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REVIEW ARTICLE

Reviewing the growth of the natural gas vehicle fleet in Egypt: A study of environmentally friendly transportation fuel

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Abstract

The United Nations considers that it is a defining moment in confronting climate change, recognizing it as a global issue of our time that has significant impacts not only on the environment but also on human beings. These impacts manifest in extreme weather events, such as the short-lived yet increasingly intense and frequent hurricanes, heat waves, freezes, and tropical storms. It is strongly attributed to human activities. Liquid fuel-powered vehicles are known as one of the main anthropogenic sources of greenhouse gas emissions (GHGs). In Egypt, road transport is considered the largest greenhouse gas contributor in the transport sector. So, Egypt is adopting natural gas vehicles as an environmentally cleaner option, as natural gas fuel is a low-carbon alternative to liquid fuel (gasoline or diesel). This study analyses the fleet growth of natural gas vehicles in Egypt, which is extending for 25 years.

Keywords: Alternative fuels, Climate change, Compressed natural gas, Greenhouse gases, Natural gas vehicles, Road transportation

1. Introduction

Climate change and the transportation sector are interlinked[1] from the perspective of transportation's fossil fuel burning, which contributes to global warming. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,[2] the transport sector alone releases about a quarter of global carbon dioxide (CO_2) emissions from fossil fuel.

As the continual tightening of environmental regulations worldwide and the speedy growth of global motor transport align with the rapid rise in fuel prices, decision-makers are expressing great concern for more efficient vehicle technologies and affording low-carbon fuel transportation and its infrastructure, in addition to robust public transportation means to reduce private vehicle demand, among other travel demand measures.

1.1. Climate change issue

The UN has warned that the rapid escalation of climate change has set off a sonic boom alarm across the world outpacing our efforts to address it,[3] and this statement shall end the political debate about the role of anthropogenic activities in climate change. The IPCC[4] defines climate change 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).'

Greenhouse gas emissions (GHGs) are the main factor responsible for this shift in climate patterns, as they cause heat to be trapped by the earth's

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atmosphere. According to the Kyoto Protocol[5,6] GHGs include methane (CH_4), CO_2, nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), in addition to nitrogen trifluoride (NF_3), which was added recently in the second compliance during the Doha Amendment. These GHGs can also be attributed to natural systems such as forest fires, earthquakes, oceans, permafrost, wetlands, and volcanoes,[7–10] and human activities mainly those related to energy production, industrial activities and forestry, land use, and land-use change.[11–13]

It is observed that the global average temperature has risen by 1.1 °C above the preindustrial era because of several decades of GHG emissions. This led governments in 2015 to adopt the Paris Agreement, at the 21st UN Climate Change Conference of the Parties (COP 21), to hold the global average temperature increase to 'well below 2 °C' and, if possible, 1.5 °C,[14] which is considered a landmark agreement in the multilateral climate change process because, for the first time, a legally binding agreement brings all parties under a common goal to undertake ambitious efforts to tackle climate change and adapt to its impacts. So, the IPCC issued a special report in 2018 to emphasize the Paris Agreement limits and consequences of global warming above the 1.5 °C limit and related global GHG pathways.[15]

1.2. Climate change framework in Egypt

On the occasion of Egypt hosting COP 27, which was held in Sharm El-Sheikh from November 6–18, 2022, Egypt seized the opportunity to improve the country's environmental credentials by accelerating well-designed initiatives, and speeding up the low-carbon economy transition, and carrying out considerable efforts on all levels, either national, regional, or international as summarized below.

1.2.1. National level

In 1982, Egypt established the Egyptian Environmental Affairs Agency (EEAA) as its first institutionalized effort to address climate change and environmental issues generally, and later it became the Ministry of State for Environmental Affairs in 1997.[16]

In 2011, Egypt issued its first national adaptation strategy, which assessed the risks attributed to climate change that the country would face as well as plans of how to adapt to those risks. The Climate Change Policy Framework has evolved from this strategy as an instrument tool to improve the country's capacity to manage risks and disasters attributed to climate change and is regularly updated to integrate new scientific information and ongoing research findings.

Moving to 2015, Egypt has issued Prime Minister's Decree Number 1912 for 2015 to establish the National Council for Climate Change as a key decision body to coordinate and integrate efforts across ministries to deal with climate change and its impacts. This council was chaired first by the Ministry of Environment. After that, in 2019, the Council was restructured according to Prime Minister's Decree Number 1129 for 2019 and it is chaired by the Prime Minister to strengthen and centralize policymaking efforts related to climate change. Currently, Egypt is updating its strategy for low-emission development and is working on developing its long-term strategy on climate change until 2050.

1.2.2. Regional level

Egypt plays a pivotal role in Africa and takes advanced steps in the climate change institutional framework. So, in the Paris negotiations during COP21 from 2015 to 2016, Egypt led the African delegation in negotiations before and after the COP. Egypt could integrate the African countries' thoughts and build a common consensus on several principles, including as a priority, facing the climate change threats and adaption to its risks; agreement on the principle of 'common but differentiated responsibility' (CBDR) for sharing in the international efforts for GHG emission reduction, and such reduction efforts shall be coherent with national circumstance scale; to achieve ambitions of sustainable development it requires affording the essential funding, implementation of the international mechanisms outlined in Article 4 of United Nation Framework Convention on Climate Change (UNFCCC) and Article 9 of the Paris Agreement for the building of national capacity and technology transfer. Moreover, in 2015, Egypt headed two important initiatives to support the African region in mitigating the adverse impact of climate change; the first initiative is the African Renewable Energy Initiative (AREI), and the second initiative is the African Adaptation Initiative (AAI).[17]

1.2.3. International level

Egypt signed the UNFCCC on June 9, 1992 as one of the first countries to participate in the cooperative international efforts aimed at combating climate change threats and then, on December 5, 1994, the parliament ratified the convention. In 1999, Egypt signed the Kyoto Protocol and later on April 12, 2005, it entered into force. Moreover, on April 22, 2016, Egypt signed the Paris Agreement at the United Nations General Conference in New York

and ratified Paris Agreement on June 29, 2017. After the ratification of the Paris Agreement, Egypt's Intended Nationally Determined Contribution (INDC) which was submitted to UNFCC in November 2015 to achieve the global targets set out Paris Agreement was considered Egypt's first National Determined Contributions (NDCs).

