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GHGs emission reductions and economic saving by enhancing switching to natural gas vehicles in Egypt

Sayed I. Shaarawi[1,2*], Khaled Abutaleb[3,4,5], Ashraf R. Aboelmagd[2] and Tarek Temraz[1]

Abstract

Background Transportation and Climate change are inextricably linked. As the transport sector is the primary consumer of petroleum products and therefore, contributes a significant share of greenhouse gases (GHGs). Mobile sources share ranges between 25 and 30% of total Egypt's GHG emissions. So, Egypt is giving a great concern for natural gas vehicles (NGVs) as low-carbon alternative to gasoline/diesel vehicles. This study aims to analyze the economic and the environmental impact of the NGV fleet growth in Egypt with future prospective scenarios, concurrently with governmental strategy based on expansion of compressed natural gas fueling stations infrastructure and incentives for NGV transformation.

Results Egypt's NGV program led to about 5 Mt CO_2 emissions reductions and about 21.57 billion EGP (US$1.4 billion) economic saving since starting up to end of 2021. And implementing of presidential initiative in 2021 to accelerate NGVs led to jumping in CO_2 emissions reductions and economic saving by about 40% and 49% of pervious year, respectively.

Conclusions It is observed that scenario no. 1, of NGV adopting percent 15%, is the most fitted business as usual scenario to the presidential initiative and will lead to emissions reduction by about 30 Mt CO_2 and economic saving by about 278 billion EGP (US$17.6 billion).

Keywords Climate change, Natural gas vehicles, Compressed natural gas, Alternative fuels, Vehicle emissions, Transportation, Greenhouse gases

*Correspondence:
Sayed I. Shaarawi
sshaarawi@egas.com.eg; s.shaarawi@gmail.com; sayed_ismail@science.suez.edu.eg
[1] Marine Science –AdapTM Program, Faculty of Science, Suez Canal University, Ismailia, Egypt
[2] Egyptian Natural Gas Holding Company (EGAS), Petroleum and Mineral Resources Ministry, 85 Nasr Road, 1st District, P. O. Box 8064, Nasr City, Cairo 11371, Egypt
[3] National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt
[4] Agricultural Research Council, Natural Resources and Engineering (ARC-NRE), Pretoria, South Africa
[5] School of Animal, Plant and Environmental Sciences, University of Witwatersrand, Private Bag X3, Johannesburg 2050, South Africa

Background

Climate change is a global issue, and the UN considered it as the defining issue of our time, and we are at a defining moment (UN 2018), Climate change can be defined according to the IPCC, 3rd Assessment Report as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). This shifting in climate patterns is mainly caused by greenhouse gas emissions (GHG's) which can be defined by the Kyoto protocol as gases of (CO_2), methane (CH_4), nitrous oxide (N_2O), and the fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) which cause heat to be trapped by the earth's atmosphere. The transportation sector is one of the most significant sources of anthropogenic GHG`s. To mitigate climate change, it is important to adopt effective and immediate policies to reduce the transportation sector's emissions. Natural gas (NG) is considered as bridge between transfer from fossil fuel into net zero fuel emissions (Gillingham and Huang 2019; Ogden et al. 2018) as NG is the cleanest and most reliable fossil fuel. And considered one of Low-carbon and clean energy policies that have been proposed as a way to mitigate energy security and climate risks (IPCC 2007, 2014).

According to International Energy Agency (IEA), CO_2 emissions from the transportation sector have the highest reliance on fossil fuels of any sector and represented alone about 37% of CO_2 emissions from end-use sectors in 2021(IEA 2022). As with current trends of the transportation sector worldwide, there is a great concern among decision makers of sustainability that a novel shifting toward low-carbon fuel transportation is needed, requiring investment in low-carbon fuel infrastructure, public transportation, and reduction in private vehicle use among other travel demand measures, as well as encouraging use of more efficient vehicle technologies.

In Egypt, according to Egypt`s first Biennial update report (BUR) (BUR1 2019) to UNFCCC transportation sector total energy consumption, representing 48% of total petroleum energy consumption and 23% of energy related CO_2 emissions.

Egypt is giving a great concern for transportation sector as large subsidy attributed to its consumption of petroleum products, mainly gasoline and gas oil and reducing CO_2 emissions to meet their GHG obligations. In December 2018, Egypt's Ministry of Petroleum (MoP) announced the country had achieved a major milestone: gas self-sufficiency (EGAS 2019). This encourages Egypt to launch its presidential initiative on Jan 2021 (https://www.gogreenmasr.com/) to speeding up plans to convert liquid fuel vehicles into CNG-powered vehicles and CNG fueling stations infrastructure. Which touches nearly every Sustainable Development Goal (SDG) (Safari et al. 2018; UN_Secretary_General 2016) and are in line Egypt vision 2030 launched in February 2016 (Egypt 2030).

Egypt is considered the leading country in the NGV industry in Middle East and Africa as it is ranked one of the first ten countries in the number of converted vehicles all around the world, and wisely programmed its NGV market development since 1995 by providing prerequisites for simultaneous development in filling infrastructure with increase in number of vehicles powered on natural gas, to solve famous "Chicken and egg" dilemma for diffusion of any alternative fuel vehicles in general (Keith et al. 2020).

In CNG, natural gas is compressed to less than 1% of the volume and it occupies at standard atmospheric pressure and stored in a rigid container at a pressure about 200 bar, usually in cylindrical shapes metallic cylinder. Table 1 represents the Combustion and physiochemical-related properties of CNG vs diesel and gasoline. CNG is a lightweight fuel as its density is 215 kg/m^3, which is substantially lower as compared to that of gasoline (750 kg/m^3) and diesel (830 kg/m^3). Therefore, it can produce a better homogeneous air–fuel mixture ratio of 17.2:1 compared to gasoline (14.7:1) and diesel (14.6:1). It is also evident by the lower molar mass of CNG (17.3 g/mol) as compared to that of gasoline (109 g/mol) and of diesel (204 g/mol). It has a higher Lower Heating Value (LHV, net calorific value) of 47.5 MJ/kg, about 10% more than gasoline (43.5 MJ/kg) (Khan et al. 2015; Saurabh and Majumdar 2022).

GHG emissions forecasting from transportation sector pose a significant concern. To help planners and decision makers to formulate appropriate policies and strategies to reduce these emissions, in the literature, there are many approaches that have been proposed to forecast GHG emissions. Such as, forecasting of energy consumption and emissions from India's transportation sector up to 2050 have been projected (Paladugula et al. 2018). In Organization of Economic Co-operation and Development (OECD) countries, Saboori et al. (2014) applied time series analysis to examine the nexus between the emissions of CO_2 from the transport sector and the economic growth of OECD countries. In Taiwan, CO_2 emission trends have been forecasted from vehicles, vehicular energy intake and population to improve management of CO_2 emissions (Lu et al. 2009). Projection of future fossil-energy use, petroleum use, and greenhouse gas (GHG)

Table 1 Physiochemical properties of CNG vs gasoline and diesel

Properties	CNG	Gasoline	Diesel
Octane/cetane number	120–130	85–95	45–55
Molar mass (g/mol)	17.3	109	204
Density at 15 °C (kg/m^3)	215	750–765	830–950
Stoichiometric (Air/Fuel ratio)	17.2:1	14.7:1	14.6:1
Stoichiometric mixture density (kg/m^3)	1.25	1.42	1.46
L.H.V. (MJ/kg)	47.5	43.5	42.7
L.H.V. of stoichiometric mixture (MJ/kg)	2.62	2.85	2.75
Combustion energy (MJ/m^3)	24.6	42.7	36
Flammability limit in air (vol% in air)	4.3–15.2	1.4–7.6	1–6
Flame propagation speed (m/s)	0.41	0.5	–
Adiabatic flame temp. (°C)	1890	2150	2054
Auto-ignition temp. (°C)	540	258	316

emissions by motor vehicles in China up to year 2050 under several potential policy options (Huo et al. 2012). In North America, GHG emissions from road transportation sector have been projected by developing multivariate linear regression and double exponential smoothing model (Alhindawi et al. 2020).

The forecasting methods are mainly aiming to improve the accuracy of the results. Partial least squares regression model (PLS) is a popular method for soft modeling in industrial applications. It has proven to be a very versatile method for multivariate data analysis and a supervised method specifically established to address the problem of making good predictions in multi-variate problems (Martens and Naes 1992). (PLS) regression model has been used in GHG emissions associated with petroleum-based fuels consumed in the USA (Venkatesh et al. 2011).

We believe that this is the first scientific research in the literature that demonstrates the Egyptian natural gas vehicle program since starting at the end of 1995 and analyze the economic and environmental impact of the NGV fleet penetration growth in Egypt by using a panel database extending for 25 years, especially with the current government strategy based on an expansion of CNG fueling stations infrastructure and incentives for transformation into NGV.

This study aims to analyze the economic saving and emissions reduction as CO_2 equivalent for the NGV fleet growth in Egypt with future projected scenarios. By using partial least squares regression model (PLS) to project the total number of vehicles (TNV) and population (responses) against years (factors) and then, assuming four scenarios for adopting NGV by different ratios gradually in all projected vehicles fleet growth as 15%, 25%, 50% and 70%, respectively, and considering liquid fuel vehicles are mainly gasoline-powered vehicles. Especially, Egypt is aiming to ramp up initiatives designed to improve the country's environmental credentials and speed up its transition to a low-carbon economy after the 27th UN Climate Change Conference of the Parties (COP27) was held in Sharm el-Sheikh.

Methods

The analysis of this study is generally based on IPCC methodologies to assesses the environmental and on fuel pricing survey to assessment economic impact of NGV program proceeding in Egypt since 1995 and presidential initiative launched on Jan 2021 to speeding up plans to convert liquid fuel vehicles into natural gas vehicles by increasing CNG infrastructures (CNG fuelling stations and transformations centers). Then, using vehicles population (excluding 2 and 3 wheelers motor vehicles) trend analysis to forecast proposed vehicles growth and transformation scenarios from 2022 to 2035. As shown in Fig. 1, flowchart simplifies research methodology steps.

