Developing a system dynamics approach for CNG vehicles for low-carbon urban transport: a case study

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Abstract
Today both the economic growth and expansion of urbanization have increased community access to private cars. Thus, the urban transportation has become a critical part of energy consumption and greenhouse gas emissions. The excessive dependence of urban transportation on high-emission fuels is the main obstacle to develop a low-carbon transport. Meanwhile, natural gas is a bridge fuel to develop a low-emission transport. To the best of our knowledge, there has been little attention towards the association between the development of natural gas-fueled vehicles and the CO2 emission. Therefore, the problem we studied is the role of compressed natural gas (CNG) vehicles in replacing high-emission fuels. In this study, we aimed to study this association by selecting the system dynamics approach due to the complexities of the social–economic system of transportation. In this modeling, different subsystems of the transport fleet were employed including CNG vehicles and urban transportation subsystems. Iran has used CNG as an alternative fuel in the transportation sector, making it one of the three leading countries in the use of natural gas in the urban transportation system. Our case study is focused on Tehran, which is the capital and the largest city of Iran. In this paper, we considered several scenarios to replace the gasoline fuel in the private car sector and the bus fleet with natural CNG fuel. The results show that the replacement of CNG fuel with high-emission fuels can have a significant effect on reducing CO2 emissions. In the synthetic scenario, CO2 emission will be decreased by 11.42% in 2030, as compared to the business as usual (BAU) scenario in this year. According to Iran's commitment to the Paris Agreement, the emission of CO2 in Iran should normally be reduced by 4% in 2030, as compared to its amount in the BAU scenario. Therefore, Iran can easily fulfill its obligations in the urban transport sector only by replacing gasoline and diesel fuel with CNG.

Keywords: low-carbon transport; system dynamics; CNG vehicles; CO2 emission; urban transport

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Received 7 July 2020; revised 11 October 2020; editorial decision 26 October 2020; accepted 26 October 2020

1. INTRODUCTION
Sustainability is the most trending issue in developing urban communities all over the world [1]. Energy is a prerequisite for sustainable development [2]–[6]. According to the International Energy Agency’s forecast [7], the transportation sector will account for 46.47% of the growth in oil consumption between 2018 and 2040. In 2018, 43.55% of the consumed crude oil and 24.5% of CO2 emission has been raised from the transportation sector [8]. According to the findings, increased use of the motor vehicles, despite the improvement of mobility and road transport, causes the resource exhaustion and global warming [9]. The transportation sector poses many challenges in reducing energy consumption and greenhouse gas emissions [10, 11]. Economic growth and the expansion of urbanization have increased community access to private cars, and urban transport has become an important part of energy consumption and greenhouse gas emissions.

The total dependence of urban transportation on high-emission fuels is a serious obstacle to the development of low-carbon transport. Energy crisis and global warming due to high-emission fuel implementation in the transportation sector have stimulated global trends to employ the alternative fuel vehicles (AFVs) in the transportation sector [12]. Therefore, the alternative fuel policy in the transportation system, as one of the main policies to reduce CO2 emissions [13], has been the subject of major studies that have addressed the policy in different aspects including the following:
1) market penetration of AFVs;
2) acceptability of AFV policy;
3) AFV policy economic impact;
4) implementation of AFV policy;
5) the impact on greenhouse gas emissions.

Multifarious studies have been conducted on the market penetration of AFVs. These studies investigated the effects of various factors, such as government subsidies [14, 15], individual preferences—including neighbors, family and co-workers—to use AFVs [16], cost savings and infrastructure development [17] and age of consumers [18] in the choice of AFVs. Using the survey method, Johnson et al. examined the acceptability of AFV policies [19]. Shin et al. [20] compared the electric vehicles and hydrogen fuel cell vehicles in terms of market penetration and consumer choice. Leaver and Gillingham examined the economic impact of different technologies, including hydrogen fuel cell, hydrogen internal combustion and battery electric technologies [21].

