions on China's roads using the factor decomposition method. Their study concluded that traffic structure and carbon emissions had a long-run relationship from 1989 to 2008. The authors also confirmed a dynamic interactive relationship between the studied variables over the same period. Fengyan and Lei (2015) examined the effect of the Multivariate Generalized Fisher Index on transport carbon emissions in Beijing using time series data for 1995-2012. Their findings showed that the Fisher Index, specifically economic growth, energy intensity, and population have a positive impact on carbon emissions. While both transportation intensity and energy structure negatively impact carbon emissions. Liu and Cirillo (2016) studied private car emissions in Washington D.C., United States. The study (private cars) was broken down into 1,182 first-class, 852 second-class, and 257 third-class cars (households' primary, secondary, and tertiary vehicles). Additional factors were considered in the analysis, such as the total number of cars, the operation type for each car, the average travel distance, and the associated greenhouse gas emissions level. Their results showed that the average greenhouse gas emission was 5.15 tonnes per year, and the implementation of fuel tax resulted in the greatest reduction in greenhouse gas emissions. Liddle (2011) also studied the effect of carbon emissions from transport in 22 OECD countries from 1960 to 2007 using the stochastic impacts by regression on population, affluence, and technology (STIRPAT) framework. The author split the population into four age groups. The author concluded that transport carbon emissions have a positive impact for the age group 20-34, while the coefficient for other age groups was found to be negative. Melo (2016) conducted a study using spatial and non-spatial panel data to analyze the causal relationship between demand-led, and supply-led factors and carbon emissions from the road transportation sector. The author introduced 10 influence factors, such as urbanization, vehicle ownership, income levels, etc., and found a long-run relationship between variables. Hasan et al. (2019) conducted a study to identify the main factors driving the emissions from passenger vehicles in New Zealand. The findings presented a significant causal relationship between fuel economy and vehicle emissions.

Mikayilov et al. (2017) investigated the impact of energy consumption, income, and population on pollution from the transport sector in Azerbaijan. They found that all the used variables have a positive and statistically significant impact on pollution; population being the most impactful. Alkhathlan and Javid (2015) studied the impact of transport oil consumption and income on CO_2 emissions from the transport sector: the only study we are aware of that has investigated transport-related emissions in Saudi Arabia. Using the structural time-series modeling approach, which enables the discovery of different aspects of relationships, Alkhathlan and Javid (2015) found that the impact of oil consumption in the transport sector on transport CO_2 emissions is positive and elastic. They also found a positive monotonically increasing impact of income on transport CO_2 emissions. In addition, they found that the CO_2 emissions trend has been falling since 1995. This finding shows that, from the 1990s, Saudi Arabia's transportation sector has been deploying fewer emission-intensive vehicles, which in turn has lessened overall pollution from transport. Alkhathlan and Javid

(2015) is a valuable study which makes substantial contributions to the environmental/energy economics literature, specifically with application to Saudi Arabia. However, there are some nuances to investigate in addition to their work. First, the study period ends in 2013, which does not allow us to see the impacts of the recent energy price reforms on CO_2 emissions from transport. Second, they used total oil consumption in transportation as one of the drivers of CO_2 emissions, which might cause some estimation issues, as discussed in Section 3. Third, they have not performed forecasting exercises.

Overall, this study contributes to the existing literature by investigating the drivers of transport emissions in Saudi Arabia. The literature review shows that no study has made forecasts for CO_2 emissions from Saudi Arabia's transport sector. Hence, this study addresses this gap in the literature and, based on the findings, discusses options for achieving a sustainable transportation sector in the country.

Functional Specification

The main objective of this study is to investigate the driving factors of carbon emissions in Saudi Arabia's transportation sector and find the long-run relationship between studied variables and carbon emissions from 1990 to 2019. For this purpose, we have used the following functional specification:

$$emitra = b_0 + b_1 gdp + b_2 pop + b_3 gasshare + b_4 pfuel + u \quad (1)$$

Here, *emitra* is carbon emissions from the transport sector, *gdp* is gross domestic product, *pop* is the total population, *gasshare* is the share of gasoline consumption in total transport energy consumption. Since carbon emissions data is not directly observable, it is calculated using energy consumption data and relevant conversion factors. The use of energy consumption data from which the emissions data is calculated results in econometric and empirical problems, as shown by Jaforullah and King (2017). Hence, to avoid the omitted variable problem and other related issues in applied work, other measures, such as energy share and energy intensity, are used to proxy the impact of energy consumption (see Liddle [2013, 2018] and Mikayilov et al. [2020a], *inter alia*). *pfuel* is the average transport fuel price, *u* the error term, b_0, b_1, b_2, b_3, and b_4 are regression coefficients of the long-run relationship. The coefficients b_1 and b_2 are expected to have positive signs, while b_3 and b_4 are expected to have negative signs. All variables in equation (1) are in logarithmic expression, hence the coefficients can be directly interpreted as elasticities.