Egypt's first, second, and third national communications have been submitted to the UNFCCC in 1999, 2010, and 2016, respectively.[18] Moreover, on December 20, 2019, Egypt's first Biennial Update Report (BUR) was submitted to UNFCCC.[19] The timeline of these reports shows how Egypt's cumulative efforts of mitigation, adaptation, and the envisaged plans to achieve its commitments under the UNFCCC.

Recently in July 2022, Egypt submitted a report on its updated NDC document to the UNFCCC secretariat, featuring its commitments to mitigate climate impacts as per the Paris Agreement.[20] The step was part of Egypt's preparations for hosting the 27th session of the COP27 to the UNFCCC in November 2022 in Sharm El-Sheikh.

1.3. The linkage between transportation and climate change

The transportation sector is one of the most significant sources of anthropogenic greenhouse gas emissions. To mitigate climate change, it is important to apply effective and immediate policies to reduce the transportation sector's emissions. A huge amount of these gases is generated by vehicles using the foretold liquid fuels.[21] According to IPCC, in 2019 GHG emissions that have directly resulted from the transportation sector were 8.7 Gt CO_2-eq (up from 5.0 Gt CO_2-eq in 1990) and it accounted for 23% of global energy-related CO_2 emissions and 70% of these emissions came from road vehicles.[22]

In 2020, IEA World Energy Outlook emerged that the transportation sector is the most reliant sector on fossil fuel of any sector and it accounts for 37% of CO_2 emissions from end-use sectors (7.1 Gt).[23]

Egypt is the largest Arab country, with more than 100 million people, which makes it the second most populous country in Africa. Egypt's transportation sector is mainly characterized by its reliance on road transportation for both passengers and freight.[19] In Egypt, the transportation sector is a main consumer of fossil fuels and therefore contributes a significant share of greenhouse gases (GHGs). CO_2 emissions from the transportation sector represent the most common GHG from mobile sources, and its share ranges between 25 and 30% of the country's total GHG emissions.[24]

In 2020, Egypt emitted 269 megatons (Mt) of CO_2, with a share of 0.73% of global emissions and 2.5 tons of CO_2 emissions per capita. And transportation sector represented about 24% of all CO_2 country emissions as shown in Fig. 1.[25] So, the level of transportation sector carbon emissions and its climate change impacts are placed worldwide and on the country level at the top of the research agenda for governments and decision-makers.

2. Natural gas as vehicle fuel

As natural gas (NG) is the cleanest and most dependable fossil fuel, numerous studies have considered NG as bridging transition fuel between fossil fuel and net zero fuel emission scenario.[26–29] And it has been proposed as a way of low-carbon policies to mitigate risks of energy security and climate change.[30,31]

NG can be used as vehicle fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG), but CNG is winning more attention and investment in the automobile industry as an alternative fuel to liquid fossil fuel products (gasoline, diesel), due to the lower cost of CNG production and storage compared with LNG as it requires an expensive cooling process and cryogenic tanks.[32] In CNG, natural gas is compressed at a pressure of 200 bar to a volume of less than 1% of its volume occupied at standard atmospheric pressure and is usually stored in a rigid safe cylindrical metallic cylinder. As shown in Table 1, the physiochemical properties comparison between the CNG gasoline and diesel[33,34] represents that CNG is the lightest weight as it has the lowest density fuel compared with that of liquid fuel. So, CNG is giving a better air/fuel (A/F) homogeneous mixture ratio of 17.2:1 than that of gasoline and diesel which are giving A/F ratio as 14.7:1 and 14.6:1, respectively. In addition, CNG has lower molar mass (17.3 g/mol) than that of gasoline (109 g/mol) and of diesel (204 g/mol). Also, CNG has a higher lower heating value (47.5 MJ/kg), about 10%, more than that of gasoline (43.5 MJ/kg).

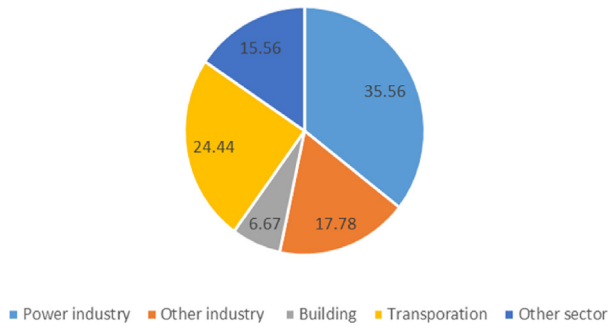


Fig. 1. Fossil CO_2 emissions by sector, Egypt 2020.[25]

Table 1. Physiochemical properties comparison for compressed natural gas gasoline and diesel.

Properties	CNG	Gasoline	Diesel
Octane/cetane number	120–130	85–95	45–55
Molar mass (kg/mol)	17.3	109	204
Stoichiometric $(A/F)_s$ mass	17.2	14.7	14.6
Stoichiometric mixture density (kg/m^3)	1.25	1.42	1.46
Lower heating value (LHV) (MJ/kg)	47.5	43.5	42.7
LHV of 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
Autoignition temp. (°C)	540	258	316
Wobbe index (MJ/m^3)	51–58	–	–

The first CNG vehicular fuel was first introduced in Italy in the 1930s[35] as natural gas inter-urban with 40 seats on FIAT chassis 635 RL of 1936.[36]

For decades, natural gas vehicles (NGVs) were not very popular until their fleet began to grow particularly following the energy crisis of the 1970s. Governments in both developed and developing nations have promoted NGVs as a cleaner substitute for liquid fuel vehicles, which show a large potential for the reduction of emissions and particulates.[37] NGVs initially became available in the United States in 1969, primarily as conversion kits from small natural gas utilities, on a modest scale. Ford began manufacturing its own Original Equipment Manufacturer (OEM) Natural Gas Vehicles later in the 1980s. In the early 1990s, NGVs market share increased dramatically owing to the Energy Policy Act (EPACT) of 1992. Since NGVs' government light-duty vehicle fleets are the main users of NGVs, t as a result of.[35,38] In Latin America, primarily Brazil and Argentina, represent most of NGV population fleet in the region as result of the governments adopting strong promotions to accelerate the replacement of liquid fuel by natural gas aiming to increase energy self-sufficiency and reduce urban air pollution, which has sparked rapid increase in the use of NGVs. In Asia, there has been notable and significant NGV growth especially for China, Iran, India, and Pakistan beginning in the late 1990s, and Asian countries currently represents about more than 70% of the total NGVs worldwide, with these four countries accounting for the highest number of NGVs.[35] In Europe, the 'European Natural Gas Vehicle Association (ENGVA) was established in 1994 (which working under the current title 'Natural Gas Vehicle Association Europe, NGVA, since 2008) It is a partnership consisting of environmental organizations, natural gas utilities, manufacturers of NGV vehicles and equipment, and people from 17 different countries coordinate pilot programs, international codes and standards, and equipment and fuel industry activity.[39]