Some researchers have also focused on creating the right infrastructure to implement AFV policy in the transport fleet. For example, Hong and Kubi discussed the importance of having adequate infrastructure and alternative fuel supply stations to change the transportation system to the low-carbon urban transport fleet [22] and Bruglieri et al. examined the effect of fuel stations on the replacement of AFVs [23].

Finally, various studies have addressed the effect of the AFV policy on the reduction of CO2 emissions. For instance, Hackney and De Neufville [24] developed a life cycle model to compare the emission and energy efficiency of AFVs; they investigated the effects of the Providence Alternative Motor Fuels Act (AMFA) to produce AFVs by manufacturing companies and the impact of using these cars on reducing greenhouse gas emissions. Ou et al. [25] examined the effect of Chinese government alternative fuel bus fleet policies on the greenhouse gas emissions.

There are various types of fuels in the world market as replacements for conventional fuels in the transportation system, such as ethanol, methanol, natural gas, fuel cell or hydrogen and biodiesel in electric or hybrid cars, and among which the compressed natural gas (CNG) is the most popular [26]. According to the International Energy Agency (IEA’s) forecast, the use of natural gas fuel consumption will be increased in the future [7], as it can reduce greenhouse gas emissions due to its high H/C ratio compared to the liquid fuels.

There have been various studies on the use of natural gas fuel as an alternative fuel in CO2 emission reduction policies. Janssen et al. evaluated the market penetration of natural gas vehicles [27]. Imran Khan identified and introduced some barriers to the expansion of natural gas as a sustainable alternative fuel [28]. Yeh [29] compared the adoption of natural gas vehicles (NGVs) in eight countries, including Argentina, Brazil, China, India, Italy, New Zealand, Pakistan and the United States. He explored a wide range of policies to promote the use of natural gas vehicles in new markets as well as mature markets [30]. Collantes and Melaina [31] examined Argentina’s experience in using natural gas in the transportation system. They conducted interviews with a wide range of stakeholders and examined the collected economic data to determine the factors that increase the acceptability of this fuel.

The pivotal objective of this study is to identify the lessons used in developed countries to deploy AFVs. Hagos and Ahlgren [32] selected natural gas vehicles and examined their emissions using a well-to-wheel method. The results showed that the use of compressed and liquefied natural gas fuel in both road and marine transport and reduces GHG emissions for all types of vehicles by 15% to 27% per kilometer.

However, the effect of natural gas which could serve as a bridge for transition toward the low-carbon future [33]. Moreover, of the various alternative vehicle fuels, CNG appears to be the most successful on demand side [34].

Given the advantages of CNG as an alternative fuel to reduce CO2 emissions, impact of this fuel on low-carbon transportation has been less systematically investigated in previous studies. Therefore, this paper studies CNG fuel with the following two novelties:

- the previous studies did not consider the relevance of the development of natural gas fueled vehicles to the CO2 emission; and
- few articles have systematically considered the incentives of various stakeholders of urban transportation.

However, the present study developed a comprehensive system model to examine the different motivations of the public and private sectors with various analyses.

In recent years, Iran has employed CNG as an alternative fuel in the transportation sector. This has caused Iran to be one of the three leading countries in the use of natural gas in the urban transportation system. The abundance of Iran’s natural gas resources and the existence of suitable infrastructure for the use of CNG vehicles in urban transportation have made natural gas as an appropriate alternative fuel policy for Iran’s transportation sector.

In this paper, several policies have been considered to increase the share of CNG use as an alternative fuel in different parts of the urban transportation system. In order to examine the impact of each of these policies on reducing carbon dioxide emissions in the urban transport sector, the extent of emissions reductions resulting from those policies has been compared with Iran’s emission reduction commitments in the Paris Agreement. According to Iran’s commitment to the Paris Agreement, the emission of CO2 in Iran should normally be reduced by 4% in 2030 compared to its amount in the BAU scenario. In addition to this commitment, Iran has pledged to reduce its CO2 emissions by another 8% under conditions such as lifting sanctions against Iran, international financial and technological support.