The choice of the potential drivers of carbon emissions from transport is based on the related literature. Income and population have been the most used drivers of environmental degradation since the early studies devoted to environmental pollution modeling based on IPAT identity (Enrlich and Holdren 1971) and then those dealing with pollution-income relationship (Grossman et al.,1991; Shafik and Bondyopadhyay [1992]; Panayotou [1993], *inter alia*), and later those using the STIRPAT framework (Dietz and Rosa [1994] and [1997], *inter alia*). Energy consumption is one of the main sources of CO_2 emissions (Baek [2015], *inter alia*). Historically fuel prices were low in oil-exporting countries, which made driving more affordable, therefore resulting in more local emissions. Hence, transport fuel prices might be one of the potential drivers of CO_2 emissions.

Econometric Methodology

First, the used variables are tested for unit-root properties, following the conventional procedure for time series data estimations. Second, if all variables are integrated of the same order, the long-run common movement, cointegration relationship should be tested. After confirming the cointegration relationship, the long-run relationship can be estimated.

For testing stationarity features of the variables, the widely used augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) test is utilized. The null hypothesis of the ADF test states non-stationarity of the variable. To test the cointegration relationship between a dependent variable (*emitra*) and independent variables (*pfuel*, *pop*, *gasshare*, and *gdp*), the Banerjee et al. (1998), and bounds tests (Pesaran and Shin 1999; Pesaran et al. 2001) are used. For both tests, the null hypothesis is the non-existence of the cointegration relationship. Since both the ADF and utilized cointegration tests are widely used in similar studies, they are not detailed here. Interested readers are referred to the above-mentioned literature.

For the estimation of the long-run relationships, and to see if different techniques produce similar results, we used different estimation techniques. Although the data generating process (DGP) does not depend on the methodology used, in the case of the small sample it is preferable to 'dig' with different estimation tools to 'reveal out the behavior' of the corresponding DGP. The general-to-specific modeling approach (Gets, Davidson et al. [1978]; Hendry et al. [1984]; Campos et al. [2005], *inter alia*) is used as the main technique, since it provides wider options to consider. In addition, the fully modified ordinary least squares (FMOLS) (Phillips and Hansen 1990; Hansen 1992a, 1992b), dynamic ordinary least squares (DOLS) (Saikkonen 1992; Stock and Watson 1993), and canonical cointegration regression (CCR) (Park 1992) methods, the bounds testing approach to auto-regressive distributed lag (ARDLBT) (Pesaran and Shin 1999; Pesaran et al. 2001) models were employed for the long-run estimations for robustness.

Data

This paper uses annual time-series data from 1990 to 2019. The span is chosen based on data availability. The used variables are defined as follows. Transport emissions (emitra) are CO_2 emissions from transport, in million tonnes of CO_2, and retrieved from Enerdata (2021); gross domestic product (GDP) is real GDP, million Saudi riyals, in 2010 constant prices, and is taken from the General Authority for Statistics (GaStat) (2020); average fuel price (pfuel) is the weighted average price of transport fuel. It is calculated using gasoline, diesel, and kerosene consumption data for the transport sector as weights and corresponding fuel prices, in SAR per tonne of oil equivalent (toe). Gasoline, diesel, and kerosene consumption data for the transport sector are taken from the International Energy Agency (IEA) (2020), and corresponding price data is retrieved from different royal decrees. The gasoline share is the percentage share of gasoline consumption in total energy consumed by the Kingdom's transport sector. It is calculated based on data taken from the IEA (2020). Population (pop) is the total population, in persons. It is taken from the United Nations database (UN 2021).

Empirical Estimation Results

Following the time series modeling methodology, the unit root properties of variables have been examined using the ADF test (Dickey and Fuller 1979). The results of the ADF test are presented in Table 1.

As Table 1 demonstrates, all the variables are integrated of the first order, except the population variable. In addition to the ADF test, we utilized the Kwiatkowski-Phillips-Schmidt-Shin (1992) test, which concluded the stationarity of the population variable at the first difference. Hence, we conclude that all variables are I(1). That is, their first differences are stationary. Therefore, one can test the variables for the cointegration relationship. The Banerjee et al. (1998) test, also called the PcGive test, and bounds (BT) cointegration tests (Pesaran and Shin 1999; Pesaran et al. 2001) were used for this exercise, and the results are reported in Table 2.

Table 1. Unit root test results.

	Level		Differenced
	i	i&t	i
emitra	-0.698	-1.143	-5.016***
pfuel	-1.156	-0.956	-4.471***
pop	-1.486	-0.859	-1.210
gasshare	-3.638**	-2.543	-4.230***
gdp	-0.583	-1.770	-5.515***

Notes: i = intercept only; i&t = intercept and trend case. In the unit-root specification, the maximum lag is set to two and the optimal lag number is chosen based on the Schwarz information criterion. "**" and "***" stand for a rejection of the null hypothesis at the 5% and 1% significance levels, respectively.

Source: Authors.

Table 2. Cointegration tests' results.

	Cointegration tests	
Test	PcGive	BT
Test value	-11.476**	28.829***

Notes: Null hypothesis of both tests is "series are not cointegrated." "**" and "***" stand for a rejection of the null hypothesis at the 5% and 1% significance levels, respectively.

Source: Authors.

