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Data-driven Analysis of Fuel Consumption Trends and Policy Options for Decarbonizing Transportation in GCC Countries

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Abstract. The transportation sector in the Middle East is a major contributor to greenhouse gas (GHG) emissions, driven by rising population and rapid economic development. This study presents a data-driven analysis of fuel consumption trends across key oil-dependent GCC economies and evaluates policy options for decarbonizing their transport systems. Using national and international datasets, time-series analysis, and scenario-based modeling, the study identifies growth patterns in gasoline consumption from 1990 to 2020. Scenario projections indicate that aggressive policy combining vehicle electrification, modal shift, fuel economy standards, and carbon pricing—could reduce transport emissions by up to 55% by 2050.

1 Introduction

Transportation systems serve as the essential input for livelihood and economic development by facilitating the efficient movement of goods, services, and people [1]. Besides providing connectivity for trade and employment, transportation networks are integral to emergency services during natural disaster and national security [2]. Given the interrelation between transportation with economic growth and rapid development in countries of Gulf Cooperation Council (GCC), expansion of transportation infrastructure needs to be planned strategically ensuring economic resilience, environmental security, and long-term regional stability [3]. Particularly, consumption of fossil fuel and production of greenhouse gas are among the priority concerns for regional policy makers. Rapid urbanization, population growth, and rising vehicle ownership have accelerated fuel consumption in the region's transport sector, exacerbating carbon emissions and compounding sustainability challenges. Countries like Saudi Arabia, United Arab Emirates (UAE), and Qatar have already initiated plans to explore low-carbon transport solutions, including electric mobility, clean fuel alternatives, and modal shifts. This study conducts a data-driven examination of fuel consumption trends across key Middle Eastern economies, mapping patterns by country, mode, and fuel type over time. It also

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evaluates the effectiveness and feasibility of policy interventions, drawing on international case studies and region-specific constraints. By integrating empirical analysis with scenario-based modeling, the paper identifies priority controls for decarbonization that include fleet electrification, sustainable urban planning, and the adoption of alternative fuels. The findings assist support governments, planners, and regional stakeholders in designing resilient, low-carbon transport systems.

2 Literature Review

2.1 Global and Regional Fuel Consumption Trends in Transportation Sector

Transportation sector accounting for roughly 23 percent of global energy-related CO_2 emissions that is persistently rising due to increasing motorization, urbanization, and trade [4]. Globally, transport energy demand has increased by more than 50 percent since 2000 and is projected to rise by 16 percent by 2050 unless drastic measures are implemented, driven largely by rising demand in developing economies.

2.2 Regional Trends and Policy Responses

In the OECD countries, decades of fuel economy regulation, public transit investment, and congestion pricing have yielded modest reductions in fuel consumption growth. Europe has made significant gains through CO_2 emissions standards, modal shifts, and electrification [5]. While many countries have adopted national transport decarbonization strategies, implementation constraints persist in different regions due to limitations of technology, human resources and funding [6].

2.3 Fuel Consumption Patterns and Dependencies in GCC

In the Middle East, transportation is the second-largest source of CO_2 emissions after power generation, primarily due to high reliance on motor vehicles and diesel-powered freight. Countries like Saudi Arabia, the UAE, Kuwait, and Qatar have among the highest per capita vehicle ownership rates globally and offer some of the lowest fuel prices, heavily subsidized by state revenues [7]. Governments have begun revising subsidy schemes, introducing EV incentives and expanding public transit but comprehensive and integrated planning is required to induce significant modal shifts.

2.4 Decarbonization Needs and Challenges in GCC Countries

Effectiveness of decarbonation policies largely depends on specific mechanisms through which their implementation instruments may affect travel and energy demand and resulting GHG emissions [8]. Research reveal that focused policies have the potential to significantly reduce transport sector energy demand and emission [9]. Moreover, decarbonization of Middle Eastern transport systems is complicated due to dependence national GDPs on fossil fuel. Cities in the region are often car-centric with limited infrastructure for active transport or high-capacity transit, transport planning is often fragmented, and climate policies are not yet fully mainstreamed into mobility governance. Despite these constraints, new-generation of pragmatic leadership is guiding strategic realignment towards visionary policies like Saudi Arabia's Circular Carbon Economy Framework with Vision 2030 and UAE's Net Zero 2050.

While global literature on transport decarbonization is growing, quantitative research correlating transportation policies and decarbonization in the context of Middle East is relative scarce. Further research is needed to map out data-driven pathways for reducing fuel consumption and transitioning toward more sustainable mobility systems tailored to the unique socio-economic and geopolitical realities of the region.