The methodology of estimating economic savings and the GHGs emission as CO_2 equivalent reductions for Egyptian NGV program growth is based on actual amounts of sold CNG and market survey for pricing CNG against liquid fuels, mainly gasoline, starting from beginning of NGV program up to the end of 2021.

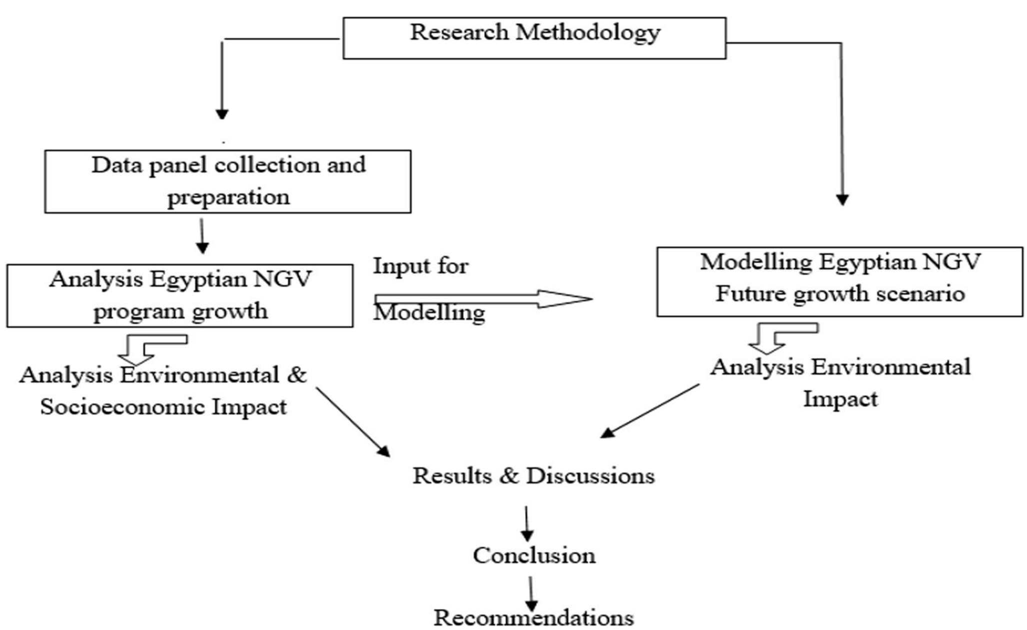

Fig. 1 Flowchart simplifying the research methodology steps of the present study

Method of CO_2 emissions calculations depends on IPCC guidelines 2006 produced by (UNFCCC) for national GHGs inventories, which provide method of work for a broad range of users to estimates GHGs emission. IPCC guidelines deal with a few key concepts:

1. Emission Factors (EF): EF is generally expressed in the form of a quantity of GHG's emitted per unit of energy or consumed fuel. The GHG emissions are calculated from multiplying the sectoral activity data (called Activity Data or AD) by corresponding emission factors (EF) following Eq. (1) and the value of (EF) differs between varies types of fuel. Depending mainly on the carbon content of the used fuel in industrial activities (Liu et al. 2020; Rypdal et al. 2006)

$$\text{Emissions} = \text{AD} \times \text{EF} \quad (1)$$

2. Anthropogenic Emission: Anthropogenic emission is a result of human activities. The distinction between natural and anthropogenic emission must be used to limit human activities and calculate their emission.
3. Tiers: A tier represents a level of methodological complexity. Usually, three tiers are provided. Tier 1 is the simplest and most accessible. Mostly based on activity levels and emission factors, they use the provided default values for emissions factors and other parameters (Vayssières and Hunsaker 2009).

According to IPCC 2006 Guidelines (IPCC 2006), Transportation represents mobile emission sources and produces direct GHGs from the combustion of various fuel types. Road transport emissions can be estimated from either the fuel consumed represented by fuel sold or the distance travelled by the vehicles. The first approach (fuel sold) is appropriate for CO_2, and the second (distance travelled by vehicle type and road type) is appropriate for CH_4 and N_2O, therefore default fuel-based emission factors for CH_4 and N_2O that do not specify vehicle technology are highly uncertain. As shown in

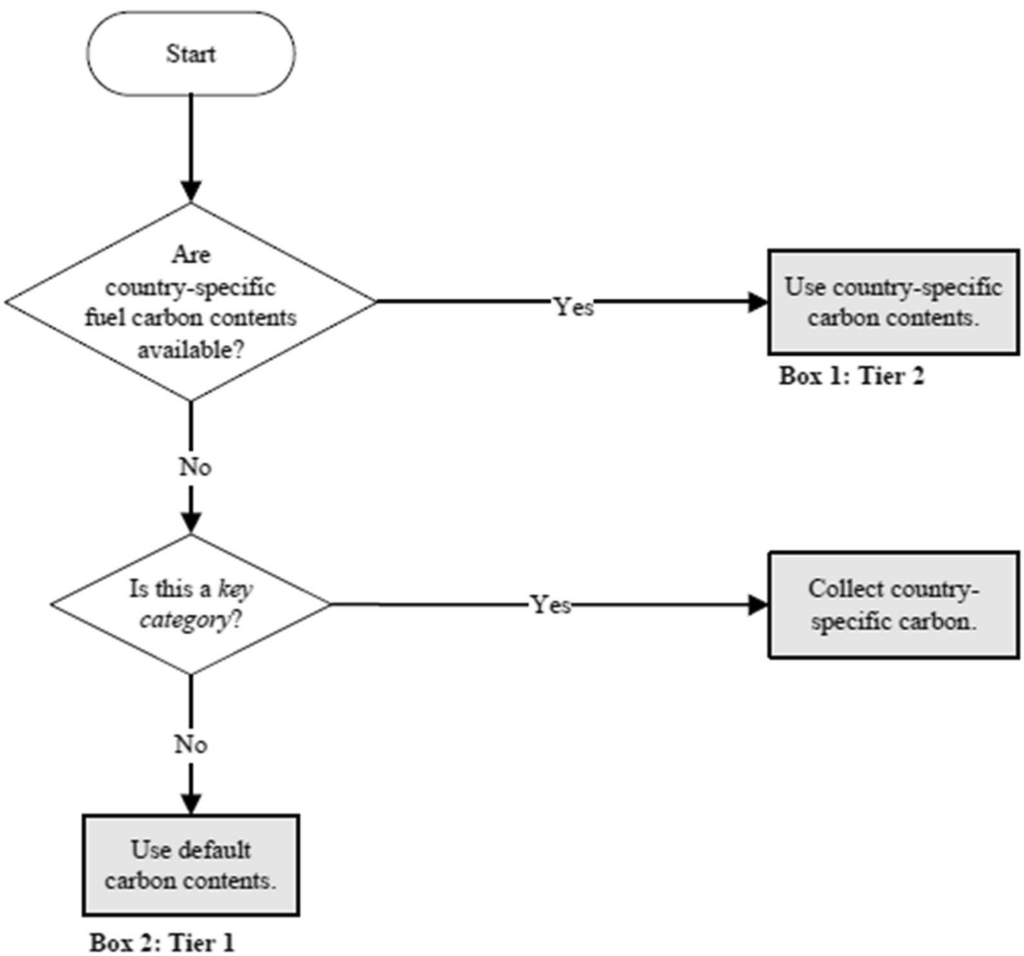

Fig. 2 Decision tree for CO_2 emissions from fuel combustion in road vehicles

Table 2 Road transport default CO_2 emission factors and uncertainty ranges* (IPCC 2006)

Fuel type	Default (kg/TJ)	Lower	Upper
Motor gasoline	69,300	67,500	73,000
Gas/diesel oil	74,100	72,600	74,800
Liquified petroleum gases (LPG)	63,100	61,600	65,600
Kerosene	71,900	70,800	73,700
Lubricants	73,300	71,900	75,200
Compressed natural gas (CNG)	56,100	54,300	58,300
Liquified natural gas (LNG)	56,100	54,300	58,300

*Values represent 100 percent oxidation of fuel carbon content (Complete and perfect combustion process, i.e., every carbon full loaded by 32gm of one oxygen molecule).

Fig. 2, the decision tree for CO_2 guides the choice of either the Tier 1 or Tier 2 method. So, the calculation methodology depends on Tire 1 to calculate CO_2 Emissions rather than CH_4 and N_2O emissions which depend largely upon the combustion and emission control technology present in the vehicles.

Tier 1 approach calculates CO_2 emissions using Eq. (2) (IPCC 2006) by multiplying amount of fuel sold with a default CO_2 emission factor as shown in Table 2.

$$\text{Road Transport Emission} \quad \text{Emission} = \sum_{a} [\text{Fuel}_a * \text{EF}_a] \tag{2}$$

where: Emission = Emissions of CO_2 (kg), Fuel_a = fuel sold (TJ), EF_a = Emission Factor (Table 2), a = type of fuel (e.g., gasoline, diesel, CNG, LPG, etc.)

Data source

The researchers collected the historical data used in this study on liquid fuel vehicles growth (excluding 2 and 3 wheelers motor vehicles) and population from the official data source of Egypt's Central Agency for Public Mobilization and Statistics (CAPMAS) bulletins. While the data for natural gas vehicles growth, CNG fuel price and amounts of sold CNG in CNG-fuelling stations starting from beginning of NGV program up to the end of 2021 have been collected from national program archiving data for vehicles transformation into natural gas-powered vehicles at EGAS.

Modeling 2022–2035 scenarios assumption

Egypt vehicle growth trend analysis versus population trend analysis starting from beginning of Egypt NGV program up to the end of 2021 was carried out to forecast vehicle fleet growth and transformation scenarios up to 2035. Then, by estimating annual vehicle fuel consumption, environmental impact can be assessed as CO_2 emissions reduction for every vehicle transformation scenario by assuming adopting NGV by different ratios gradually in all vehicles fleet growth as 15%, 25%, 50% and 70%, respectively. Research in science and engineering often involves using controllable and/or easy-to-measure variables (factors) to explain, regulate, or predict the behavior of other variables (responses). Partial least squares (PLS) is a widely used statistical modeling technique employed in various research domains and data analysis. PLS offers a comprehensive framework for analyzing intricate relationships between predictor and response variables. PLS has been widely used in many environmental and economic studies such as Peacock et al. explored how dissolved GHGs were related to the other biogeochemical variables in urban ponds by conducting PLS (Peacock et al. 2019). Moreover, PLS has been used to identify the environmental and economic factors consolidation on sustainable entrepreneurship over time with sustainable development goals (Moya-Clemente et al. 2020). In this study, the Partial least squares regression model (PLS) is used as an explicitly composite-based technique (Tu 2021) to project population (responses) against years and then, total number of vehicles (TNV) (factors) using multilinear regression as shown in Eqs. (3) and (4). All these analyses are carried out by R software package as an extremely powerful program for manipulating and analyzing data.

$$\text{Population} = a * \text{Year} - b \tag{3}$$

$$\text{TNV} = c * \text{Population} + d * \text{Year} + e \tag{4}$$

where a, b, c, d, and e are constants.