Empirical Estimation Results

As can be seen in Table 2, both tests conclude the existence of a cointegration relationship among the studied variables. For the next step, the long-run estimations were carried out. The detailed estimation results from the *Gets* approach in the dynamic form are provided in Table 3. The results from the *Gets* approach were then converted into static long-run form and the results are given in Table 4. Table 4 also demonstrates the long-run estimation results from the CCR, DOLS, FMOLS, and ARDL approaches, which serve as a measure of the robustness of the long-run results.

Table 4 shows that all utilized estimation techniques provide close results. All the variables were found to have relevant signs and are statistically significant.

It is important to note that in the literature it is not clear as to which income measure, GDP or non-oil GDP is a better proxy for transport-related energy consumers' income (Atalla et al. 2018). Consequently, the same can be said in terms of transport-related CO_2 emissions. Hence, as an additional check, we used non-oil GDP as an income measure and the results are provided in Table A1 in the appendix. One can see from Table A1 that the results with non-oil GDP are not substantially different than the results with GDP.

Table 3. Estimation results of the *Gets* approach in dynamic form.

Panel A: Final model specification results in ADL form											
variable	emitra (-1)	pfuel	gdp(-1)	pop(-1)	gasshare	gasshare(-1)	constant	I2014	S12004	S12005	S12017
coefficient	0.3648	-0.0971	0.2508	0.8331	-0.8981	0.4666	-14.6055	-0.0304	0.0373	0.0272	0.0502
p-value	0.0000	0.0000	0.0003	0.0000	0.0000	0.0002	0.0000	0.0106	0.0052	0.0492	0.0002
Panel B: Diagnostic tests' results for the final model specification											
test	AR 1-2 test	ARCH 1-1 test	Normality test	Hetero test	RESET23 test		R-square		Adjusted R-square		
test statistics	3.2551	0.9752	2.7375	1.7043	0.5073		0.9999		0.9994		
p-value	0.0652	0.3322	0.2544	0.1803	0.6115						

Notes: Dependent variable is emitra; AR = autocorrelation test (Godfrey 1978); ARCH = autoregressive conditional heteroscedasticity test (Engle 1982); Normality test = Doornik and Hansen (1994) normality test; Hetero test = heteroscedasticity test (White 1980); RESET23 = Regression Specification Test (Ramsey 1969).

Source: Authors.

Table 4. Long-run estimation results.

	DOLS	FMOLS	CCR	ARDL	*Gets*
gdp	0.172***	0.391***	0.398***	0.178**	0.395***
pfuel	-0.150***	-0.137***	-0.115***	-0.152***	-0.153***
pop	1.561***	1.253***	1.080***	1.554***	1.312***
gasshare	-0.788***	-0.416***	-0.360***	-0.787***	-0.679***

Notes: Dependent variable is *emitra*; "***" stands for the rejection of the null hypothesis at the 1% significance level.

Source: Authors.

Discussion of the Results

In this section, we discuss the results of our empirical findings. According to the unit root test results, documented in Table 1, *gdp, pfuel, pop* and *gasshare* are non-stationary variables, meaning that their mean, variance, and covariance (at least one of them) change over time, while their first differences are stationary.

Table 2 shows that the variables of interest are cointegrated, meaning that there is a long-run relationship between them. Hence, it is useful to estimate numerical values for this relationship and use it as a basis for policy recommendations.

The impact of *gdp, pfuel, pop* and *gasshare* on transport fuel emissions was estimated, employing five different estimation techniques, *Gets*, ARDL, DOLS, FMOLS, and CCR, as a robustness check. The results show that there is a theoretically expected and statistically significant relationship between transport-related CO_2 emissions and its drivers. It is worth mentioning at this point that the numerical values, i.e., elasticities, from the different estimation techniques are very close to each other, indicating the robustness of the findings.

According to the estimation results, a 1% increase in fuel prices is associated with a 0.12%-0.15% decrease in transport-related CO_2 emissions in the long run. The fuel price is one of the main policy instruments for reducing CO_2 emissions. Raising fuel prices acts as an economic disincentive, thereby encouraging direct reduction in vehicle travel and, correspondingly, fuel consumption and CO_2 emissions. Moreover, fuel price increases also encourage the adoption of energy-efficient technologies, thereby further facilitating an indirect reduction in fuel consumption and CO_2 emissions. As the related literature suggests (see for example Klenert et al. [2018]; Hasanov et al. [2020], *inter alia*), implicit carbon policies, such as adjusting fuel prices to international prices and removing fossil fuel energy incentives, are more relevant policy measures for developing countries.

Our analysis suggests that a 1% increase in income is associated with an increase of 0.17%-0.40% in transport-related CO_2 emissions in the long run. This finding accords with the literature. Several prior studies confirm that income is positively correlated with transport emissions (Baiocchi et al. [2010]; Brand and Boardman [2008]; DEFRA [2008]; Druckman and Jackson [2008]; Fahmy et al. [2011]; Gough et al. [2011]; Weber and Matthews [2008], *inter alia*).