In this research, we considered Tehran as our case study for three reasons: it is the capital and the largest city of Iran, it has experienced of implementing CNG fuel consumption policy in the transportation system, and there is sufficient data in Tehran to assess the policy impact on carbon dioxide emissions.
2. METHODOLOGY

Transportation system requires a systematic study because it can have economic, social, behavioral and environmental aspects. In other words, multiple variables such as economy, demography, government and market variables can influence the performance of transportation system. Thus, it is necessary to use an inclusive method to examine the states of the variables and their relationships over time. Thus, we employed the system dynamics approach due to the complexities of the social-economic system of transportation.

Previous studies applied the system dynamics method to simulate and study the transportation system. Han et al. evaluated the dynamics of the Delhi transport system using a dynamic system method to evaluate the effectiveness of policies and reduce the impact of transportation on the environment and energy consumption [35]. Lei et al. used the System Dynamics to simulate and evaluate the Shanghai low-carbon transportation system [36]. Haghshenas et al. [37] evaluated the sustainable development policies in the urban transportation system of Isfahan via the system dynamics.

Cheng et al. [38] investigated some strategies to reduce energy consumption and carbon dioxide emissions in the urban transportation system of Kaohsiung City and applied a dynamic system approach to modeling. Xue Liu et al. [39] studied the reduction of energy consumption and carbon dioxide emissions in Beijing using a dynamic system with an economy subsystem, population subsystem, transport subsystem and CO2 emissions subsystem. Barisa and Rosa [40] studied the CO2 reduction policies in the road transport system using the dynamic system as a modeling approach. In the latest articles in this field, Gupta et al. [41] investigated the impact of carbon tax policy on the Indian road transport system using the system dynamics.

As has been observed in this research, the system dynamics method has been used to study the reduction of energy consumption and CO2 emissions. Therefore, system dynamics modeling is a common method to study the complex systems, such as urban transportation systems. However, none of these studies have discussed natural gas as an alternative fuel in urban transport and its impact on reducing CO2 emissions as a fuel for the transition from high emission fuels to low emission fuels. In these studies, natural gas fuel is not seen as a separate subsystem.

The basic concept of system dynamics was presented by Forrester [42]. System dynamics is the study of the policies and decision making on system control as well as the structural characteristics of the systems, on the basis of several unique features in the methodology. Firstly, system dynamics considers the dynamic behavior of the systems, more particularly the changes in the system behavior according to the time. Secondly, system dynamics seeks the root causes of the dynamic changes in its feedback structure. The feedback structure refers to the closed circuit generated by the interconnection of the causal sequences of the variables. The most important merit of system dynamics is that it can overcome the limit of conventional statistical methodologies that focused on the analysis of the correlations among variables, as it can analyze the circular relationship among multi-variables using computer simulation techniques. This is why system dynamics is now being applied in a wide range of areas, including the spread of innovation and new technologies [43]. In this approach, the system is based on existing feedbacks and delays to better understand the dynamic behavior of complex systems.

We modeled and simulated the Tehran city transport fleet system via system dynamics approach. The purpose of this modeling is to investigate the overall policy of replacing high emission fuels with CNG in the urban transport fleet to reduce CO2 emissions. The study involved applying comparing different policies and finally proposing the best case.

As shown in Figure 1, the low-carbon urban transportation system is composed of a combination of private CNG vehicles and urban transport subsystems. The subsystems of the developed model are described as follows.