In Africa, Egypt is the market leader of NGV and represent about more than 90% of Africa's NGVs, according to the information available at the International Association for Natural Gas Vehicles.[40] The regional NGVs growth in 2019 is shown in Fig. 2 with about more than 28 million NGVs in the world.[40]

As shown in Fig. 3, the global statistics for NGVs indicate that the number of NGV grew by 8.2% from 2017 to 2018 and by 6.1% for 2019. Although the upward trend may slow down because of the coronavirus disease (COVID) pandemic and its economic impact, it is anticipated the NGV count will surpass 30 million before the end of 2021.[41]

3. Natural gas reserve

3.1. World reserve

The world NG reserves were estimated at 6641.8 trillion cubic feet as shown in Table 2. The Russian Federation reserves are largest in the world, nearly 20% of proven gas reserves. Nearly half of the world's natural gas reserves are found in Qatar,

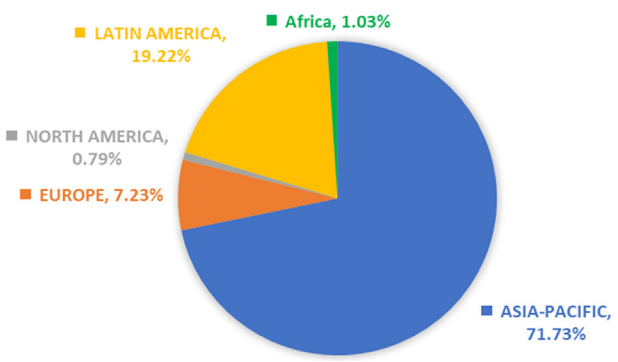


Fig. 2. Natural gas vehicles growth by region in 2019.

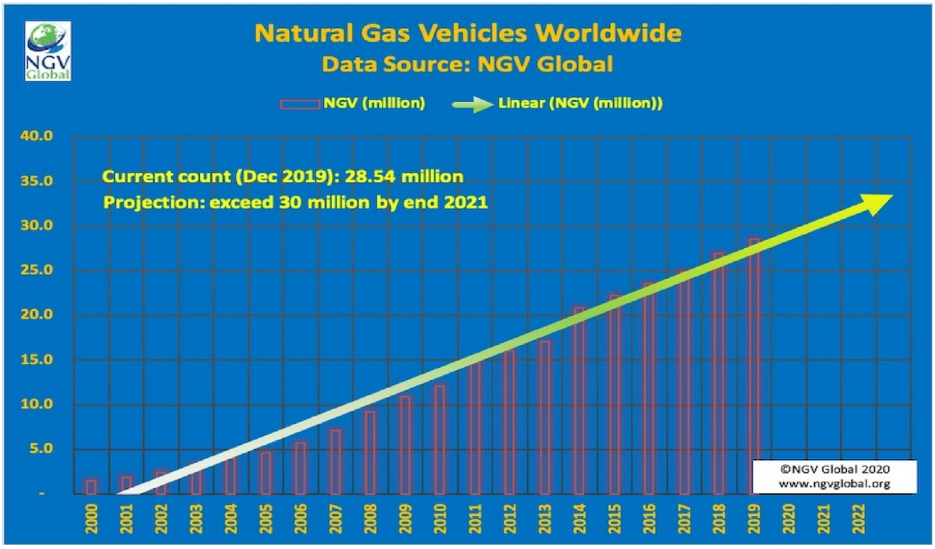


Fig. 3. Worldwide natural gas vehicle's growth from 2000 to 2019.

Iran, and Russia combined. However, natural gas reserves are rather evenly distributed to the rest of the world on a regional basis.

While natural gas consumption has increased at rapid rates, especially in the last 10 years, most regional ratios of the 'reserves-to-production' (R/P) have continued to rise, and this ratio is influential in projecting national or global availability of natural gas. Worldwide, the R/P ratio is estimated to be 48.8 years.[42] The Commonwealth of Independent States (CIS) has a reserves-to-production ratio of 70.5 years, and Africa has 55.7 years, whereas the European Union has 9.2 years, while the ratio of reserves to production in the Middle East is more than 110 years.

Natural gas consumption is the fastest growing component of world primary energy demand. Consumption of natural gas worldwide increases at an average rate of 2.9% annually from 2009 to 2019 compared with annual growth rates of 1.5% for oil consumption and 0.9% for coal consumption. However, energy demand decline in 2020 due to COVID lockdown, natural gas is still the lowest fuel consumption decline by −2.3% compared with a

Table 2. World reserves of natural gas by country as per Jan. 1, 2021[42].

Country	Reserves Trillion cubic meters	Reserves Trillion cubic feet (Tcf)	Share of total	R/P ratio
Total World	188.1	6641.8	100.0%	48.8
Russian Federation	37.4	1320.5	19.9%	58.6
Iran	32.1	1133.6	17.1%	128.0
Qatar	24.7	871.1	13.1%	144.0
Turkmenistan	13.6	480.3	7.2%	230.7
United States	12.6	445.6	6.7%	13.8
China	8.4	296.6	4.5%	43.3
Venezuela	6.3	221.1	3.3%	333.9
Saudi Arabia	6.0	212.6	3.2%	53.7
United Arab Emirates	5.9	209.7	3.2%	107.1
Nigeria	5.5	193.3	2.9%	110.7
Iraq	3.5	124.6	1.9%	336.3
Azerbaijan	2.5	88.4	1.3%	96.9
Australia	2.4	84.4	1.3%	16.8
Canada	2.4	83.1	1.3%	14.2
Algeria	2.3	80.5	1.2%	28.0
Kazakhstan	2.3	79.7	1.2%	71.2
Egypt	2.1	75.5	1.1%	36.6
Kuwait	1.7	59.9	0.9%	113.2
Libya	1.4	50.5	0.8%	107.4
Norway	1.4	50.5	0.8%	12.8

decline rate of −9.2% for oil consumption and −4.2% for coal consumption.[42]

Natural gas demand increases in all scenarios presented in the world energy outlook 2021 over the next five years as shown in Fig. 4.