Our analysis suggests that a 1% increase in the gasoline share (gasoline consumption divided by total energy consumption in the transport sector) is associated with a 0.36%-0.79% decrease in transportation emissions in the long run. The share of gasoline in transport fuels is representative of the fuel consumption within the Kingdom's light-duty vehicle sector. This is because diesel and kerosene are mainly used in the heavy-duty vehicle and aviation sectors, respectively. Historically, the penetration of diesel vehicles in the light-duty vehicle sector has been low because of the high sulphur content of diesel fuel in the Kingdom. Historically, it could be argued that an increase in the share of gasoline in the Kingdom's transport fuels was associated with higher fuel demand from the light-duty vehicle sector, which is inherently more efficient than the heavy-duty vehicle and aviation sectors. This could explain why, historically, the overall CO_2 emissions from the transport sector declined with the rising share of gasoline in transport fuels.

Discussion of the Results

Finally, population was found to have a significant impact on transport-related CO_2 emissions. A 1% increase in the total population was found to be associated with a 1.08%-1.56% increase in transport-related CO_2 emissions in the long run. This finding is consistent with economic theory: Population growth is a major driver of increased transport demand and, eventually, transport emissions.

The obtained elasticity estimates are consistent with the nature of Saudi Arabia's transportation sector. A high population growth rate leads to increased demand for the transportation network. A high economic growth rate increases incomes and allows people to own their own vehicles rather than use public transport; the latter represents only a small share of transport in the Kingdom.

It should be noted that all the estimated coefficients across the estimation methods in Table 3 are very close to each other, indicating the robustness of the obtained results. Unfortunately, we are unable to compare the numerical values we obtained in this research with those from other studies as we could not find any prior econometric studies[1] on this topic for Saudi Arabia.