2.1. Private CNG vehicles subsystem

One of the natural gas-fueled transport subsystems is the one that determines the share of private CNG cars. The influential variables of this share include the number of natural gas stations, the maintenance cost of CNG cars, the relative price of CNG to gasoline and the price of a CNG car. Figure 2 shows the causal loop diagram of this subsystem. This subsystem has two positive and negative loops. Positive loops include variables as natural gas vehicle share, total sales of natural gas fuel, sales of natural gas in one station, expected profit of the stations and number of stations. In this loop, the overall demand natural gas will increase with the share of natural gas vehicles due to the increased consumption of natural gas in the transportation sector. Thus, increasing the quantity sales of this fuel at natural gas stations can enhance the expected profitability of these sites, and consequently the incentive to build new ones. Constructing these new ones can increase their number. Increasing number of stations means the availability of natural gas fuel. Therefore, this variable will increase the use of the gas vehicles in the fleet of private cars.

However, by increasing in the number of new stations supplying the natural gas, the sale of existing stations can decrease their expected profits, which in turn will have a negative impact on the growth of new stations and create three main variables of the negative loop. The state and flow diagram of this subsystem are shown in Figure 3.

2.2. Urban transport subsystem

To assess the effect of CNG, an alternative fuel on CO2 emissions in urban transport, we considered the urban transport subsystem. In this subsystem, whose cause and effect diagram is shown in Figure 4, investigated that in each of Tehran’s transportation sector, how many trips (in Vehicle Kilometers (VKm)) are made per year. After calculating the VKm of each sector of Tehran’s transportation system, based on their emission factor, the amount of CO2 emissions and their cumulative value over the coming
Fig. 1. Low-carbon transport system flow diagram.
years have been studied. To further explain this, the VKm of private vehicles have been calculated and described. The first effective variable on the VKm of a private car or any sector of a different urban transport system is the amount of travel demand that is in turn influenced by the number of urban populations. To calculate the VKm, travel demand in Tehran was first estimated using linear population-based regression. The relationship of this regression was estimated according to the past data on two variables of population and travel demand. The attractiveness variable was used to calculate the share of different sectors of the transportation system from total travel demand. Depending on the cost and time of travel in each segment, this variable specifies the sector which travelers choose for their journey. In other words, the attractiveness variable is considered as a state variable, and an initial value to which it is assigned.

This initial amount is determined according to the statistics provided by Tehran Traffic Organization (TTO). This variable changes with the rate of car attractiveness (CA).

The relationship between these variables and how to calculate the rate of private car’ attractiveness is given in Eq. 1.
Eq. 1 shows that “rising fuel prices” has a far greater effect on the attractiveness of the private cars than “increasing travel time”. In other words, people are more sensitive to the “cost” of using a private car than to the “travel time”.

To determine the shares of different sectors according to their attractiveness, the “normalized attractiveness variable (NAV)” is defined. This variable makes the sum of all sectors of the transport system equal to one. The relationship of these variables is given in Eq. 2:

\[
\text{Norm Factor} = \left( \frac{\text{CA} + \text{Taxi Att.} + \text{Bus Att.} + \text{Rail Transit Att.} + \text{Motorcycle Share}}{} \right)
\]  

Eq. 3 calculates the variable of the private car’s normalized attractiveness:

\[
\text{NCA} = \frac{\text{CA}}{\text{Norm Factor}}
\]  

Now, by calculating the total travel demand (TD) and the share of private cars from that, the VKm of this sector can be calculated by multiplying these two variables. However, to accurately calculate the VKm of the private cars, one has to include another variable which is the Car Occupancy (CO). This variable represents the average number of people who travel on a trip with a private car. This quantity is 1.34 based on the latest statistics for private cars. The exact value of VKm of a private car can be calculated using Eq. 4.

\[
\text{Car Travel Volume} = \frac{(\text{NCA}) \times (\text{TD})}{\text{CO}}
\]  

Where NCA is normalized attractiveness variable, TD is travel demand and CO is car occupancy. The Car Travel Volume variable represents the amount of travel (in VKm) done in the private car sector. The fuel for these private cars is either gasoline or CNG. The share of CNG vehicles is calculated by CNG vehicles subsystem. Thus, by multiplying the Car Travel Volume in share of CNG cars, one can calculate the share of CNG cars from the total VKm of private cars. Also by multiplying this variable by the CO2 emission factor, the share of the private CNG cars in the CO2 emission is calculated. There is also a similar relationship for gasoline cars. The flow diagram of urban transport subsystem is shown in Figure 5.