3 Analytical Methodology

This study employs a mixed-methods analytical framework to examine fuel consumption trends and evaluate policy options for decarbonizing the transportation sector in oil-dependent economies, with a particular focus on the Middle East. The methodology integrates quantitative time-series analysis, comparative policy evaluation, and scenario-based modeling based on national and international datasets and policy literature.

To assess baseline trends, the study conducts a longitudinal analysis of vehicle, population and fuel consumption trends from 1990 to the most recent available year using regression modeling Equation (1), elasticity estimation to evaluate the sensitivity of fuel demand to GDP growth and population, and sectoral breakdown of transportation parameters. To assess policy effectiveness, a policy typology matrix is constructed, categorizing interventions into various domains.

$$GHG\ Emission = aP^bG^c \tag{1}$$

Where, (a) Constant, (P) Population and (G) GDP (per capita).

The study uses a log-linear regression model Equation (1), which is a common strategy in energy demand analysis and interprets coefficients as elasticities. This form is recommended because it captures the nonlinear relationship. The primary assumptions of the model are homoscedasticity (constant variance of error), independence of errors, linearity of the parameters, and normality of residuals.

The study further analyzes three decarbonization scenarios to project the impact of different policy mixes on transport-sector emissions for the future. The scenarios include Business as Usual (BAU), Moderate Reforms and Proactive Intervention. For each scenario, transport energy demand and CO_2 emissions are projected using a bottom-up energy accounting framework which integrates projected fleet composition, vehicle energy, modal shares and policy implementation timelines. All analyses are performed using Python (pandas, matplotlib, statsmodels) based tools for data cleaning, visualization, and forecasting.

To provide extensive and trustworthy coverage, this study uses a synthesized dataset obtained from international and national sources. The King Abdullah Petroleum Studies and Research Centre (KAPSARC) provided primary statistics on fuel consumption, energy, and greenhouse gas emissions, which were supplemented with data from The World Bank Open Data repository and GCC countries' national statistical offices.

Before analysis, all data were harmonized and checked for consistency. The analysis of central patterns spans the period 1990-2020.

4 Results and Findings

This section presents the empirical findings derived from the analysis of transportation fuel consumption trends and the assessment of decarbonization policy options across selected oil-dependent economies in the Middle East. The countries analyzed include Saudi Arabia, the UAE, Kuwait, Oman, Bahrin and Qatar, representing a range of income levels, vehicle ownership rates, and policy maturity.

Two crucial trends for the decarbonization of GCC transportation are revealed by the developed model: While population density lowers per capita emissions, indicating that urbanization and transit-oriented development could reduce fuel consumption, GDP growth (per capita) significantly increases emissions, reflecting the region's car-dependent, fuel-intensive economies where rising incomes amplify vehicle ownership and travel demand. In order to counteract economic-driven demand, these findings highlight two policy imperatives: (1) break the GDP-emissions link through strict fuel efficiency standards, adoption of Electric Vehicles (EV), and carbon pricing; and (2) employ urban density by growing metro systems and transit-oriented zoning in order to take advantage of the observed scale efficiencies.

The model's autocorrelation (DW = 0.165) and multicollinearity (Cond. No. = 330) limits, on the other hand, show that there are still some temporal dynamics phenomena that haven't been taken into account such as the lagged effects of policies. In addition, that there may be interactions between GDP and population variables. This means that GCC policymakers need to use dynamic modeling and targeted pilot interventions such as congestion pricing in Dubai/Riyadh in order to gain better information for decisions makers.

4.1 Trends in Population and GDP Growth Patterns in GCC Region (1990–2020)

Regional statistics show that GCC countries have been experiencing rapid population and economic growth during the last four decades (Figure 1). The GCC population significantly increased, more than doubling from approximately 7.5 million in 1990 to nearly 58 million in 2020. The countries also achieved remarkable economic growth by increasing GDP from about US$280 Billion in 1990 to US$2.1 Trillion in 2020.

Table 1. Modal analysis outputs.