Forecasting Transport Emissions

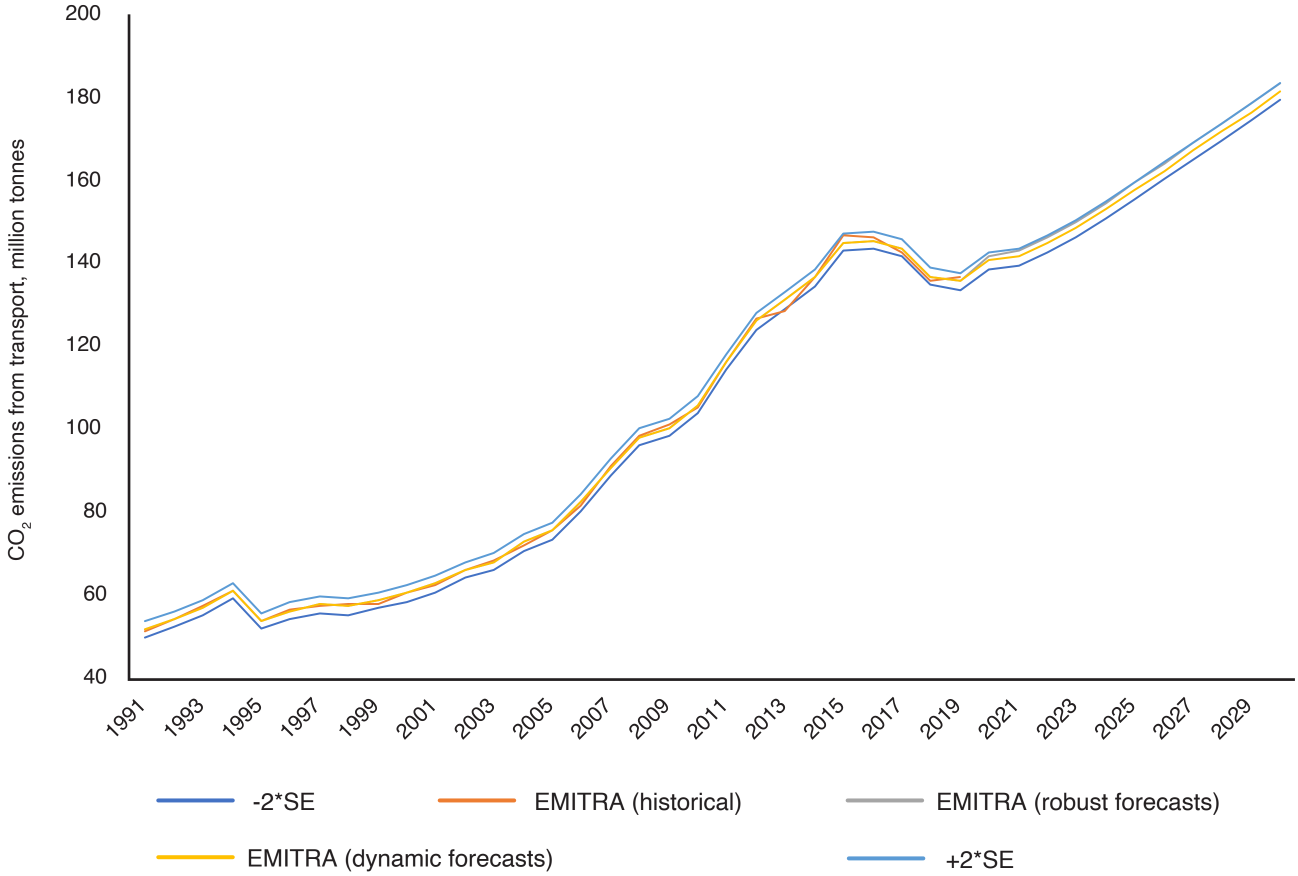
Forecasting Assumptions

This section first discusses the forecast assumptions, and then develops a forecast for the 2020-2030 horizon. Using Matar and Anwer's (2017) finding on the cost of different transport fuel types, we assume that in 2030 the prices of transport fuels will reach their production costs. Namely, we assume that in 2030 the prices will be 1.94 SAR/l, 1.98 SAR/l, 0.65 SAR/l, and 1.89 SAR/l for gasoline-91, gasoline-95, transport diesel, and jet fuel, respectively. Starting from 2021, transport fuel prices are increased each year by the same rate to reach the 2030 target prices. Forecasts for GDP under this fuel price scenario are taken from simulation results of the macro-econometric model (Hasanov et al. 2020). Population size forecast assumptions are made using UN population data for Saudi Arabia (UN 2021). Looking at the historical behavior of the gasoline share in transportation energy consumption, we assumed the growth rate over the estimation period to be the average (52%) for the forecast horizon as well. Some readers might question this assumption though, considering the potential penetration of alternative low- or zero-carbon transport fuels including 'green' electricity and hydrogen. The assumption is based on the logic that the potential for an increase in the penetration of low- or zero-carbon transport fuels would reduce the share of gasoline as a percentage of transport fuels. This could mean that the growth in total transport CO_2 emissions could reduce and even reverse. That being said, given the lack of policies in the Kingdom supporting the penetration of alternative fuel vehicles at this point, the likelihood of the share of gasoline used in transportation decreasing significantly by 2030 due to the rising share of alternative fuels remains low. Furthermore, since we do not have any further information about the future evolution of gasoline as a share of transportation fuel, we assume it remains at its historical average. Our assumptions for the forecasting exercises are provided in Table A2 of the appendix.

Forecasting Results

Utilizing the estimated models and assumptions made in the previous sub-section, we performed forecasting runs. In these runs, we used all the estimated model results, and the models produced very close results. To avoid having several figures, we only report the *Gets* forecasting results for the forecast horizon (other forecasting results are presented in Figure A1 of the appendix). We used dynamic forecasts and a robust forecasting device (Hendry and Doornik 2014). As can be seen from Figure 4, both techniques produced very similar results.

Figure 4. Forecasts for CO_2 emissions from the transport sector with 95% confidence interval bars.



Time	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Dynamic	140.93	141.82	144.94	148.66	153.11	157.82	162.53	167.23	171.94	176.73	181.65
Robust	141.89	143.15	146.42	150.23	154.75	159.51	164.28	169.03	173.79	178.63	183.61

Source: Authors.

Based on the applied assumptions and robust results, CO_2 emissions from transport in 2030 are forecast to be 183.61 million tonnes.

From 2021 through 2030, price targeting only results in 2.6% growth per annum of CO_2 emissions from transport. Between 2006 and 2015 (the 10-year period before Saudi Arabia's fuel price reform), the annual growth rate of transport CO_2 emissions was 6.53%. Hence, targeting price results in the substantial mitigation of transport CO_2 emissions.

Conclusions and Policy Recommendations

We have examined the long-run impact of income, fuel prices, population, and the share of gasoline in transportation fuel on Saudi transportation emissions. We employed different estimation methods to achieve more robust results and, as a result, well-grounded policy recommendations. Our empirical analysis shows that there are long-run effects of the studied variables on transportation emissions in Saudi Arabia. The estimation results we derived from different methods are very similar, which indicates the robustness of the results obtained.

The findings from our empirical analysis suggest that increasing fuel prices with some mitigation measures seem relevant policy options for policymakers to consider for the sector. The results derived from the empirical analysis support Saudi Arabia's energy price reform policy that it has implemented since 2016. While fuel prices affect demand and emissions, the consumer response to rising prices has not been very strong, probably due to the absence of alternative options for road-based transport. Furthermore, since the end of December 2015, the Saudi government has been implementing a gradual phase-out of energy incentives, i.e., increasing domestic energy prices to reflect market prices, alongside mitigation measures. This policy helps smooth the transition away from gasoline and gives some time for the sectors of the economy to adapt to the new environment. Several researchers (Wu [2009]; Cohen et al. [2016]; Steinbuks and Neuhoff [2014], *inter alia*) concluded that increasing energy prices could result in energy efficiency improvements. Thus, energy prices play a significant role in incentivizing energy efficiency measures, setting energy demand and consumption, and rationalizing energy incentives.

Increasing fuel prices to reflect actual market prices will reduce the energy incentives given and will make additional resources available to the government. These saved resources could later be utilized for different purposes (Klenert et al. 2018), in line with the objectives of Saudi Vision 2030 to diversify the economy and reduce its dependency on oil (Hasanov et al. 2020). This will also help strengthen the government's fiscal position and support social welfare or economic development. For example, the government could use these additional resources to facilitate the transition to renewable energy in the transportation sector (Klenert et al. 2018). Electric and solar-powered vehicles could be developed and financed using these additional resources. Moving toward increasing the share of renewable power used in transportation could also help achieve the goals of the circular carbon economy concept and lower the sector's total emissions.