3. POLICIES

Because the private and public urban transport decision-making mechanisms for CNG fuel replacement are different, the implementation of CNG fuel replacement policies should also be different in these two different sectors. The policy focuses on increasing...
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The use of CNG vehicles in the private sector by reducing the relative price of CNG fuel and increasing the efficiency of gas-burning vehicles, and in the public sector, government support has been provided to increase the share of CNG fuel in this sector. This model considers three central policies, which are different in private and public sectors in terms of CNG fuel replacement rate in the urban transport fleet. In the first policy, the goal is to develop CNG-fueled private cars. To accomplish this goal, there are two sub-policies: one to improve technology and one to make the price of CNG fuel competitive with that of other fuels. The first sub-policy assumes that the technology of the CNG-fueled private cars can improve due to the government investment and technology advancement. This can reduce the amount of consumed CNG, the cost of maintaining CNG-fueled vehicles and CO₂ emissions. In the second sub-policy, the growth of CNG price is assumed to be relatively lower than that of the gasoline price, which can increase the CNG consumption and the share of CNG-fueled private cars.

In the second policy, it is assumed that the government support the public transport (e.g. taxi and bus fleet) to increase CNG fuel share in this sector, so that all the taxis and buses will use CNG fuels by 2030. The third policy is a combination of the first and the second.

These policies are illustrated by two different scenarios in the model: 1) BAU and 2) Low carbon scenarios. Under BAU scenario, it is assumed that all variables will be changed based on

Fig. 5. Urban transport subsystem flow diagram.
Table 1. Details of policies and scenarios.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Sub-policy</th>
<th>Variable Description</th>
<th>BAU scenario</th>
<th>Low-carbon scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG as an alternative fuel</td>
<td>Technology improvement</td>
<td>CNG-fueled vehicles fuel consumption</td>
<td>1/14</td>
<td>1% decrease per year</td>
</tr>
<tr>
<td>in private car sector</td>
<td></td>
<td>emission factor</td>
<td>156 g/kg</td>
<td>2% decrease per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance cost</td>
<td>0</td>
<td>40,000 Toman reduction per year</td>
</tr>
<tr>
<td>Government support for CNG</td>
<td>CNG competitive price</td>
<td>Natural gas price</td>
<td>(0%)</td>
<td>(0%)</td>
</tr>
<tr>
<td>fuel for public transport</td>
<td>Governmental support</td>
<td>Gasoline price</td>
<td>(4.8%)</td>
<td>Growth of 14% per year</td>
</tr>
<tr>
<td>sector</td>
<td></td>
<td>CNG-fueled taxis growing rate</td>
<td>(4.8%)</td>
<td>Growth of 6.5% per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CNG-fueled buses growing rate</td>
<td>(2.3%)</td>
<td>Growth of 7.4% per year</td>
</tr>
<tr>
<td>Synthetic</td>
<td>Expansion of private CNG-fueled cars and expansion of CNG-fueled vehicles in the public sector scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

their previous trend. And under low carbon scenario, the change of variable in each policy is shown in Table 1.

3.1. Policy 1: CNG as an alternative fuel in private car sector
This policy is applied to the private car sectors, including the first and second sub-policies. These two sub-policies are different because of the type of effect they have on increasing the share of CNG-fueled cars. Implementing the first sub-policy will decrease the maintenance cost and increase the productivity. Therefore, with the improvement of the CNG technology, more CNG-fueled cars will be welcomed. Implementing the second sub-policy will replace CNG as a low-emission fuel with other high-emission fuels due to the competitive price of CNG.

3.2. Sub-policy 1: technology improvement
With the improvement of CNG private car technology, the influence of CNG cars tends to increase among consumers. In this sub-policy, the improvement of technology will affect the consumption of cars, their CO2 emission coefficient and the cost of maintaining CNG cars.