Results

Economic saving of enhancing switching to NGV in Egypt

A summary of retail fuel prices since beginning of NGV program in Egypt till end of 2021 is shown in Fig. 3, which prove that the CNG fuel price was the cheapest vehicle fuel available choice for people ever.

The Economic saving for Egyptian NGV program growth can be estimated as shown in Fig. 4 starting from beginning of NGV program up to end 2021, and it is about 21.57 billion EGP (US$1.4 billion on basis of currency exchange rate at end of 2021) economic saving based on actual amounts of sold CNG yearly and market survey for pricing CNG against liquid fuels (mainly 90-octane gasoline to end 2003, after that 92-octane gasoline) in this year to calculate cost of gasoline amount relevant to amount of sold CNG. As shown in Fig. 4, economic saving curve is notably raised after 2014 because of the start of applying energy subsidy reforming program and increasing of the fuel prices as a result. Then, in 2019, it experienced a remarkable

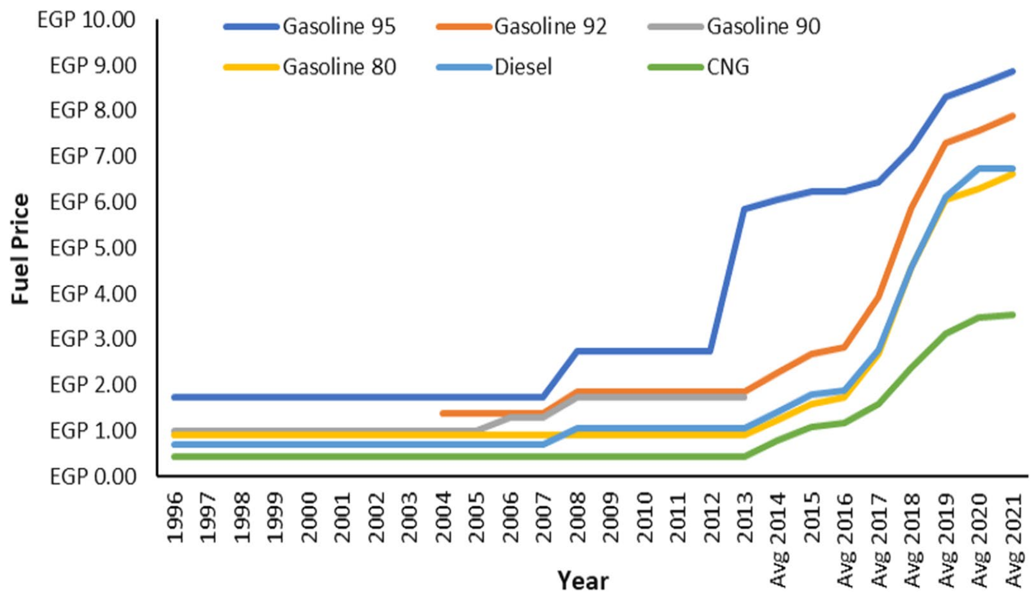

Fig. 3 Retail fuel prices in Egypt in EGP per unit volume. (Liter for Liquid fuel, M^3 for CNG) (*Note*: 92-octane gasoline is starting in 2004, while 90-octane gasoline was stopped in 2014)

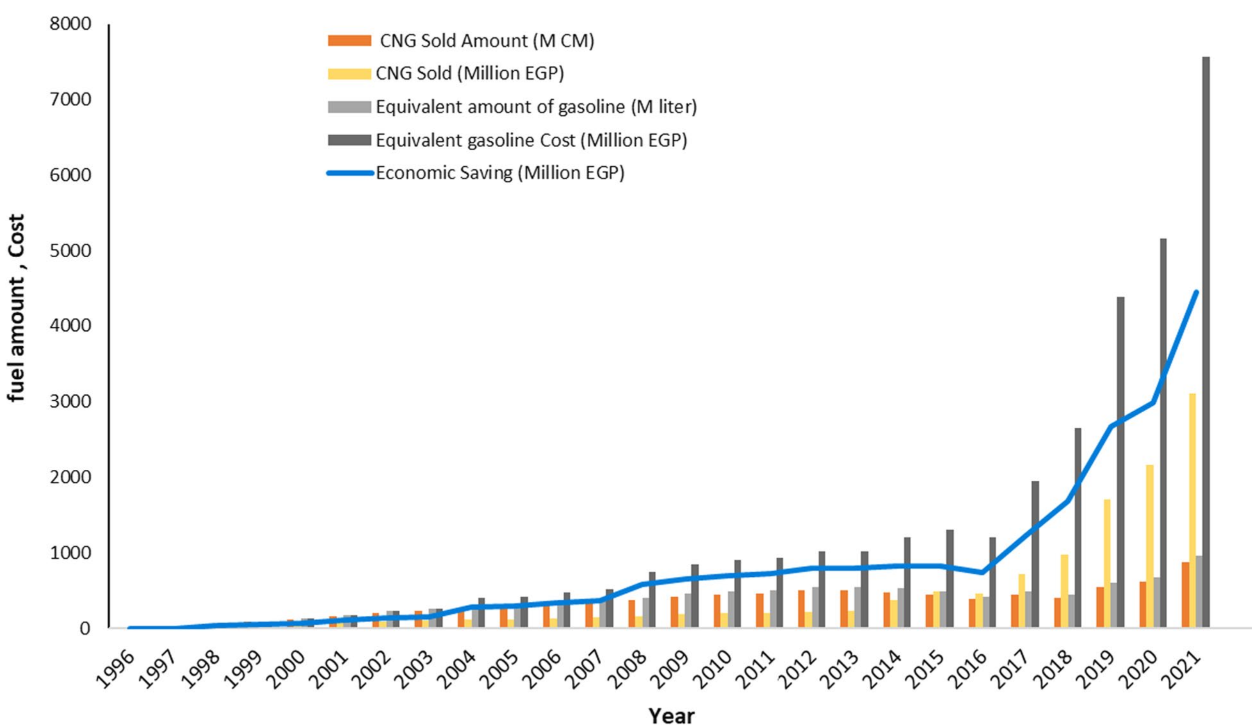

Fig. 4 Economic saving for Egypt NGV program growth

Table 3 Ton CO_2 emission per ton of fuel

Fuel type	Calorific value (MMBTU/ton)	Ton CO_2 emissions per ton of fuel	Volume of 1 ton
CNG	47.79	2.8285	1340 M^3
Gasoline (92 Octane)	44.5	3.2536	1346 Liter

shifting up about 59% of previous year by establishing of a new automatic price indexation mechanism for petroleum products on a quarterly basis with relevant of international prices. And continued in increasing in 2021 by about 49% of pervious year as implementing of the presidential initiative to accelerate NGVs which raise CNG fuel demand.

GHGs emission reductions as switching to natural gas vehicles in Egypt

Based on the default factor in Table 2, Ton CO_2 emissions per ton of fuel can be calculated according to its calorific values as Egyptian petroleum ministry records as shown in Table 3.

So, CO_2 emissions reduction, since starting of NGV program in Egypt up to end 2021 as shown in Fig. 5, can be calculated as 5 Mt CO_2 based on amount of CNG sold yearly as the difference between CO_2 emissions resulting from amount of sold CNG and that of resulting from equivalent amount as gasoline (92 octane) which currently, represent most of vehicle's fuels in Egypt. For example, as shown in Table 4, in 2021 total sold CNG was 872 Million m^3 which is equivalent to 959 Million liter gasoline (92 octane) and resulting in CO_2 emissions reduction by about 478 kt.

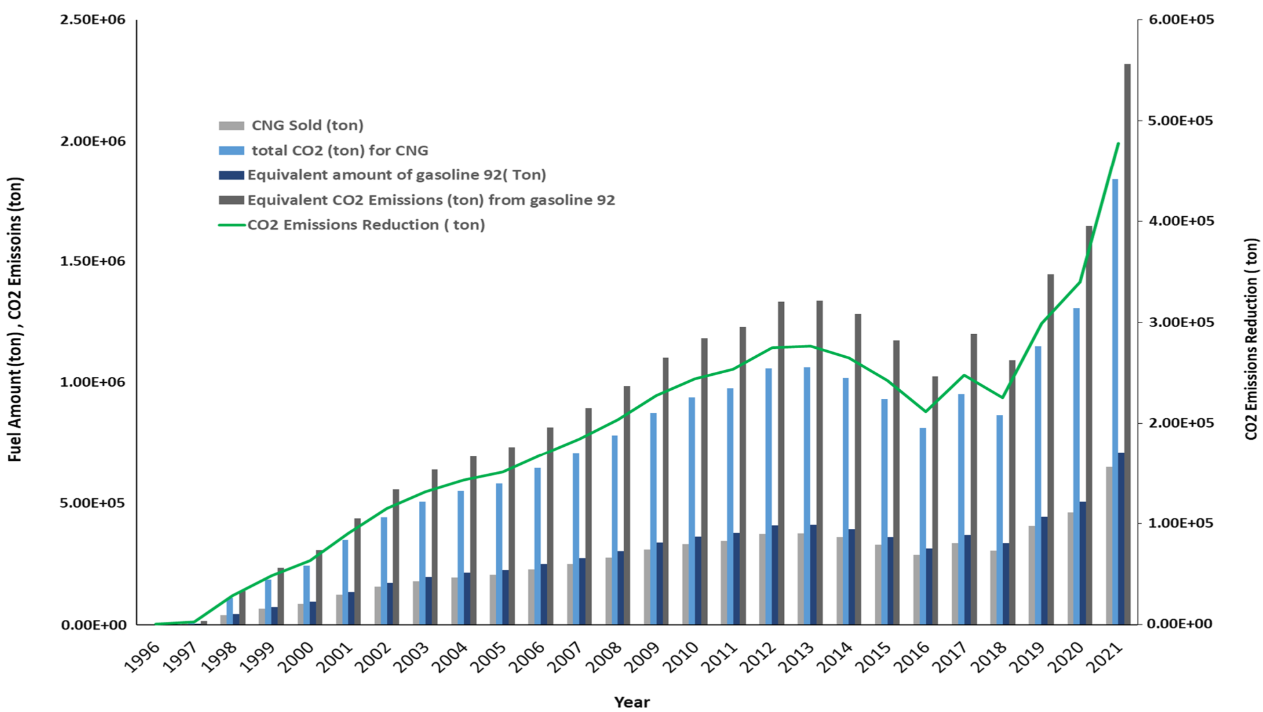

Fig. 5 Annual CO_2 emission reduction as per NGV growth

Table 4 CO_2 emissions reduction for sold CNG by year 2021

Fuel type	Fuel amount	Ton CO_2 emissions per ton of fuel	Total CO_2 emissions (ton)
Sold CNG (Million m^3)	872	2.8285	1,840,635.821
Equivalent gasoline (Million liter 92- Octane)	959	3.2536	2,318,613.02
CO_2 emissions reduction (ton)			477,977.20