High population growth, high standards of living, rapid development, limited public transportation services, harsh climatic conditions, and urbanization have resulted in expanding the energy consumption in the Kingdom's transportation sector. Furthermore, rising fuel prices could prompt greater interest in fuel-efficient vehicles (Sheldon and Dua 2021). Chaaban et al. (2000) stated that switching to low-carbon emission fuel and applying vehicle emission standards — similar to The Corporate Average Fuel Economy standards — could substantially mitigate greenhouse gas emissions from the transportation sector.

Potential policy options for reducing energy consumption in the transportation sector include developing vehicle efficiency standards, setting measures to moderate private vehicle use, and low-carbon standards for transportation fuels. The government's current strategy is to increase public transportation services, sidewalks and connect the major regions through a modernized transportation network. This could moderate private vehicle use and reduce energy consumption in the sector (MOT 2021). One example of increased public transportation is the 450-km Haramain high-speed railway, which connects Medina and Mecca via the King Abdullah Economic City.

The findings of this study show a positive correlation between income and total emissions. This is because additional vehicles are purchased as incomes increase, in turn increasing fuel consumption and carbon emissions. Providing educational programs and vehicle maintenance practice programs to moderate the number of vehicles per household and at the company level, and ensure vehicles are well run with optimum fuel efficiency could help reduce emissions. Additionally, since lifestyle and personal activities affect patterns of road travel, training and awareness programs to inform the public about the negative impact of climate change are essential in providing long-term benefits for human health and quality of life.

The policy opions discussed in this study offer a sustainable way to close the loop between economic development and environmental protection. The study concluded that the government's current strategy to reform energy prices and gradually adjust mitigation measures to reduce transport emissions is relevant and timely.

Lastly, this research forecast the impact of a policy option (price governance) on reducing transport CO_2 emissions. We found that energy price governance, in addition to efficiency targeting, are the most impactful tools to mitigate transport CO_2 emissions in Saudi Arabia. Clearly, if these policy options are managed properly, the transportation sector can play a significant role in rationalizing the country's energy consumption and related carbon emissions.

Endnotes

[1] Alkhathlan and Javid (2015) used quadratic specification with respect to income variable and did not report the found elasticity.

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Appendix

Table A1. Long-run estimation results with non-oil GDP.

	DOLS	FMOLS	CCR	ARDL
gdp	0.152***	0.264*	0.306**	0.150*
pfuel	-0.135***	-0.097***	-0.098***	-0.135***
pop	1.408***	1.069***	0.974***	1.415***
gasshare	-0.689***	-0.437***	-0.400***	-0.704***

Notes: Dependent variable is *emitra*; "***","**","*" stand for rejection of the null hypothesis at the 1%, 5% and 10% significance levels, respectively.

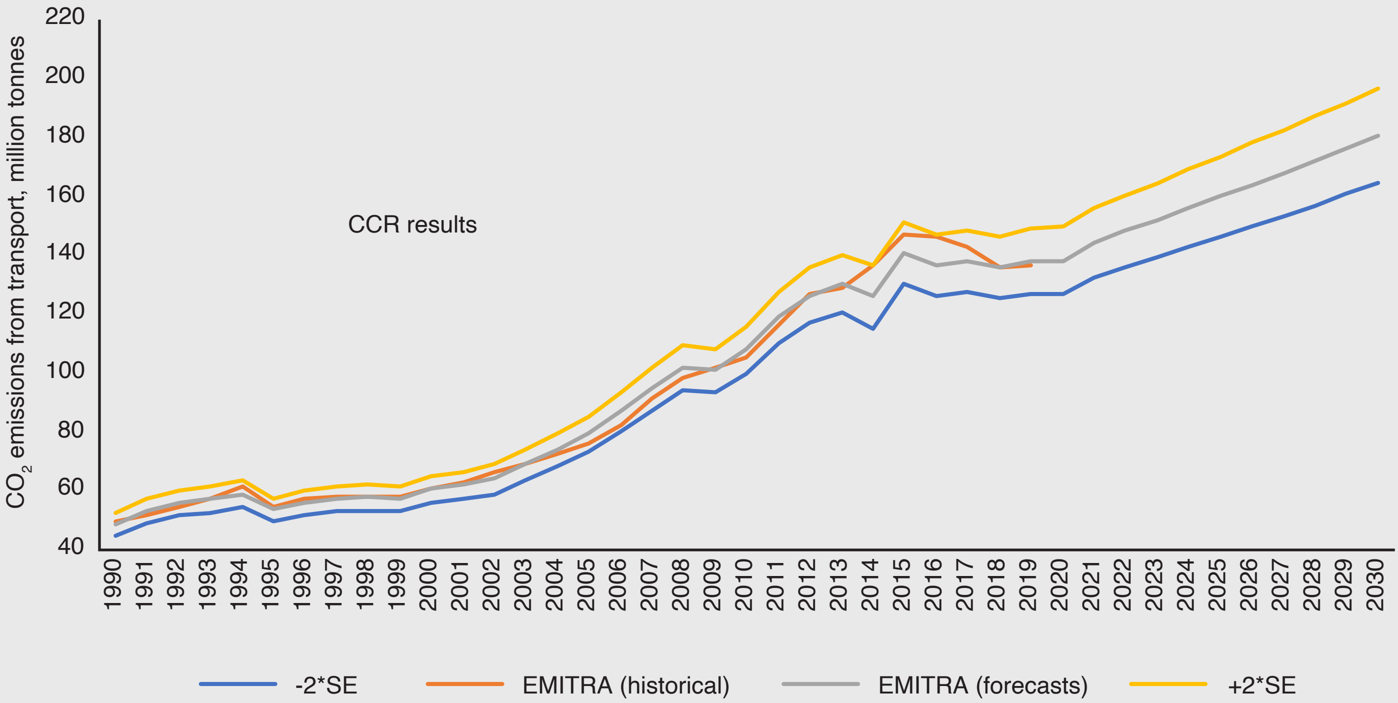
Source: Authors.