This sub-policy aims to reduce the consumption of natural gas by CNG-fueled vehicles by upgrading their technology. In this policy, the government encourages the owners of CNG-fueled vehicles by providing incentive schemes, such as providing facilities to upgrade their car technology or enforcing regulatory policies. Therefore, they can make it necessary for the manufacturers of CNG-fueled vehicles to upgrade the technology of manufacturing these vehicles and reduce their consumption.

As stated above, the variables that underpin this sub-policy in the model are “CNG-fueled car consumption per kilometer” and “CNG-fueled car maintenance cost”.

This sub-policy also assumes that the technology of CNG-fueled cars will reach the highest level in the world by 2030. It also assumes that the annual fuel consumption of CNG vehicles is reduced by 1% and their CO2 emissions are reduced by 2%. As a result, the maintenance cost of CNG-fueled vehicles will be reduced as much as that of the gasoline-fueled ones, which is 400,000 rials per year.

3.3. Sub-policy 2: CNG competitive price
The second sub-policy attempts to make the consumption of CNG more competitive against gasoline by lowering its cost to increase the acceptance of the CNG-fueled cars. This sub-policy is applied in such a way that the price of CNG increases in proportion to inflation in the previous trend, so its real price does not increase. However, the price of gasoline increases annually which can increase its real price up to the Persian Gulf Hub.

The relative depreciation of CNG increases the market share of private CNG cars. This sub-policy is also indicated by two different scenarios in the model: 1) BAU and 2) low carbon. The variables affected by this sub-policy are the relative price of natural gas and the relative price of CNG fuel vehicles.

3.4. Policy 2: government support for CNG fuel for public transport sector
As shown in Figures 2 and 4, the dynamics of the system, that affects the public transport sector, is different from that in the private sector. In the public sector, public investment plays a major role, that is, the government pursues a policy to increase the share of natural gas in the public transport sector. In this policy, the government provides incentives such as facilities for taxi and bus drivers or a relative reduction in the price of natural gas for the given sector, in which case the drivers of these vehicles tend to change their vehicles or convert them into CNG-fueled vehicles.

In this policy (Table 1), we assume that gasoline and diesel fuels will supplant CNG in the taxi and bus fleet under the government support. Also, the shares of CNG-fueled taxis and CNG-fueled buses should increase annually by 6.5% and 7.4%, which by 2030 can reach into 100%.

3.5. Policy 3: synthetic policy
This policy ensures that all actions in the first and second policies apply together and simultaneously for the private and public transport fleets.
4. RESULTS AND DISCUSSION

Continuing the previous trend in the BAU scenario, we can assume that all variables will change based on their previous trend. As a result of this scenario, CNG fuel consumption in the Tehran fleet will increase to 784.3 million m$^3$ in 2030; the share of CNG-fueled private cars will increase to 7.18%, and CO$_2$ emissions will reach 11.28 million tons which is a 33.18% increase, compared to 2019. The results of this scenario are shown in Figure 6.

The results of each policy, presented in the previous section under low carbon scenario, are presented below.

4.1. Policy 1: CNG as an alternative fuel in private car sector

This policy is applied to the private car sector, which includes the first and second sub-policies. These two sub-policies are different because of the type of effect on increasing the share of CNG-fueled cars.

4.2. Sub-Policy 1: technology improvement

This sub-policy seeks to increase the influence of these vehicles among consumers by improving the technology of CNG-fueled vehicles. Here, the improvement of technology will affect the consumption of cars, the CO$_2$ emission and the maintenance cost of CNG-fueled cars.

Because of the increasing the share of CNG-fueled cars among consumers, the use of gasoline cars will decrease, and due to their lower CO$_2$ emissions vs. gasoline cars, overall CO$_2$ emissions will decrease as a consequence of this sub-policy.