As shown in Fig. 5, CO_2 emissions reduction curve experienced a notably jumping up after 2019 by about 32% of pervious year because of implementing new vehicle fuel pricing instrument tool on a quarterly basis by indexing local fuel prices with relevant of international prices, which led to an increase in CNG fuel demand.

And continued rising in a consistent manner in 2021 by about 40% of pervious year as result of the presidential initiative to accelerate NGVs.

Projection model scenarios

The Pearson correlation method is used as shown in Fig. 6. It is considering a strong positive correlation would be expected for the two set of variables are "population" against "year" and total number of vehicles "TNV" against "years" and "population" as every year, population is increasing as well as vehicle demand. Therefore, the correlation between year against both of population and TNV probably gives a value over 0.9 as shown in Fig. 6.

A well-fitting regression model results in predicted values are close to the actual data values that can be observed in Figs. 7 and 8 when run model Eqs. (3) and (4) for historical population and TNV trend giving regression Eqs. (5) and (6)

$$\text{Population} = 1.77E + 06 * \text{Year} - 3.48E + 09 \quad (5)$$

$$\text{TNV} = 2.49E - 01 * \text{Population} - 2.24E + 05 * \text{Year} + 4.34E + 08 \quad (6)$$

The root mean square error (RMSE) and Mean Absolute Error (MAE) are calculated for both population prediction model and TNV prediction model for historical data (1995 to 2021) giving about 1.5e+6 and 1.8%, respectively, in case of population model, while as for TNV prediction

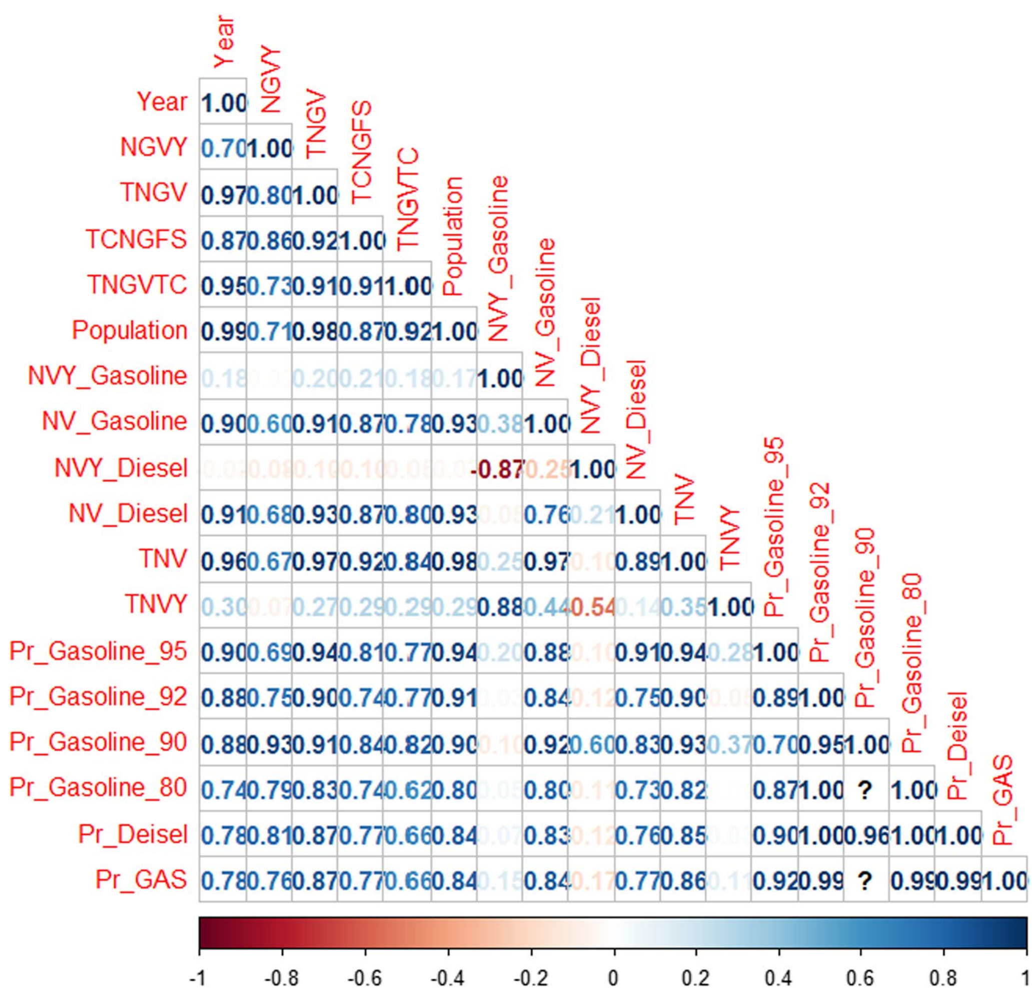

Fig. 6 Pearson correlation for variables

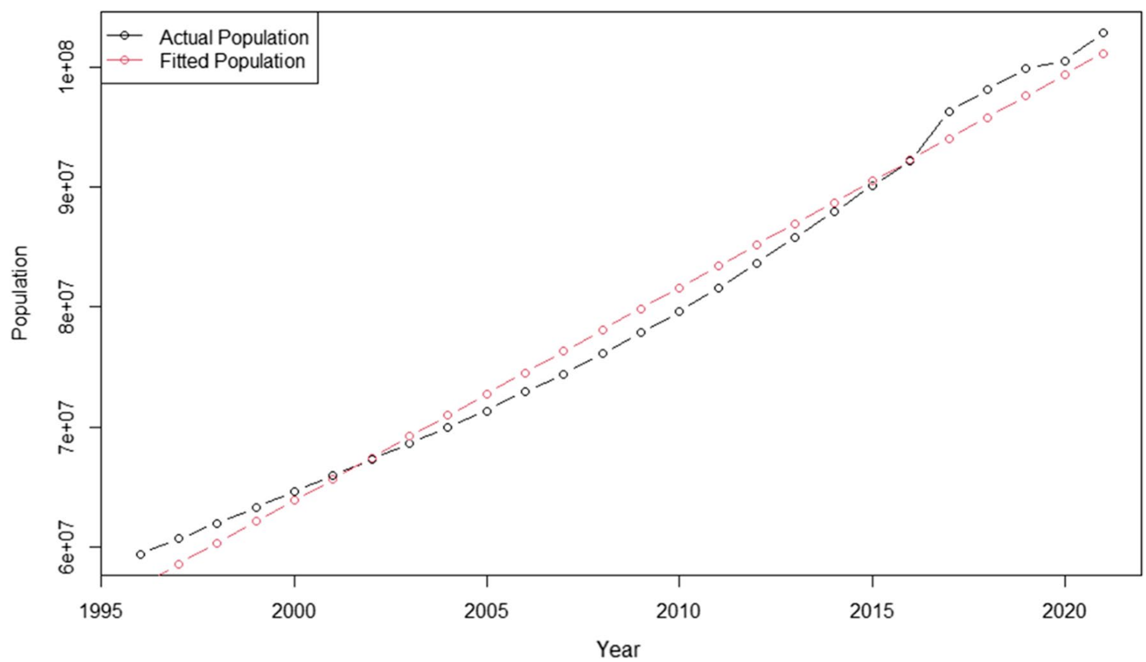

Fig. 7 Population historical actual/fitted data

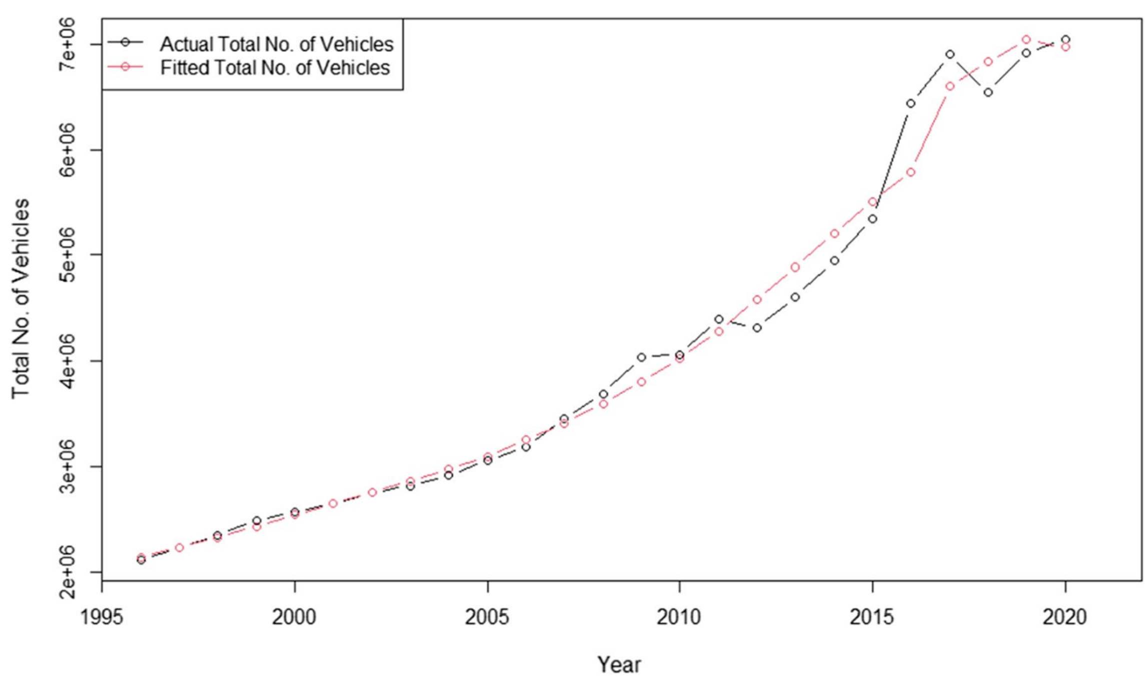

Fig. 8 TNV historical actual/fitted data

model gives 1.9e+5 and 2.7%, respectively, which reflects the robustness of prediction models. By applying prediction models Eqs. (5) and (6) to project the population and TNV up to 2035 as shown in Table 5 to estimate the environmental and socioeconomic impacts for different scenarios for adopting natural gas as vehicle fuel.