[23]However, there are subsequent severe divergences. Every scenario shows a decline in demand in advanced economies starting in the middle of the 2020s, but the 'Announced Pledges Scenario' (APS) demonstrates this decline more quickly than the 'Stated Policies Scenario' (STEPS), and as observed, the decline is the fastest in the 'Net Zero Emissions by 2050 Scenario' (NZE). As 'APS' anticipates, every government will fulfil all of its climate-related obligations on schedule. While 'STEPS' investigates where the energy system might go in the absence of new policy implementation, it does not assume that governments will achieve all stated goals.

Moving through 2050, emerging markets and developing economies will significantly demonstrate natural gas's demand expansion above current levels in the APS and STEPS, while it will remain contained in the NZE. Natural gas's percentage of the world's energy mix stays at approximately 25% in the STEPS until 2050, but it drops to 20% in the APS and 11% in the NZE. By 2050, 'NZE' shows that about 70% of used natural gas will be equipped with carbon capture, storage, and utilization (CCSU).

Natural gas was initially viewed as a by-product of crude oil production, natural gas's environmental credentials and cost-effectiveness relative to other fossil fuels were major drivers of natural gas demand growth. To combat the threat of global warming, CO_2 emissions into the atmosphere are to be decreased. Natural gas emits lower CO_2 and other harmful gases and particles (such as nitrogen and sulfur compounds) into the atmosphere. Gas-fired electricity generation will take the place of coal- and oil-powered plants in the Middle East and Asia, respectively. North America's natural gas consumption will likewise keep rising. Global apprehensions regarding the safety and dependability of nuclear power are a contributing factor to the rise of gas-fired generation.[43]

3.2. Natural gas in Egypt

Egypt is the largest oil producer in Africa outside of the Organization of the Petroleum Exporting Countries (OPEC) and the third largest natural gas producer on the continent following Algeria and Nigeria. So, the Egyptian government, cognizant of the potential opportunities associated with natural gas value chain which becomes an essential pillar of energy supply in the Egyptian economy.

The first natural gas field to be discovered in Egypt was found in 1967 by 'Belayiem Petroleum Company' (PETROBEL) in Abu Madi concession, in the Nile Delta. This was followed in 1969 by the discovery of the Abu Qir offshore gas field in the Mediterranean Sea, which was Egypt's first offshore gas field, and in 1971 by the discovery of the Abu El-Gharadig gas field in the western desert.

The Nile Delta accounts for 19% of Egypt's natural gas production, followed by the western desert (18%). The majority of Egypt's natural gas (about 62%) is coming from Mediterranean Sea concession areas. The country's most significant operating companies are mainly PETROBEL, Khalda, Pharaonic Petroleum Company (PhPCo), Badr El Din Petroleum Company (BAPETCo), and Burullus. Egypt's natural gas market is attracting many

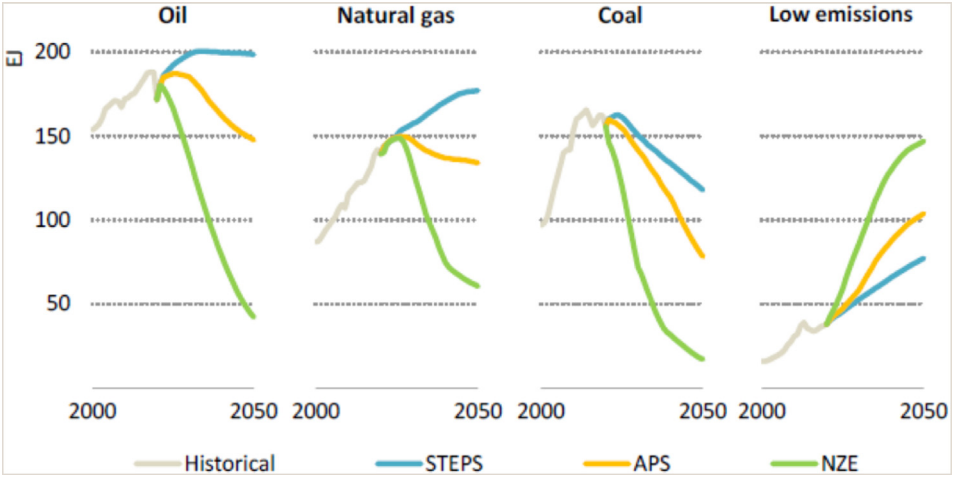


Fig. 4. Demand for oil, natural gas, coal, and low emissions fuel up to 2050.

international partners such as ENI, APACHE, BP, SHELL and Wintershall Dea.

In response to the local market demand, a number of natural gas discoveries have been made recently. These include the discoveries of Nooros in the Nile Delta, North Alex and West Nile Delta in the Mediterranean Sea, and the booming discovery in Zohr field, which is thought to be the largest natural gas discovery in the Mediterranean Sea and among the largest discoveries globally.

As a result of a boom in natural gas production and exploration the discovery of the giant offshore Zohr gas field in 2015 spurred them to act. Egypt became self-sufficient in natural gas in late 2018. By producing 66.1 bcm in FY 2018/2019, the consumption reached 61.8 bcm. According to the Petroleum and Mineral Ministry, Egypt's natural gas production capacity during the fiscal year (FY) 2020/2021 has reached 6.8 billion cubic feet per day (bcf/d) as a result of the efforts of new explorations and development of the natural decline of wells during the past 5 years.[44]

4. Egyptian vehicle population

As shown in Fig. 5 depicting Egypt's automobile fleet excluding 2 and 3-wheelers, the improving standard of living and credit facilities tend to encourage an expansion in Egypt's automobile fleet, with private cars accounting for ~71.4% of licenced vehicles according to the CAMPAS bulletin 2021 of licensed vehicles.[45]

The Egyptian vehicle population has substantially increased over the past 25 years, mainly since the beginning of the Egyptian NGV project in 1996, as shown in Fig. 6. However, the estimated level of