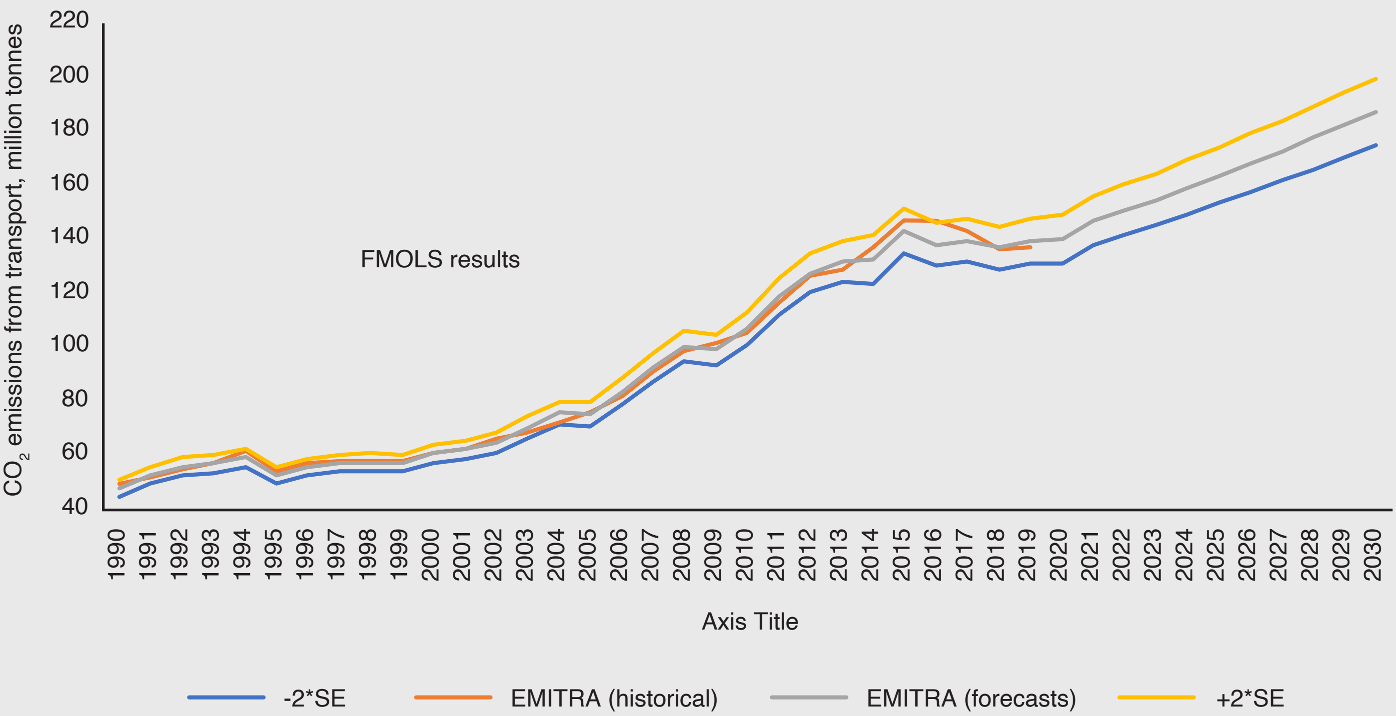
Table A2. Forecasting assumptions.