Table 5 Projected population and TNV up to 2035

Year	Population	TNV
2022	101,953,000	6.92E+6
2023	103,724,000	7.14E+6
2024	105,495,000	7.36E+6
2025	107,266,000	7.57E+6
2026	109,037,000	7.79E+6
2027	110,808,000	8.01E+6
2028	112,579,000	8.22E+6
2029	114,350,000	8.44E+6
2030	116,121,000	8.66E+6
2031	117,892,000	8.87E+6
2032	119,663,000	9.09E+6
2033	121,434,000	9.31E+6
2034	123,205,000	9.52E+6
2035	124,976,000	9.74E+6

Table 6 Adopting CNG scenarios

Year	TNV	Scenario 1 15% NGV	Scenario 2 25% NGV	Scenario 3 50% NGV	Scenario 4 70% NGV
2022	6.92E+6	1.04E+6	1.73E+6	3.46E+6	4.85E+6
2023	7.14E+6	1.07E+6	1.79E+6	3.57E+6	5.00E+6
2024	7.36E+6	1.10E+6	1.84E+6	3.68E+6	5.15E+6
2025	7.57E+6	1.14E+6	1.89E+6	3.79E+6	5.30E+6
2026	7.79E+6	1.17E+6	1.95E+6	3.90E+6	5.45E+6
2027	8.01E+6	1.20E+6	2.00E+6	4.00E+6	5.60E+6
2028	8.22E+6	1.23E+6	2.06E+6	4.11E+6	5.76E+6
2029	8.44E+6	1.27E+6	2.11E+6	4.22E+6	5.91E+6
2030	8.66E+6	1.30E+6	2.16E+6	4.33E+6	6.06E+6
2031	8.87E+6	1.33E+6	2.22E+6	4.44E+6	6.21E+6
2032	9.09E+6	1.36E+6	2.27E+6	4.54E+6	6.36E+6
2033	9.31E+6	1.40E+6	2.33E+6	4.65E+6	6.51E+6
2034	9.52E+6	1.43E+6	2.38E+6	4.76E+6	6.67E+6
2035	9.74E+6	1.46E+6	2.43E+6	4.87E+6	6.82E+6

Adopting scenarios of natural gas vehicle fuel

By assuming adopting NGV by different ratios gradually in all vehicles, fleet growth as 15%, 25%, 50% and 70%, respectively, and considering liquid fuel vehicles are mainly gasoline powered vehicles as shown in Table 6.

Environmental impact of adopting scenarios of natural gas vehicle fuel

The Environmental impact can be estimated for every scenario as emissions reduction resulting from every NGV adopting scenario as a difference between CO_2 emissions from NGV and CO_2 emissions as if these vehicles are still gasoline powered and not converted into natural gas-powered vehicles.

According to historical data for CNG fuel consumption and NGV fleet growth since starting of NGV adopting program in 1995, average of yearly CNG fuel consumption was 3111 M^3 per vehicle (=3422-L gasoline). Therefore, CO_2 emissions reduction resulting from every NGV adopting scenario as well as no action scenario and full conversion scenario can be calculated as shown in Table 7 can be calculated by using CO_2 emission factor in Table 3.

Figure 9 and Table 6 evidently show that a significant difference in CO_2 emissions pattern in case of no action scenario (100% gasoline powered vehicles) and full conversion scenario (100% CNG powered vehicles) which represent about 21% percent of CO_2 emissions (about 200 megatons) can be reduced from predicted vehicles growth in Egypt if all of them are converted to NGVs.

The same procedure has been followed to predict the emission reduction for partial conversion of predicted TNV into NGVs for the years 2022–2035. The results are shown in Tables 8, 9, 10 and 11.

By analysis of different assumed above scenarios as shown in Fig. 10, it is observed that the most fitted business as usual scenario to the presidential initiative, which is targeting total NGVs to reach 1 million by end of 2023, is scenario no. 1 with NGV adopting percent 15%, which represent about CO_2 emissions about 30 megatons can be reduced from predicted vehicles growth if Egypt is adopting scenario number, while if Egypt adopting other scenarios 2, 3 and 4, it will lead to CO_2 emissions reduction by 50, 100 and 140 megatons, respectively.

Economic saving of adopting scenarios of natural gas vehicle fuel

The Economic impacts are estimated as economic saving resulting from each NGV adopting scenario as a difference between 92-octane gasoline fuel (as a main liquid fuel) and CNG retail prices by considering latest average retail fuel prices for year 2021. Economic saving for different NGV adopting scenarios as shown in Tables 12, 13, 14 and 15 and Fig. 11 can be calculated by considering yearly CNG fuel consumption as 3111 M^3 per vehicle according to historical data for CNG fuel consumption and NGV fleet growth since starting of NGV adopting program in 1995, which is equivalent to about 3422 L gasoline. So, economic saving as a difference between cost of CNG fuel for every NGV adopting percent and cost of theses NGVs if they are still gasoline powered and not converted into natural gas-powered vehicles.

By analysis of different assumed above scenarios, it is observed that the economic saving result from scenario number 1, which is the most fitted business as usual

Table 7 No action and full conversion scenario

Year	TNV	100% CNG powered vehicles (M^3)	100% gasoline powered vehicles (Liter)	CO_2 emissions		CO_2 emissions reduction (ton)	Economic Saving (Million EGP)
				No action scenario	Full conversion scenario		
2022	6.92E+6	2.15E+10	2.37E+10	5.73E+7	4.55E+07	1.18E+07	7.67E+4
2023	7.14E+6	2.22E+10	2.44E+10	5.91E+7	4.69E+07	1.22E+07	7.91E+4
2024	7.36E+6	2.29E+10	2.52E+10	6.09E+7	4.83E+07	1.25E+07	8.15E+4
2025	7.57E+6	2.36E+10	2.59E+10	6.27E+7	4.97E+07	1.29E+07	8.39E+4
2026	7.79E+6	2.42E+10	2.67E+10	6.44E7	5.12E+07	1.33E+07	8.63E+4
2027	8.01E+6	2.49E+10	2.74E+10	6.62E+7	5.26E+07	1.37E+07	8.87E+4
2028	8.22E+6	2.56E+10	2.81E+10	6.80E+7	5.40E+07	1.40E+07	9.11E+4
2029	8.44E+6	2.63E+10	2.89E+10	6.98E+7	5.54E+07	1.44E+07	9.35E+4
2030	8.66E+6	2.69E+10	2.96E+10	7.16E+7	5.68E+07	1.48E+07	9.59E+4
2031	8.87E+6	2.76E+10	3.04E+10	7.34E+7	5.83E+07	1.51E+07	9.83E+4
2032	9.09E+6	2.83E+10	3.11E+10	7.52E+7	5.97E+07	1.55E+07	1.01E+5
2033	9.31E+6	2.90E+10	3.18E+10	7.70E+7	6.11E+07	1.59E+07	1.03E+5
2034	9.52E+6	2.96E+10	3.26E+10	7.88E+7	6.25E+07	1.62E+07	1.05E+5
2035	9.74E+6	3.03E+10	3.33E+10	8.06E+7	6.40E+07	1.66E+07	1.08E+5

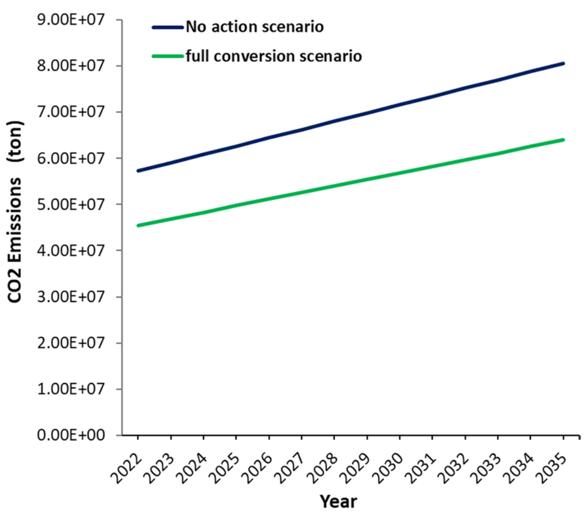

Fig. 9 CO_2 emissions pattern for no action and full conversion scenario

scenario to the presidential initiative, is about 278 billion EGP (US$17.6 billion). While if Egypt adopting other scenarios 2, 3 and 4, it will lead to economic saving by 463 (US$ 29.4 billion), 927 (US$ 58.8 billion) and 1300 billion EGP (US$ 82.5 billion), respectively, currency exchange rate at end of 2021 (US$ 1 = 15.76 EGP).