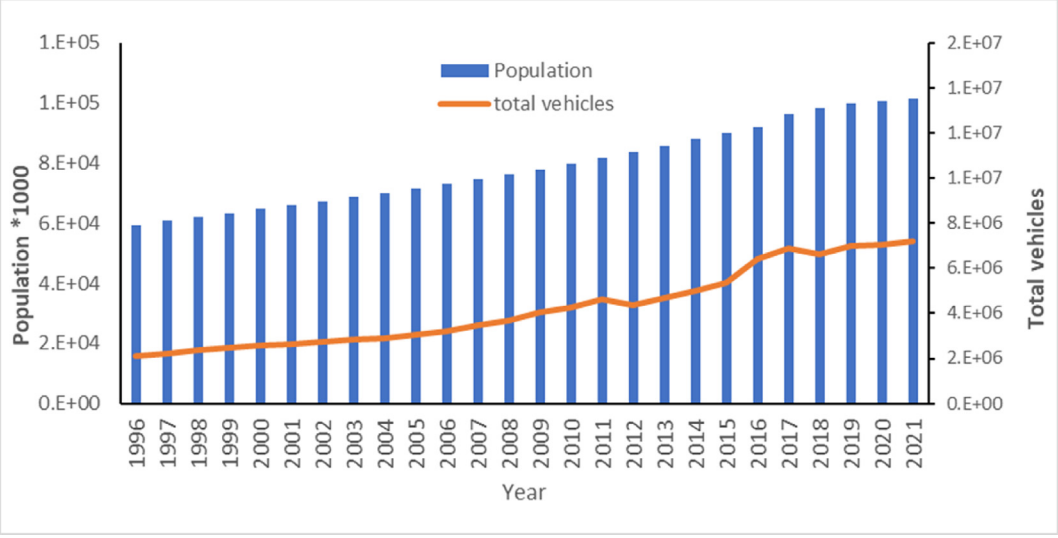


Fig. 5. The evolution of vehicle numbers.

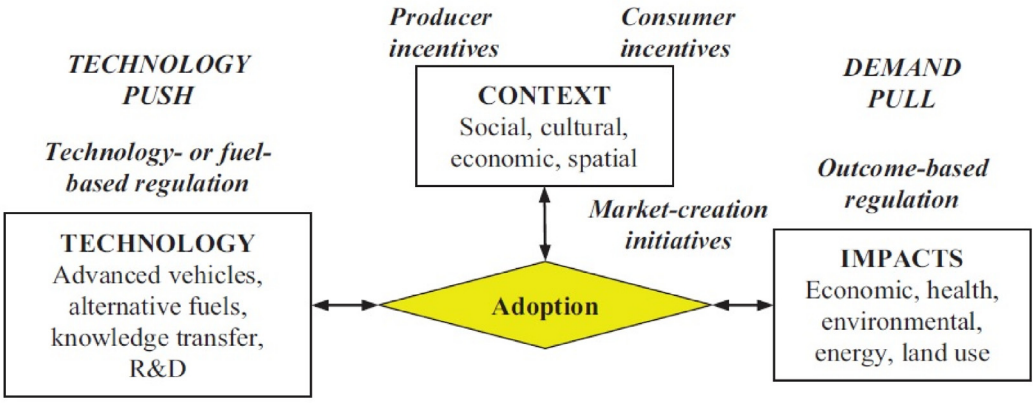


Fig. 6. The conceptual model for policy instrument tools encourages the adoption of cutting-edge transportation technologies, such as CNG fuel as an alternative fuel and natural gas vehicle as an alternative fuel vehicle.

motor vehicles is about 41 vehicles per 1000 population (excluding two and three wheelers) in the period 2000–2005. However, for the same time, the vehicles per 1000 people were 153 worldwide, 536 in more developed countries, and 43 in less developed countries.[46]

So, the growth of Egypt's fleet during the middle of 1990s and the beginning of 2000s was still lower than or about close to less developed countries.

The Egyptian vehicle population was exhibiting a continual increase and reached in 2019 a level of motor vehicles of about 69.3 vehicles per 1000 population, which exceeds Africa's level of 41.2, and is still lower than Asia, Middle East level of 159.4.[47] After that, Egypt's vehicle population remained slightly constant due to the outbreak of the COVID-19 pandemic, which has dramatically affected global economic activity. Then in 2021, the Egyptian vehicle population represented a significant increase in the level of motor vehicles which is about 71.19 vehicles per 1000 population, due to the starting recovery of global economic activity after the pandemic lockdown. The Egyptian automobile fleet age is being refreshed due to many factors contributing to this significant interest: income level growth rate, liberalization of the vehicle market, and Egyptian supporting programs and initiatives such as in 2009, Egypt launched the Old Vehicles Scrapping and Recycling Program (OVSRP) as a supportive tool to implement traffic law number 121, which states that 'mass transport vehicles aged more than 20 years old are not eligible for new operating licences or licence renewal.' In addition, in January 2021, Egypt launched its presidential initiative (https://www.gogreenmasr.com/) for accelerating the conversion of liquid fuel vehicles into natural gas vehicles and providing 'green incentives' to citizens who choose to replace their outdated liquid fuel vehicles with more sophisticated natural gas vehicles.

Historically, the first woman to obtain a driver's licence in Egypt was Abbasia Ahmed Farghali, an Arab woman who may have been the first in the developing world overall. She obtained her licence in France in July 24, 1920, and later obtained one in Egypt in 1928. These sociocultural factors define the Egyptian automobile fleet as having gender equality in the acquisition of a driver's licence under Egyptian traffic law.

5. Natural gas vehicles in Egypt

Egypt is regarded as the leader in the Middle East and Africa for NGVs, accounting for one of the top ten global rankings in terms of the converted vehicle market.

Egypt has been the focus of many successful story analyses for a number of years because of its well-planned NGV market development, which allowed it to overcome the famous 'chicken and egg' problem[48] by developing essential infrastructure for natural gas filling stations and conversion centers concurrently with an increase in the number of natural gas vehicles. The introduction of natural gas automobiles, first in Egypt, dates back to the early 1990s. This was a significant achievement of the Clean Air Initiative, which aimed to maximize the use of natural gas as a cleaner fuel in all economic sectors and applications, including vehicle fuel. The Petroleum Ministry launched two pilot projects in 1992 to officially embrace the use of natural gas as a vehicular fuel.