	GDP mln SAR, 2010 prices	Average Fuel Price SAR/TOE	Population, persons	Gasoline share, ratio
2020	2531405.40	1391.08	34813867	0.52
2021	2648514.64	1438.99	35367883	0.52
2022	2747975.32	1488.63	35930716	0.52
2023	2843563.76	1540.05	36502505	0.52
2024	2927922.01	1593.32	37083394	0.52
2025	2999713.02	1648.52	37673527	0.52
2026	3064338.61	1705.72	38273051	0.52
2027	3126462.74	1764.99	38882115	0.52
2028	3189875.80	1826.41	39500872	0.52
2029	3256228.50	1890.06	40129476	0.52
2030	3323787.79	1956.03	40768083	0.52

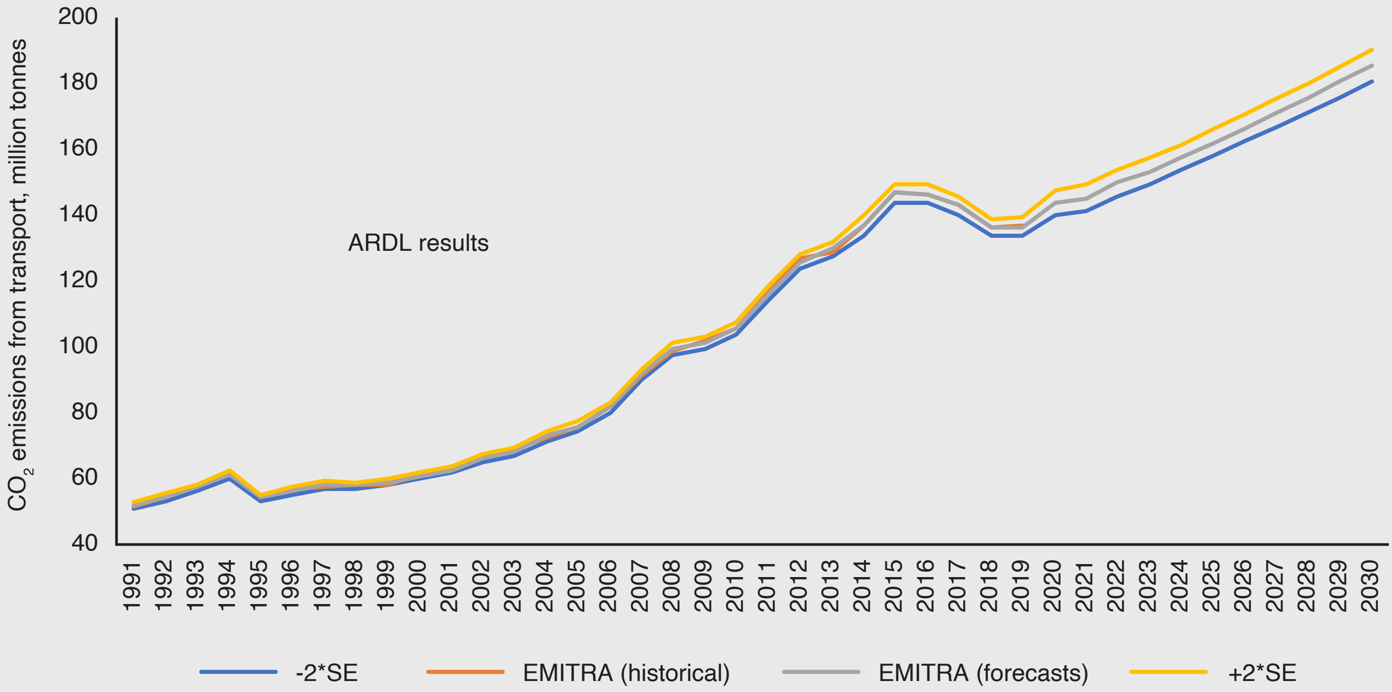
Notes: mln = million; SAR = Saudi riyals; TOE = tonne of oil equivalent.
Source: Authors.

Figure A1. Forecasting results of the CCR, FMOLS and ARDL approaches.





Appendix A



Source: Authors.

Notes

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About the Authors

Sa’d Shannak

Sa’d is a scientist at Hamad Bin Khalifa University – Qatar Environment & Energy Research Institute. He is an experienced environment and energy professional with quantitative and qualitative research skills such as econometric modeling, short- and long-term forecasting, model optimization, financial analysis, and risk analysis. He has a strong track record in energy and water policy and technology, gained over 15 years of work in research institutions, consultancy, local authorities and non-governmental organizations in the United States and the Middle East. He received his master’s degree and Ph.D. from Texas A&M University.

Jeyhun I. Mikayilov

Jeyhun is a research fellow at KAPSARC and leads the Modeling Energy Consumption and its Impacts in Saudi Arabia project. His primary research interests include, but are not limited to, applied time series econometrics, the economics of energy and environment, and sustainable development. He holds a Ph.D. in Applied Mathematics.

Rubal Dua

Rubal is a research fellow at KAPSARC working on vehicle regulatory policy and shared mobility research from the consumer perspective. He holds a Ph.D. from KAUST, Saudi Arabia, an M.Sc. from the University of Pennsylvania, and a B.Tech. from the Indian Institute of Technology, Roorkee.

About the Project

The Modeling Energy Consumption and its Impacts in Saudi Arabia project aims to conduct advisory and applied research activities focused on modeling and forecasting indicators of energy consumption and their impacts in Saudi Arabia. In line with the ongoing energy policies the Kingdom is implementing, the project focuses on three main areas:

• Modeling and forecasting energy consumption indicators.

• Modeling and forecasting the environmental impacts of energy consumption.

• Investigating the trajectories and potential of energy efficiency.

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