Discussion

The crucial factor in promoting users to switch to CNG vehicles is the price difference between CNG fuel and conventional liquid fuels (gasoline and diesel), as CNG fuel price is commonly about of at least 40–60% below the gasoline price as in the most successful adopters NGV countries (Gwilliam 2000; Khan and Yasmin 2014) as shown in Figs. 3 and 4 which reflect local market survey for different vehicular fuel retail prices in Egypt. Usually, natural gas is less vulnerable to price fluctuations; furthermore, its resources are evenly distributed over the earth as compared to oil (Ji et al. 2018; Khan et al. 2015). As natural gas to be used as a vehicle fuel passes through a very slight process from production field (Well) to vehicle (Wheel). While on the other hand, conventional liquid fuels (gasoline and diesel) pass through more complicated processes starting from crude oil upstream activity and fractionated through complex refinery process. Retail fuel prices in Egypt are also affected by many waves of subsidies phasing out as the energy was subsided for long time by the Egyptian government which was amounted in FY 2013/14 about $21 billion or 8.5% of GDP as a combined energy subsidy and the first partial attempts to reduce the level of energy subsidization in Egypt were implemented in 2012 and 2013. Then, in July 2014, the Egyptian government re-introduced major reforms to phase-out energy subsidies through a staged series of increases in the officially mandated prices for petroleum, gas, and electricity. As a result of this energy subsidy reforming program, the fuel prices have been raised by implementation the first wave of subsidy reforming program in 2014 by increasing diesel prices by 64%, 80-octane gasoline by 80%, and 92-octane gasoline by 40%. Overall prices averaged at a 50% increase (Breisinger et al. 2019).

Table 8 CO_2 emissions reduction (ton) from scenario 1

Year	15% NGV	CNG Fuel consumption (M3)	Equivalent amount of gasoline (liter)	total CO_2 (ton) for NGV	Equivalent CO_2 emissions (ton) from gasoline	CO_2 emissions reduction (ton) from scenario 1	Economic saving (Million EGP)
2022	1.04E+6	3.23E+9	3.55E+9	6.82E+06	8.59E+6	1.77E+06	1.65E+4
2023	1.07E+6	3.33E+9	3.67E+9	7.03E+06	8.86E+6	1.83E+06	1.70E+4
2024	1.10E+6	3.43E+9	3.78E+9	7.25E+06	9.13E+6	1.88E+06	1.75E+4
2025	1.14E+6	3.53E+9	3.89E+9	7.46E+06	9.40E+6	1.94E+06	1.81E+4
2026	1.17E+6	3.64E+9	4.00E+9	7.67E+06	9.67E+6	1.99E+06	1.86E+4
2027	1.20E+6	3.74E+9	4.11E+9	7.89E+06	9.94E+6	2.05E+06	1.91E+4
2028	1.23E+6	3.84E+9	4.22E+9	8.10E+06	1.02E+7	2.10E+06	1.96E+4
2029	1.27E+6	3.94E+9	4.33E+9	8.31E+06	1.05E+7	2.16E+06	2.01E+4
2030	1.30E+6	4.04E+9	4.44E+9	8.53E+06	1.07E+7	2.21E+06	2.06E+4
2031	1.33E+6	4.14E+9	4.55E+9	8.74E+06	1.10E+7	2.27E+06	2.12E+4
2032	1.36E+6	4.24E+9	4.67E+9	8.95E+06	1.13E+7	2.33E+06	2.17E+4
2033	1.40E+6	4.34E+9	4.78E+9	9.17E+06	1.15E+7	2.38E+06	2.22E+4
2034	1.43E+6	4.44E+9	4.89E+9	9.38E+06	1.18E+7	2.44E+06	2.27E+4
2035	1.46E+6	4.54E+9	5.00E+9	9.59E+06	1.21E+7	2.49E+06	2.32E+4

Table 9 CO_2 emissions reduction (ton) from scenario 2

Year	25% NGV	CNG Fuel consumption (M^3)	Equivalent amount of gasoline (liter)	total CO_2 (ton) for NGV	Equivalent CO_2 emissions (ton) from gasoline	CO_2 emissions reduction (ton) from scenario 2	Economic saving (Million EGP)
2022	1.73E+6	5.39E+9	5.92E+9	1.14E+07	1.43E+07	2.95E+06	2.75E+4
2023	1.79E+6	5.55E+9	6.11E+9	1.17E+07	1.48E+07	3.04E+06	2.84E+4
2024	1.84E+6	5.72E+9	6.29E+9	1.21E+07	1.52E+07	3.14E+06	2.92E+4
2025	1.89E+6	5.89E+9	6.48E+9	1.24E+07	1.57E+07	3.23E+06	3.01E+4
2026	1.95E+6	6.06E+9	6.66E+9	1.28E+07	1.61E+07	3.32E+06	3.09E+4
2027	2.00E+6	6.23E+9	6.85E+9	1.31E+07	1.66E+07	3.41E+06	3.18E+4
2028	2.06E+6	6.40E+9	7.04E+9	1.35E+07	1.70E+07	3.51E+06	3.27E+4
2029	2.11E+6	6.56E+9	7.22E+9	1.39E+07	1.75E+07	3.60E+06	3.35E+4
2030	2.16E+6	6.73E+9	7.41E+9	1.42E+07	1.79E+07	3.69E+06	3.44E+4
2031	2.22E+6	6.90E+9	7.59E+9	1.46E+07	1.83E+07	3.78E+06	3.53E+4
2032	2.27E+6	7.07E+9	7.78E+9	1.49E+07	1.88E+07	3.88E+06	3.61E+4
2033	2.33E+6	7.24E+9	7.96E+9	1.53E+07	1.92E+07	3.97E+06	3.70E+4
2034	2.38E+6	7.41E+9	8.15E+9	1.56E+07	1.97E+07	4.06E+06	3.78E+4
2035	2.43E+6	7.57E+9	8.33E+9	1.60E+07	2.01E+07	4.15E+06	3.87E+4

The fuel prices are also passed an increase the day following the floatation of the Egyptian pound that was announced by the Egyptian central bank on 3 November 2016 (The_Central_Bank_of_Egypt 2016).

In conjunction with the steps taken to implement the energy subsidy reform program, the Egyptian government issued a decree number 2764 in December 2018 to establish a new automatic price indexation mechanism for petroleum products. Under this mechanism, the price of fuel products will fluctuate along with the international prices. However, the price changes will be kept at ± 10% band and petroleum products will be re-priced on a quarterly basis (Prime_Ministry_Decree 2018).

Natural gas vehicles growth in Egypt is accelerated after reaching to gas-self-sufficient in 2018, by launching presidential initiative on Jan 2021 (https://www.gogreenmasr.com/) to speeding up plans to convert liquid fuel vehicles into natural gas vehicles by spreading CNG infrastructures (CNG fuelling stations and Transformations centers) and giving incentives called "green Incentive" to encourage citizens to replace old liquid fuel vehicles by more advanced natural gas vehicles. Egypt speeding up

Table 10 CO_2 Emissions reduction (ton) from scenario 3

Year	50% NGV	CNG Fuel consumption (M3)	Equivalent amount of gasoline (liter)	Total CO_2 (ton) for NGV	Equivalent CO_2 emissions (ton) from gasoline	CO_2 emissions reduction (ton) scenario 3	Economic saving (Million EGP)
2022	3.46E+6	1.08E+10	1.18E+10	2.27E+07	2.86E+07	5.90E+06	5.50E+4
2023	3.57E+6	1.11E+10	1.22E+10	2.34E+07	2.95E+07	6.09E+06	5.67E+4
2024	3.68E+6	1.14E+10	1.26E+10	2.42E+07	3.04E+07	6.27E+06	5.85E+4
2025	3.79E+6	1.18E+10	1.30E+10	2.49E+07	3.13E+07	6.46E+06	6.02E+4
2026	3.90E+6	1.21E+10	1.33E+10	2.56E+07	3.22E+07	6.64E+06	6.19E+4
2027	4.00E+6	1.25E+10	1.37E+10	2.63E+07	3.31E+07	6.83E+06	6.36E+4
2028	4.11E+6	1.28E+10	1.41E+10	2.70E+07	3.40E+07	7.01E+06	6.53E+4
2029	4.22E+6	1.31E+10	1.44E+10	2.77E+07	3.49E+07	7.20E+06	6.71E+4
2030	4.33E+6	1.35E+10	1.48E+10	2.84E+07	3.58E+07	7.38E+06	6.88E+4
2031	4.44E+6	1.38E+10	1.52E+10	2.91E+07	3.67E+07	7.57E+06	7.05E+4
2032	4.54E+6	1.41E+10	1.56E+10	2.98E+07	3.76E+07	7.75E+06	7.22E+4
2033	4.65E+6	1.45E+10	1.59E+10	3.06E+07	3.85E+07	7.93E+06	7.39E+4
2034	4.76E+6	1.48E+10	1.63E+10	3.13E+07	3.94E+07	8.12E+06	7.57E+4
2035	4.87E+6	1.51E+10	1.67E+10	3.20E+07	4.03E+07	8.30E+06	7.74E+4

Table 11 CO_2 emissions reduction (ton) from scenario 4

Year	70% NGV	CNG Fuel consumption (M3)	Equivalent amount of gasoline (liter)	Total CO_2 (ton) for NGV	Equivalent CO_2 Emissions (ton) from gasoline	CO_2 Emissions Reduction (ton) scenario 4	Economic Saving (Million EGP)
2022	4.85E+6	1.51E+10	1.66E+10	3.18E+07	4.01E+07	8.27E+06	7.70E+4
2023	5.00E+6	1.56E+10	1.71E+10	3.28E+07	4.13E+07	8.52E+06	7.94E+4
2024	5.15E+6	1.60E+10	1.76E+10	3.38E+07	4.26E+07	8.78E+06	8.18E+4
2025	5.30E+6	1.65E+10	1.81E+10	3.48E+07	4.39E+07	9.04E+06	8.42E+4
2026	5.45E+6	1.70E+10	1.87E+10	3.58E+07	4.51E+07	9.30E+06	8.67E+4
2027	5.60E+6	1.74E+10	1.92E+10	3.68E+07	4.64E+07	9.56E+06	8.91E+4
2028	5.76E+6	1.79E+10	1.97E+10	3.78E+07	4.76E+07	9.82E+06	9.15E+4
2029	5.91E+6	1.84E+10	2.02E+10	3.88E+07	4.89E+07	1.01E+07	9.39E+4
2030	6.06E+6	1.89E+10	2.07E+10	3.98E+07	5.01E+07	1.03E+07	9.63E+4
2031	6.21E+6	1.93E+10	2.13E+10	4.08E+07	5.14E+07	1.06E+07	9.87E+4
2032	6.36E+6	1.98E+10	2.18E+10	4.18E+07	5.26E+07	1.09E+07	1.01E+5
2033	6.51E+6	2.03E+10	2.23E+10	4.28E+07	5.39E+07	1.11E+07	1.04E+5
2034	6.67E+6	2.07E+10	2.28E+10	4.38E+07	5.51E+07	1.14E+07	1.06E+5
2035	6.82E+6	2.12E+10	2.33E+10	4.48E+07	5.64E+07	1.16E+07	1.08E+5

plan is aiming to rise the country's CNG fuelling stations to 1000 stations, and total NGV to about 1 million.