The first pilot project was embraced by GUPCO (BP Egypt, EGPC partnership) by converting 150 vehicles from their company vehicles fleet and establishing three CNG fueling stations to serve these transformed vehicles.

The second pilot project was embraced by PETROBEL (ENI and EGPC Partnership) by converting 30 mid-size buses from their company vehicles fleet and establishing two CNG fueling stations to serve these transformed vehicles. The main objective of these two pilot projects in their demonstration phase was:

(a) To prove that Egypt's natural gas functioned well as a vehicular fuel
(b) To demonstrate that the available technology of CNG fueling stations would reliably perform to support customers for using natural gas as vehicle fuel.

The success of the outcome of two pilot projects as a demonstration phase encouraged the Egyptian government to startcommercializing natural gas vehicles (NGVs) through the natural gas vehicle program.

By establishing the Natural Gas Vehicles Company (NGVC) in 1995, which later rebranded to 'CARGAS,' Egypt became the first country to commercialize vehicular natural gas as an alternative fuel for vehicles. Following that in 1996, he second CNG operating company named the Egyptian International Gas Technology (GASTEC) was established.

The success story of these first two CNG companies encouraged Egypt to set up a package of incentives, including 5-year tax holidays for CNG companies, to accelerate the rate of CNG market growth.

Thus, the Ministry of Petroleum grew its CNG operating firms by partnering with the private

sector by establishing four more CNG companies: Arabia-Gas and Shell Egypt in 2002 and Master-Gas in 2004, and Total in 2005. So, by the end of 2005, there were 26 centers for conversion vehicles into CNG-powered motors in the Greater Cairo area, along the Suez Canal, and north to Port Said and Alexandria, in addition to six CNG operating companies, 93 CNG fueling stations established by the government and private sector. More than 63 000 NGVs, mostly in Cairo, 75% of which are taxis. This amounts to approximately 3% of all NGVs globally.

In 2009, Egypt initiated the Old Vehicles Scrapping and Recycling Program (OVSRP) to raise the replacement of old liquid fuel vehicles with newer more energy-efficient and environment-friendly vehicles, especially CNG vehicles. As the first UNFCCC's transport-based implemented CDM project worldwide it received financial supported from the World Bank Carbon Fund.[49] Based on OVSRP data, by the end of 2014 the number of old taxis that had been replaced by newer CNG ones was 22967 vehicles of the total of 42616 vehicles.[50,51]

The Ministry of Petroleum declared in December 2018 that Egypt had reached a significant milestone: gas self-sufficiency. This prompted Egypt to announce its presidential initiative (https://www.gogreenmasr.com/) in January 2021 to accelerate the conversion of liquid fuel vehicles to natural gas vehicles. This will be accomplished by expanding CNG infrastructure (CNG fueling stations and transformation centers) and providing incentives (known as 'green incentives') to citizens to encourage them to swap out their outdated liquid fuel vehicles for more modern natural gas vehicles. Egypt's accelerating plan aims to increase the number of NGVs to around 1 million and the number of CNG fueling stations to 1000.

This speeding-up plan of Egypt's presidential initiative accelerated the growth of NGV, CNG fueling stations, and transformation centers during 2021 by 171%, 479%, and 171%, respectively, of that for the previous year, 2020. So, by the end of 2021, the total country's NGVs reached about 40,000, with 493 CNG fueling stations and 112 transformation centers, respectively.

6. Natural gas vehicles growth policies in Egypt

Since the energy supply is a major driver of social and economic development, many nations may view the use of NG as a transitional fuel to reach net zero emissions and combat climate change, which calls for a fundamental shift in the patterns of energy production and consumption while also not interfering with the needs of economic progress or human well-being.[52,53] Moreover, natural gas is mainly composed of C1 compound (methane −CH4) and it represents the H/C ratio among other fossil fuels. So, CNG fuel combustion produces the smallest amount of CO_2 in comparison to the combustion of other liquid fuels.[54,55] Furthermore, usually, CO_2 emissions of the well-to-wheel (WTW) phase are mainly 20% higher than CO_2 emissions of the pump-to-wheel (PTW) phase.[56]

So, Egypt has adopted early its NGV program since 1996, and recently it is a part of Egypt's vision 2030 launched in February 2016. The vision consists of eight main national goals to be met by 2030, which are in line with the SDGs launched in 2015, and the Sustainable Development Strategy for Africa 2063 which was launched in 2013.[57,58]

Egypt recognizes the great importance of natural gas as a fuel as the low-carbon transition of the energy system for road transportation and helping to achieve sustainable development[59,60] as shown in Table 3 that linking between NGV market and SDGs.

The adoption of NGVs can be promoted by many policy instruments that target a wide range of stakeholders, which can be categorized mainly into five groups of stakeholders: governmental bodies, the natural gas business industry, equipment and logistics suppliers such as fueling stations and conversion centers, conversion system component and OEM NGVs; customers and environmental supporting groups that promote the use of cleaner fuels.

Fig. 6 illustrates how the adoption of vehicle technologies and fuels is conceptually influenced by three main factors: (1) context (cultural, socioeconomic, and spatial geographic properties); (2) fuel choices and technologies (availability, safety, performance, cost, and reliability); and (3) impacts (environmental, health, energy, economic, and land-use change patterns).[35]

Successful effective policy instrument tools for accelerating the promotion of alternative cleaner fuels and vehicles shall include combinations of information, incentives, market development, and regulatory standards in a well-thought-out manner. Due to some case studies such as New Zealand, a robust government incentive and credit programs (such as 100% loan for vehicle conversion) enabled New Zealand to establish a very successful NGV market by the mid-1980s. NGVs in New Zealand accounted for slightly more than 10% of the market by 1985. However, the NGV market gradually vanished after political and legislative changes that prompted the government to modify its NGV-

Table 3. Connection between natural gas vehicle market development and SDGs.