Component	Statistic	Value	Policy Implication
Model Fit	R-squared	0.740	Strong explanatory power for GCC transport emissions
	Adj. R-squared	0.738	
Significance	F-statistic (p-value)	337.9 (3.98e-70)	Highly significant model
Coefficients	Population ($p < 0.001$)	-0.2837	Efficiency increases may be made possible via urbanization.
	GDP per capita ($p < 0.001$)	0.3193	Emissions are currently driven by economic growth.
Durbin-Watson = 0.165		Cond. No. = 330	

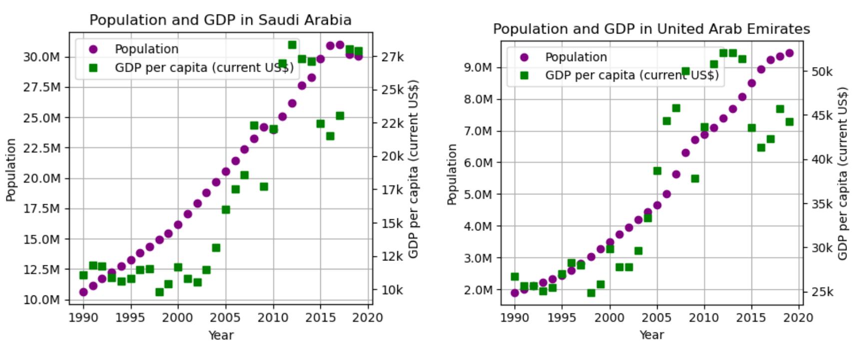

Fig.1. Population and GDP of Saudi Arabia and United Arab Emirates

4.2 Trends in Transport Fuel Consumption (1990–2020)

The time-series analysis revealed several consistent increasing trends across the region (Figure 2). All countries exhibited rising transport fuel consumption over the past two decades, with Saudi Arabia and UAE experiencing the most rapid growth—averaging 3.5%–4.8% annually in total fuel use. This growth was strongly correlated with population expansion, urbanization, and increased motorization.

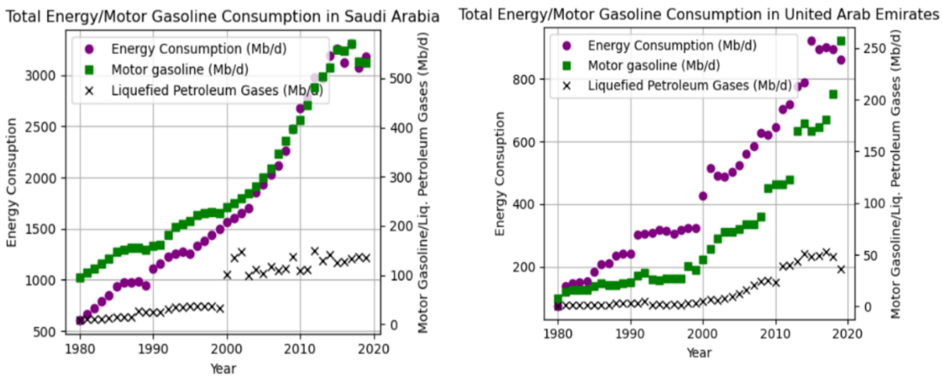

Fig. 2. Energy Consumption Patterns in Saudi Arabia and United Arab Emirates

4.3 Greenhouse Gas Emission in Transport Sector in GCC

Figure 3 and 4 show that greenhouse gas emission has also been gradually increasing during the past few decades. Although, the rate of increase of greenhouse gas emission and per-capita GHG emission have been controlled through technological intervention the aggregate upsurge is still a significant roadblock towards sustainable development.