Introduction of alternative fuels for the transport sector has become an integral part of the energy policy of many countries to achieve their climate and environmental agendas. Natural gas vehicles (NGV) as alternative fuel vehicles have received continuous attention owing to natural gas is considered A bridge to a Low-Carbon Future (Ermakov et al. 2022), so environment friendly properties of CNG fuel such as negligible sulfur and nitrogen content, thus burns cleaner. As the highest H/C ratio, almost 4:1, of CNG fuel (which is mainly composed of methane –CH4) in comparison with any other hydrocarbons (HCs) as 2.3:1 for gasoline and 1.95:1 for diesel fuel (Khan et al. 2015). So, the smallest amount of CO_2 can be produced from CNG fuel combustion in comparison with the combustion of other liquid fuels (Usman et al. 2021). Furthermore, usually Well-to-Wheel (WTW) CO_2 emissions are mainly 20% higher than Pump-to-Wheel (PTW) CO_2 emissions (Huo et al. 2007).

Egypt did not reach yet to self-sufficient of liquid fuels (gasoline, diesel) according to CAPMAS (CAPMAS

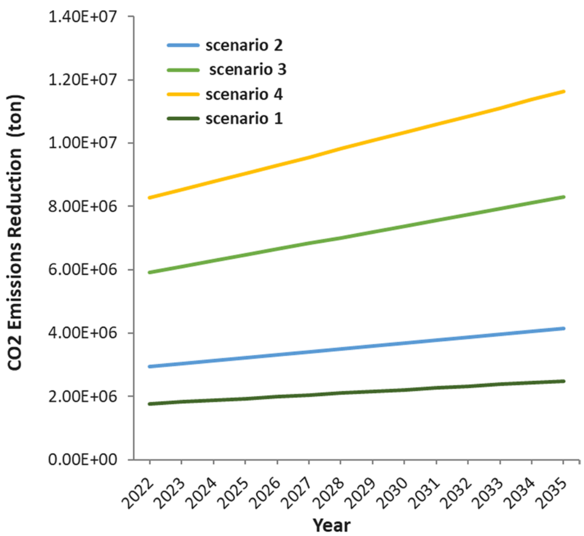

Fig. 10 CO_2 emissions reduction for modeling scenarios

Table 12 Economic saving from scenario 1

Year	15% NGV	CNG Fuel consumption (M^3) Unit price 1 M^3 = 3.56 EGP	Equivalent amount of gasoline (liter) Unit price 1 L = 7.88 EGP	Economic Saving (Million EGP)
2022	1.04E+6	3.23E+09	3.55E+09	1.65E+4
2023	1.07E+6	3.33E+09	3.67E+09	1.70E+4
2024	1.10E+6	3.43E+09	3.78E+09	1.75E+4
2025	1.14E+6	3.53E+09	3.89E+09	1.81E+4
2026	1.17E+6	3.64E+09	4.00E+09	1.86E+4
2027	1.20E+6	3.74E+09	4.11E+09	1.91E+4
2028	1.23E+6	3.84E+09	4.22E+09	1.96E+4
2029	1.27E+6	3.94E+09	4.33E+09	2.01E+4
2030	1.30E+6	4.04E+09	4.44E+09	2.06E+4
2031	1.33E+6	4.14E+09	4.55E+09	2.12E+4
2032	1.36E+6	4.24E+9	4.67E+09	2.17E+4
2033	1.40E+6	4.34E+09	4.78E+09	2.22E+4
2034	1.43E+6	4.44E+09	4.89E+09	2.27E+4
2035	1.46E+6	4.54E+09	5.00E+09	2.32E+4

2021) and imports petroleum products to sufficient local demand. Unlike the other fuels, Egypt reaches to self-sufficient in natural gas, and CNG is transported using a national pipeline grid that is highly developed in Egyptian, Fig. 12, which is much-expanded inside and outside the country. While Liquid fuels are mainly transported internally by road trucking whereas as per EGPC FY 2020/2021 report about 20 million tons of liquid fuels (Gasoline and Diesel) were transported by trucks to liquid fuel stations. This makes the CNG supply chain easier and more efficient than that of liquid fuels.

Table 13 Economic saving from scenario 2

Year	25% NGV	CNG Fuel consumption (M^3) Unit price 1 M^3 = 3.56 EGP	Equivalent amount of gasoline (liter) Unit price 1 L = 7.88 EGP	Economic saving (Million EGP)
2022	1.73E+6	5.39E+09	5.92E+09	2.75E+4
2023	1.79E+6	5.55E+09	6.11E+09	2.84E+4
2024	1.84E+6	5.72E+09	6.29E+09	2.92E+4
2025	1.89E+6	5.89E+09	6.48E+09	3.01E+4
2026	1.95E+6	6.06E+09	6.66E+09	3.09E+4
2027	2.00E+6	6.23E+09	6.85E+09	3.18E+4
2028	2.06E+6	6.40E+09	7.04E+09	3.27E+4
2029	2.11E+6	6.56E+09	7.22E+09	3.35E+4
2030	2.16E+6	6.73E+09	7.41E+09	3.44E+4
2031	2.22E+6	6.90E+09	7.59E+09	3.53E+4
2032	2.27E+6	7.07E+09	7.78E+09	3.61E+4
2033	2.33E+6	7.24E+09	7.96E+09	3.70E+4
2034	2.38E+6	7.41E+09	8.15E+09	3.78E+4
2035	2.43E+6	7.57E+09	8.33E+09	3.87E+4

Table 14 Economic saving from scenario 3

Year	50% NGV	CNG fuel consumption (M3)	CNG Fuel consumption (M^3) Unit price 1 M^3 = 3.56 EGP	Equivalent amount of gasoline (liter) Unit price 1 L = 7.88 EGP
2022	3.46E+6	1.08E+10	1.18E+10	5.50E+4
2023	3.57E+6	1.11E+10	1.22E+10	5.67E+4
2024	3.68E+6	1.14E+10	1.26E+10	5.85E+4
2025	3.79E+6	1.18E+10	1.30E+10	6.02E+4
2026	3.90E+6	1.21E+10	1.33E+10	6.19E+4
2027	4.00E+6	1.25E+10	1.37E+10	6.36E+4
2028	4.11E+6	1.28E+10	1.41E+10	6.53E+4
2029	4.22E+6	1.31E+10	1.44E+10	6.71E+4
2030	4.33E+6	1.35E+10	1.48E+10	6.88E+4
2031	4.44E+6	1.38E+10	1.52E+10	7.05E+4
2032	4.54E+6	1.41E+10	1.56E+10	7.22E+4
2033	4.65E+6	1.45E+10	1.59E+10	7.39E+4
2034	4.76E+6	1.48E+10	1.63E+10	7.57E+4
2035	4.87E+6	1.51E+10	1.67E+10	7.74E+4

For modeling and forecasting vehicle population in Egypt, Partial least squares regression model (PLS) is proposed and among the most popular data-driven soft-sensor development methods for soft modeling in industrial applications. It is commonly used modeling technique due to its transparent inherent structure and feature extraction ability which has proven to be a very versatile method for multivariate data analysis and a supervised method specifically established to address

Table 15 Economic saving from scenario 4

Year	70% NGV	CNG Fuel consumption (M^3) Unit price 1 M^3 = 3.56 EGP	Equivalent amount of gasoline (liter) Unit price 1 L = 7.88 EGP	Economic saving (Million EGP)
2022	4.85E+6	1.51E+10	1.66E+10	7.70E+4
2023	5.00E+6	1.56E+10	1.71E+10	7.94E+4
2024	5.15E+6	1.60E+10	1.76E+10	8.18E+4
2025	5.30E+6	1.65E+10	1.81E+10	8.42E+4
2026	5.45E+6	1.70E+10	1.87E+10	8.67E+4
2027	5.60E+6	1.74E+10	1.92E+10	8.91E+4
2028	5.76E+6	1.79E+10	1.97E+10	9.15E+4
2029	5.91E+6	1.84E+10	2.02E+10	9.39E+4
2030	6.06E+6	1.89E+10	2.07E+10	9.63E+4
2031	6.21E+6	1.93E+10	2.13E+10	9.87E+4
2032	6.36E+6	1.98E+10	2.18E+10	1.01E+5
2033	6.51E+6	2.03E+10	2.23E+10	1.04E+5
2034	6.67E+6	2.07E+10	2.28E+10	1.06E+5
2035	6.82E+6	2.12E+10	2.33E+10	1.08E+5

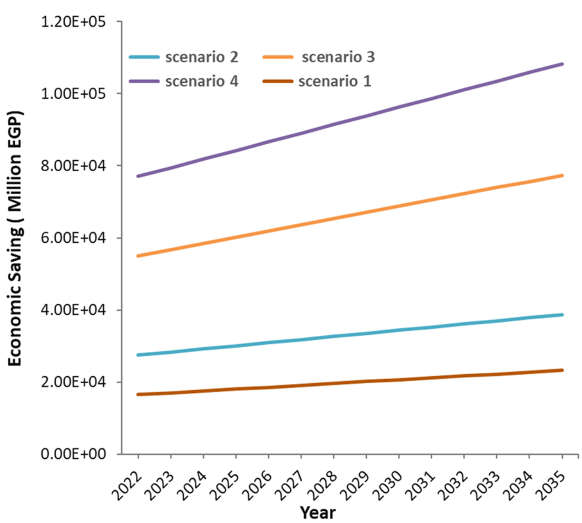

Fig. 11 Economic saving for modeling Scenarios

the problem of making good predictions in multi-variate problems (Chen et al. 2020; Jiang et al. 2019). The Pearson correlation method is used as the most common method for numerical variables (Armstrong 2019). The root mean square error (RMSE) and mean absolute error (MAE) are used as estimators (Dulakshi 2022) to evaluate regression model fit and indicate the absolute fit of the model to the data—how close the actual data points are to the model's predicted values. For projected data, the motor vehicles per 1000 population raised and ranges from 67 to 77 but still lower than more developed countries (World_Population_data_Sheet 2008).