SDG	Influence factor	Description
Goal #1. No poverty	Low CNG fuel is less expensive than other liquid fuels (gasoline or diesel). Low cost of NGV ownership.	Reducing transport costs for those in socially vulnerable groups within society, as the prospect of lowering transport expenses is highly sensitive for these vulnerable groups of society. So, CNG as an affordable and costly effective fuel contributes to reducing transportation and logistics costs.
Goal #3. Good health and well-being	NGV aims to reduce vehicle emissions and particulates (PM10, PM2.5)	Transport as a source of toxic emissions has a negative impact on the environment and human health. Environmentally friendly CNG fuel aims to minimize impacts on air quality and human health.
Goal #6. Clean water and sanitation	Use of CNG fuel for water transport allows to avoid fuel spills	Rivers and lakes are the most widely used sources of drinking water worldwide and can be utilized as transportation infrastructure. So, water quality is impacted by water transport. For this reason, it is crucial to choose fuel for water transportation that minimizes the impacts of liquid petroleum fuels spilling into lakes and rivers. According to this perspective, electricity, natural gas, and hydrogen are the most promising fuels.
Goal #8. Decent work and economic growth	CNG is cost-effective compared with diesel and gasoline. Natural gas fuel cannot be stolen from the fuel tank or pipeline, unlike liquid petroleum fuels.	Enhancing the effectiveness of the transportation industry and cutting expenses related to transportation and logistics can expedite economic expansion. As mentioned above, one strategy to lower transportation costs is switching to more affordable and efficient fuels, such as CNG fuel. Another factor is that, in contrast to liquid petroleum fuels, these fuels cannot be stolen from the fuel tank or pipeline.
Goal #9. Industry, innovation, and infrastructure	The development of NGV infrastructure (fueling station, transformation centers) increases the access of final customers to natural gas as an alternative fuel.	Adopting alternative fuel transport such as NGVs requires spreading infrastructure of CNG fueling stations and conversion centers to be accessible and affordable for customers. To reduce land-use impact, fueling stations should be hybrid fueling stations to allow refueling of alternative fuels such as the CNG fuel in addition to other traditional liquid fuels (gasoline and diesel). As per target no.4 of SDG # 9, by 2030, all countries must take action in line with their respective capacities to upgrade their infrastructure and retrofit industries to make them sustainable. This includes increasing resource use efficiency and adopting more clean and environmentally sound technologies and industrial processes.
Goal #10. Reduced inequalities	CNG fuel is cost-effective compared with diesel and gasoline. Low cost of NGV ownership.	Poor people deserve a quality environment no less than wealthy people. Enabling low-income individuals to obtain affordable forms of environmental fuel, mostly natural gas, is a viable approach to ensuring clean air in urban areas. The availability of inexpensive fuel has increased household disposable income. Natural gas is a far less expensive method of promoting decarbonization and improving urban air quality.
Goal #11. Sustainable cities and communities	NGV allows to minimize air pollution	The cleanliness of the air has a major impact on both the quality of the urban environment and the human health of its residents. Thus, one of the main forces behind the sustainable growth of contemporary cities is the shift in transportation to cleaner fuels.
Goal #13. Climate action	CNG-powered motors are mature-enough technology and can be simply implemented in the short and medium-term action to combat climate change.	Natural gas combustion results in reduced CO_2 emissions and a smaller 'carbon footprint' than when a vehicle powered by an oil motor produces energy. Therefore, investing in mature technology is essential to meeting sustainable development targets until 2030.
Goal #15. Life on land	Decreasing the GHG emissions that will result from transportation, by promoting NGV fleet.	NGV supports life on land by reducing CO_2 emissions in addition to spills and leakages that may result from crude oil and liquid petroleum fuel facilities.

promoting instrument tools and remove advantageous CNG loan conditions in 1985.[35,61]

In Egypt, NGV promotion among people is one of the main environmental challenges facing Egypt to achieve its vision 2030.[57] So, Egypt launched its presidential initiative 'gogreenmasr' in Jan 2021 to enhance the growth of NGV fleets. This is not based on only one type of policy instrument, rather it is designed as a combination of different policy instruments as follows:

6.1. Incentive-based instrument

Provide financial incentives to encourage individuals to switch from outdated liquid fuel vehicles to more modern natural gas vehicles as well as facilitating the required CNG infrastructure such as CNG fueling stations, transformations centers, etc. So, the Prime Minister issued decision number 575 for the year 2021[62] as a regulatory framework for incentive-based instrument to implement the presidential initiative by giving the financial incentive called the 'Green Incentive' as a percent from the cost of new NGV instead of old liquid fuel vehicle (either private car, taxi, or microbus) aged more than 20 years.

In addition, it is considered that the Egyptian energy subsidies reform program, which was initiated in 2014, to reform longstanding fossil fuel subsidies, is another financial incentive-based instrument that promotes NGVs growth. This subsidy reforming program is leading to raising the price of liquid fuel to about double the price of CNG fuel.

6.2. Coalition- or information-based policies

These include collaborations and partnerships among governmental entities, industry 'vehicle manufacturers,' banks, and insurance providers[63] as a coalition- or information-based policies instrument to implement the presidential initiative to develop programs promoting the NGV industry and affording newer NGV vehicle model alternatives and offset any perceived 'risk' for vehicle manufacturers or people using NGVs.

6.3. Market-creation based instrument

Also, the Ministry of Petroleum and Mineral Resources launched[64] its policy instrument as a Market-creation-based instrument to implement the presidential initiative by establishing enough stations and centers for natural gas conversion and supply across the country. By targeting to have an overall 1 million vehicles running on natural gas within the coming 3 years, and to have the number of the stations to 1000 during 1 year instead of 250 stations since the launch of the initiative, by using existing liquid fuel station and incorporating the CNG filling system to reduce land use impact.

Egypt is placing great importance on the NGVs-to-CNG fueling station ratio, due to several international case studies showing that a the too low CNG fueling station ratio is leading to an unprofitable CNG fueling infrastructure and represents a main barrier to NGVs market growth, such as, some countries that were early adopters of NGVs include New Zealand, Switzerland, and Canada. These countries had a low ratio of CNG fueling stations, and their NGV markets failed after achieving a considerable successful start.

The NGVs-to-CNG fueling stations ratio plays a principal key indicator in assessing the profitability and density of CNG fueling stations in a given area. Higher ratios are preferable as they indicate greater demand and draw more investment to CNG filling stations.