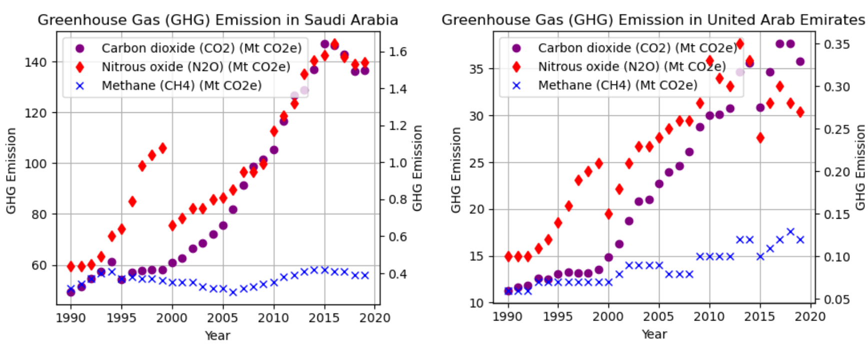

Fig. 3. CO2, NOx and Methane Emission Trends in GCC Countries

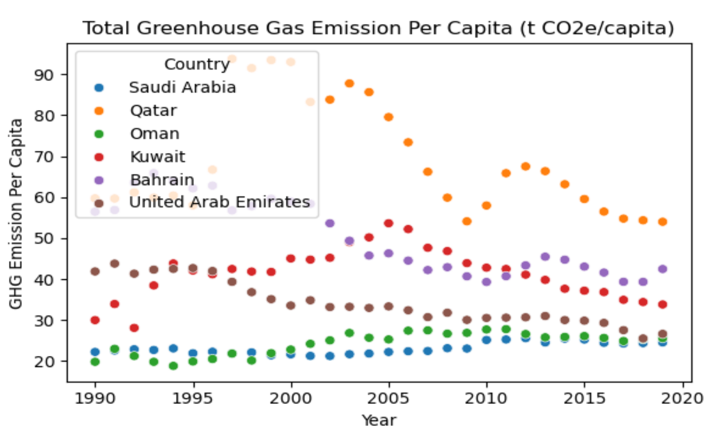

Fig. 4. Per-Capita Total Greenhouse Gas Emission in GCC Countries

4.4 Transport Sector Decarbonation Policy Options and Their Implications

Globally transport sector is one of the major producers of GHG contributing about 8.7 $GtCO_2e$/year. As summarized in Table 2 effective implementation of policies, ranging from vehicle electrification and fuel efficiency enhancement to urban planning and awareness, have the potential to reduce transport sector emission by more than 50 percent.

Analytical reveals that under business-as-usual scenario transport sector emission may increase by about 52 percent by 2050. Moderate intervention in the form of gradual transition to EVs and transit oriented development may result in about 22 percent reduction in transport sector emission. To achieve the goal of more than 50 percent reduction in transport sector emission, aggressive policy interventions in the form of full electrification of fleet, modal shift, and carbon tax will be required.

Global mitigation potential estimates across important techniques demonstrate that decarbonizing the transportation industry necessitates a diverse strategy. While efficiency requirements, economic tools, and urban planning provide lesser but crucial shares (5–12%), vehicle electrification has the greatest impact (25–30% of transport emissions), followed by sustainable fuels (15–20%) and modal changes (12–18%). Incremental increases of 1–5% are made possible by behavioral modifications and intelligent transportation systems [10]. The necessity for policy portfolios suited to regional contexts such as the GCC is shown by these ranges.

Table 2. Decarbonization Policies and Their Implications in Transport Sector

Strategy	Estimated Global Reduction Potential ($MtCO_2$ equiv./year)	% of Total Transport Emissions
Vehicle Electrification	2,000–3,500	25–30%
Fuel Efficiency & Standards	500–1,000 $MtCO_2e$/year	10–12%
Sustainable Fuels & Alternatives	1,200–2,500 $MtCO_2e$/year	15–20%
Shift to Low-Carbon Modes	1,000–1,800 $MtCO_2e$/year	12–18%
Economic Instruments	300–800 $MtCO_2e$/year	5–8%
Intelligent Transport Systems (ITS)	200–500 $MtCO_2e$/year	2–5%
Urban Planning & Design	500–1,200 $MtCO_2e$/year	8–10%
Behavioral Change & Awareness	100–300 $MtCO_2e$/year	1–3%

5 Discussion and Conclusion

The findings of this study underscore the importance and urgency of decarbonizing the transport sector in oil-dependent GCC economies. Unlike many regions that are transitioning away from fossil fuels, the Middle East's transport systems are deeply entwined with its hydrocarbon-driven economic model, heavily subsidized fuel pricing structures, and car-oriented urban development patterns.

The scenario-based analysis indicates that aggressive and integrated policy packages, that include combining electrification, fuel pricing reforms, modal shifts, and infrastructure investments, will be required for achieving the level of emission reduction consistent with mid-century net-zero goals.

Decarbonizing transportation in the GCC countries is both a strategic necessity and a transformative opportunity. This study shows that pursuing commensurate policies desired goal for the reduction transport sector emission can be achieved. Further research will be continued to analyze functional pathways and effective utilization of technologies like artificial intelligence to optimize transport sector emission reduction.

The study provides a solid macro-level assessment, but its limitations suggest promising paths for further research. While aggregate national data is necessary for regional study, it always obscures important sub-national differences in urban structure and travel behaviour. Furthermore, while the 1990-2020 period provides a significant timeframe, it may not fully capture longer-term structural economic changes. Our modelling approach also simplifies complex realities by omitting behavioural feedback effects and comprehensive technology learning curves, which are critical for accurate cost and adoption estimates.

In order to take time-dependent trends and policy feedback loops into consideration, future research should use dynamic modeling techniques (such as ARIMA or panel data analysis).

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