By comparing different assumed scenarios against national determined contributions, it is demonstrated that Scenario 1 can achieve about 18 megatons CO_2 emissions reduction by the year 2030 which is representing more than double of Egypt`s mitigation target by 2030 for transport sector as introduced in Egypt's first updated nationally determined contributions under UNFCCC (NDC 2022) as shown in Fig. 13.

Conclusions

From the study, it is concluded that:

- The presidential initiative launched on Jan 2021 to accelerate NGV growth achieved in its first year of implementation about emissions reduction by 478 kton CO_2 and economic saving by about 4.45 billion EGP on the basis of average of 2021 CNG and 92-octane gasoline fuel retail prices.
- A significant difference in CO_2 emissions pattern in case of no action scenario (100% gasoline powered vehicles) and full conversion scenario (100% CNG powered vehicles) which represent about 21% percent of CO_2 emissions (about 200 Mt) can be reduced from projected vehicles growth in Egypt if all of them are converted to NGVs.
- By analysis of different assumed scenarios, it is observed that scenario no. 1, of adopting NGV percent 15%, is the most fitted business as usual scenario to the Egyptian presidential initiative, which is targeting total NGVs to reach 1 million by end of 2023, that will lead to emissions reduction by about 30 Mt CO_2 and economic saving by about 278 billion EGP (US$17.6 billion). In addition, Scenario 1 can also achieve about 18 megatons CO_2 emissions reduction by the year 2030 which is representing more than double of Egypt's mitigation target by 2030 for transport sector as introduced in Egypt's first updated nationally determined contributions under UNFCCC.
- While if Egypt adopting other scenarios 2, 3 and 4, it will lead to emissions reduction by 50, 100 and 140 Mt CO_2, respectively, and economic saving by 463 (US$ 29.4 billion), 927 (US$ 58.8 billion) and 1300 billion EGP (US$ 82.5 billion), respectively.
- The results obtained in this study show Natural Gas vehicles will help the country`s economy significantly and provide a way to reduce GHG emissions which would create a tremendous direct impact on the

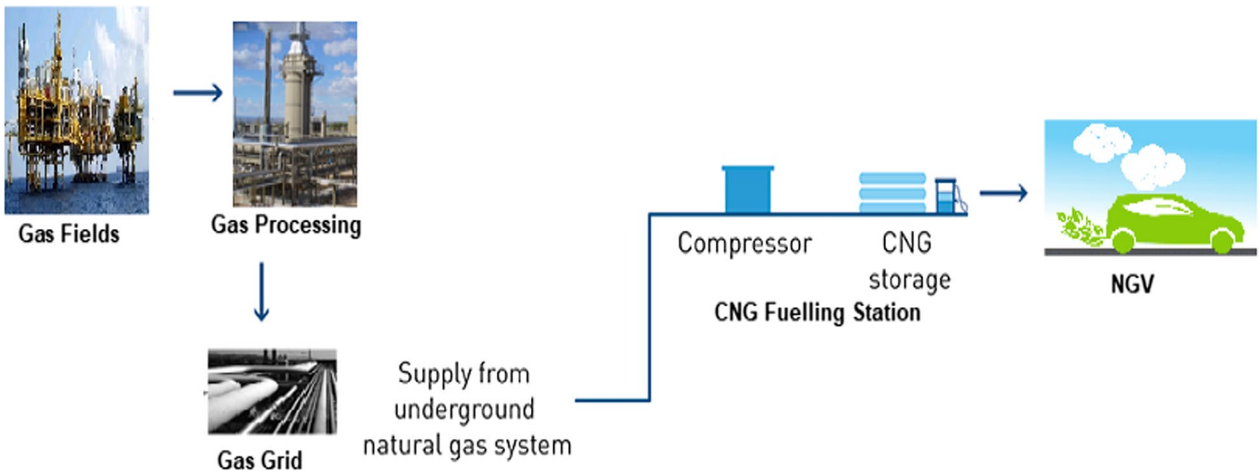

Fig. 12 CNG supply chain

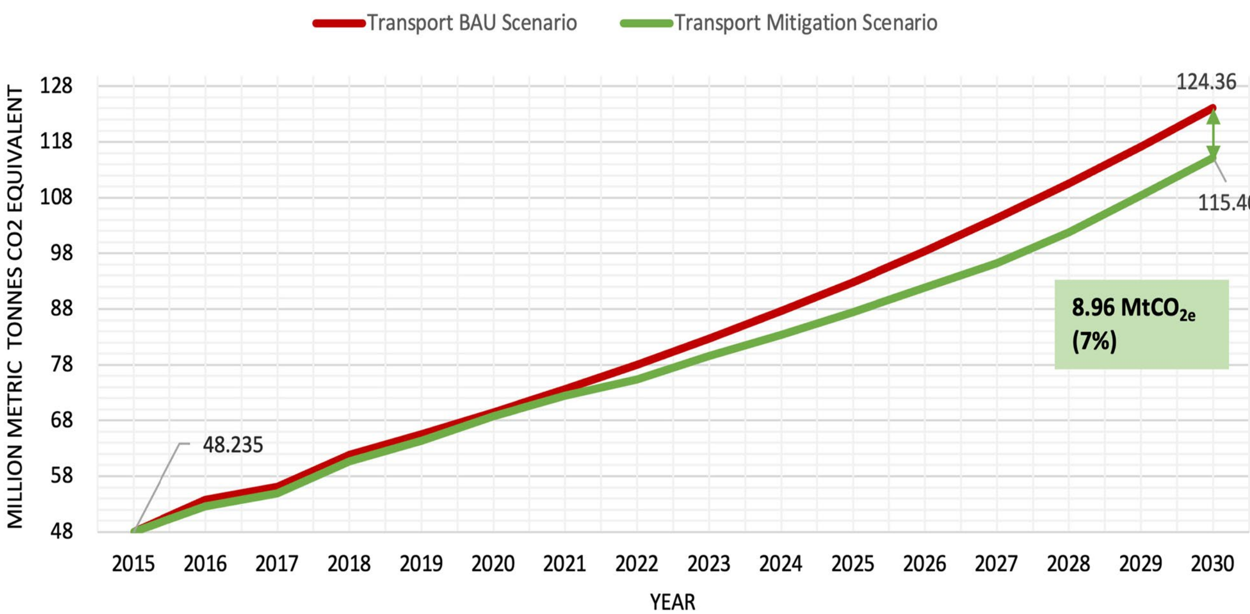

Fig. 13 Emissions mitigation target by 2030 for transport sector in Egypt

cleanliness of Egypt's air, since Egypt ranks in Africa as the third-largest natural gas producer on the continent following Algeria and Nigeria and having a well-developed distribution network of natural gas across the country. Moreover, gas-powered motors technology is a matured-technology and available for less developed countries other than more advanced high technology motors industry. This indication should be good enough for decision-makers to consider NGV projection scenarios and keeping package of financing and incentives measures such as the presidential initiative that launched in Jan 2021.

Abbreviations

AdapTM Climate change management through adaptation and mitigation
Bcf Billion standard cubic feet
Bcm Billion cubic meter
CNG Compressed natural gas
COP Conference of the parties
CAPMAS Egypt's Central Agency for Public Mobilization and Statistics
EEAA Egyptian Environmental Affairs Agency
EGAS The Egyptian Natural Gas Holding Company
EGPC Egyptian General Petroleum Corporation
EGP Egyptian pound
FY Fiscal year
Gt Gigatonnes (1000 Megatonnes)
GHGs Greenhouse gases
Kt Kiloton (1000 ton)
HCs Hydrocarbons

IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquified natural gas
LPG	Liquified petroleum gas
M^3	Cubic meter
Mcm	Million cubic meter
Mt	Megatonnes (10^6 tonnes)
MMBTU	Million British thermal unit
MAE	Mean absolute error
NG	Natural gas
NGV	Natural gas vehicle
OECD	Organization of Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PLS	Partial least square
PTW	Pump to wheel
PM	Particulate matter
RMSE	Root mean square error
SDGs	Sustainable development goals
scf	Standard cubic feet
UNFCCC	United Nations Framework Convention on Climate Change
WTW	Well to wheel

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Author contributions
SI initially suggested the idea of the research article, searching in literature, conceived and designed the study, collecting the data, performed calculation and the analysis of GHG reductions and Economic saving, major contribution in results and discussion interpretation, wrote the research article and responded to reviewers' comments and recommendations. KA participated in developing the idea of the research article, participated in calculation and performed the analysis of GHG reductions and Economic saving, develop numerical forecasting modeling, participated in conceived and designed the study, analysis and interpretation of forecasting data, revise drafted work as it is critically for important intellectual content, and approved the version to be published and response to reviewers' comments about model validation. AR collecting data about Natural gas vehicles and CNG, participated in analysis of natural gas vehicles growth in Egypt, participating in calculation and performed the analysis of GHG reductions and Economic saving from natural gas vehicles and participated in conceived and designed the study. TT participated in conceived and designed the study, participating in developing and acknowledge the idea of the research article as Dr. Tarek, is a Coordinator of AdapTM Program, Faculty of Science- Suez Canal University, participating in interpretation of results scenarios and discussion and linked them with national determined contribution, participate in conclusion and recommendation, revise drafted work as it is critically for important intellectual content, and approved the version to be published. All authors read and approved the final manuscript.

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Availability of data and materials
The data of The Egyptian NGV program that support the findings of this study are available from [EGAS] but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are, however, available from the authors upon reasonable request and with permission of [EGAS].

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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