So, it is considered that the presidential initiative is balancing between NGVs growth and CNG fueling stations to achieve a rational ratio between NGVs and CNG fueling stations of about 1000, which represents the most appropriate balance between fueling stations' profitability and NGV drivers' s convenience, based on an average NGVs-to-CNG fueling ratio for most successful stories of top leading NGVs adopters countries such as China, Iran, India, Pakistan, Argentina, Brazil, and Italy as shown in Fig. 7.[65–67]

As shown in Fig. 8, natural gas vehicles promote an increase in the Egyptian automobile fleet which mainly consists of liquid fuel vehicles as shown in the figure excluding 2- and 3-wheeler motor vehicles.

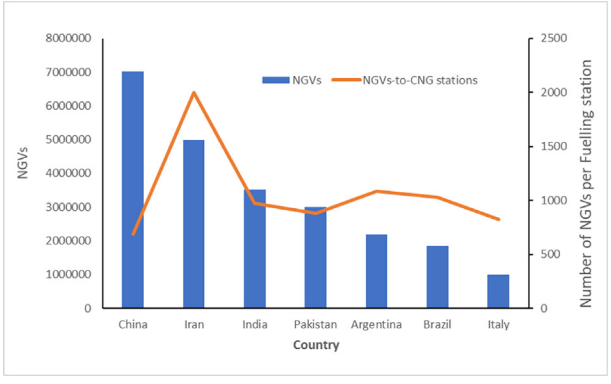


Fig. 7. Natural gas vehicles per Fueling Station.

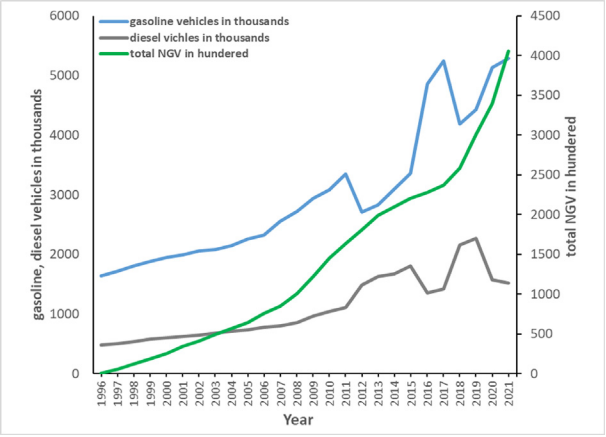


Fig. 8. Natural gas vehicle growth against liquid fuel vehicles growth.

Fig. 9 illustrates the evolution of the number of NGVs per CNG fueling station across the years since the starting of NGVs project in Egypt. At first, more NGVs were entering the Egyptian market than CNG fueling stations, and both increased symmetrically, as NGVs to CNG fueling station ratio increases from 203 to 1567 between 1996 and 2019, and then the ratio decreased after 2019 with a notable curve steeper at the end of 2021 as a result of launching of presidential initiative, which is accelerating the spread of CNG fueling stations spreading across the country.

Figs. 8 and 9 represent the effectiveness of policy instruments that have been taken to implement the presidential initiative to accelerate the growth of NGVs and CNG fueling stations by achieving about 50% of the initiative targets of NGVs and CNG fueling stations by the end of 2021.

6.4. Conclusions

The majority of Egypt's transport sector's GHG emissions come from road transport,[20] and motor vehicles share strongly in the road transport system in Egypt which reached, according to CAPMAS, about 11 million vehicles in 2021.[45] As Egypt's vehicle fleet grows, energy- and environmental-related problems urge a greater need for cleaner and more abundant vehicle fuel. So, in the early 1990s, Egypt adopted its NGV program, recognizing natural gas as a low-emission vehicle fuel and a transitional solution for reducing GHG emissions reduction and combating climate change. Natural gas represents a major axis of Egypt's energy policy. This is proven by Egypt's natural gas reserves that are an abundant and robust system of natural gas facilities and infrastructure networks distributed across the country. In addition, the CNG-powered motor technology is mature enough and available for less developed countries other than the more advanced high technology motors industry. Egypt is deploying many policy instruments to accelerate its NGV program, and recently launched its presidential initiative to speed up NGV expansion and its infrastructure plans by balancing NGVs growth and CNG fueling stations to achieve a rational ratio equal to about 1000, which represents the most fit ratio balanced between profitability for fueling stations based on an average NGVs-to-CNG fueling ratio for most successful stories of top leading NGV adopter countries such as China, Iran, India, Pakistan, Argentina, Italy, and Brazil.[65–67] This speeding-up plan is accelerating the spread of NGV, CNG fueling stations, and transformation centers

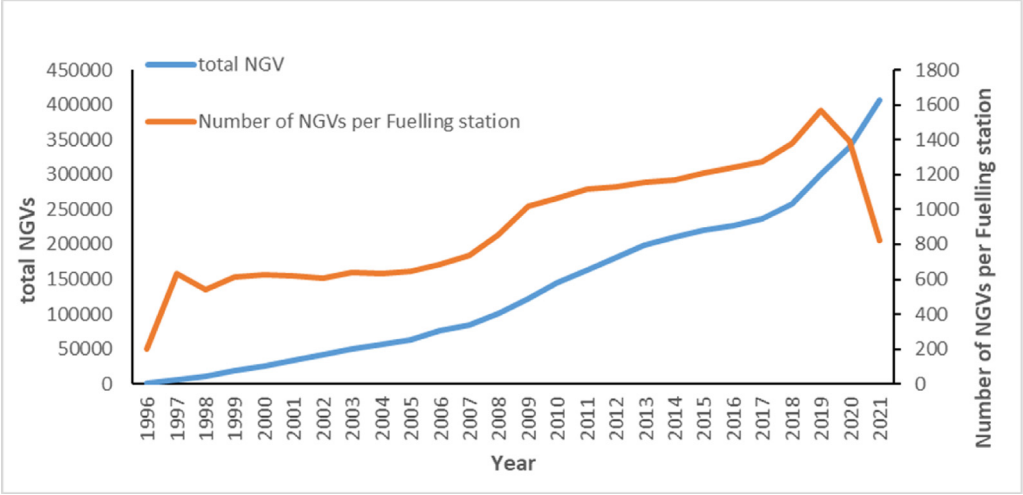


Fig. 9. Evolution of the number of natural gas vehicle per fueling station across the years.

during the year 2021 by 171, 479, and 171%, respectively, over that of 2020.

Conflicts of interest

There are no conflicts of interest.

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Ethics

This article does not contain studies with human/animal subjects.

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