According to Figure 7, the share of CNG-fueled cars will increase to 31.11% by 2030, due to the policy to improve the technology of these cars. Also, the total CNG fuel consumption will increase to 814.1 million m$^3$ per year. However, CO$_2$ emissions will decrease to 10.78 million tons, which is down for 4.43%, compared to the base scenario.

4.3. Sub-policy 2: CNG competitive price

Under this sub-policy, CNG price will not change until 2030, but gasoline price will rise by 14% annually, increasing the real price of the gasoline up to 4817$ in 2030. Because of this sub-policy, as shown in the Figure 8, the share of CNG-fueled cars will increase to 20.22% by 2030 and total CNG consumption in the transportation fleet will reach 1179 million m$^3$ by 2030. By replacing the gasoline fuel with CNG, CO$_2$ emissions will reach 10.94 million tons by 2030, which is 3.01 percent lower than the BAU scenario.

4.4. Policy 2: government support for CNG fuel for public transport sector

Using CNG as an alternative fuel in taxis and buses can increase the CNG consumption and decrease the CO$_2$ emissions. As shown in the Figure 9, the total CNG consumption in the transport fleet in 2030 will reach 835.7 million m$^3$. In this policy, the amount of CO$_2$ emissions does not change much compared to the BAU scenario. So, by 2030 it will be 11.22 million tons. i.e. it declined 0.53% compared to the BAU scenario.

4.5. Policy 3: synthetic policy

This policy assumes that all actions in the first and second policies apply together and simultaneously for the private and public transport fleets.

According to the Figure 10, because of this policy, the share of CNG cars among private cars in 2030 will reach 29.45%, which
represents a 310% growth over the BAU scenario. In other words, by applying the first and second policies simultaneously, the share of private CNG cars will become more than quadruple by 2030.

According to the model results, by increasing CNG’s share in the Tehran transport fleet, CNG consumption will reach 1353 million m$^3$ by 2030, which is a 72.51% increase, compared to BAU scenario. As expected, CO$_2$ emissions will fall as a result of policies above, reaching 9.99 million tons in 2030, which shows a 11.42% decrease from the BAU scenario.

5. CONCLUSION AND FURTHER RESEARCH

The strong reliance of urban transportation on high emission fuels is the main obstacle to the development of a low-carbon transport. In recent years the policy of AFVs in the urban transportation system has been high considered as one of the main policies to reduce CO$_2$ emissions. Compared to conventional fuels in both transport applications and for all vehicle classes, the use of compressed and liquefied natural gas had a 15–27% GHG emissions reduction effect per kilometer of travel. However, the effect of
natural gas which could serve as a bridge for transition toward the low-carbon future [33]. Moreover, of the various alternative vehicle fuels, CNG appears to be the most successful on demand side [34]. Given the advantages of CNG as an alternative fuel to reduce CO2 emissions, impact of this fuel on low-carbon transportation has been less systematically investigated in previous studies. Moreover, Iran is rich in natural gas resources. With abundant natural gas resources and suitable infrastructures for the use of
CNG in transportation, Iran has the capacity to make extensive use of that in the transportation sector. Tehran as capital and largest city of Iran, is considered as a case study because it has experienced of implementing CNG fuel consumption policy in the transportation system, and there is sufficient data in Tehran to assess the policy impact on carbon dioxide emissions.

The current study attempted to examine the AFV policies under two scenarios and evaluate its effect on reducing CO₂ emissions in the urban transport.

Here, we modeled and simulated the Tehran city transport fleet system using system dynamics. In this modeling, we considered the subsystems of the transport fleet, including CNG vehicles and urban transportation subsystems. The purpose of this modeling was to investigate the overall policy of replacing high emission fuels with CNG in the urban transport fleet to reduce CO₂ emissions. In this study, we applied different policies and proposed the best case.

As mentioned above, there are three underlying policies in terms of the CNG fuel replacement rate in the private and public sectors in the urban transport fleet. The first policy aims at developing CNG-fueled private cars, which contains two sub-policies. The first sub-policy aims to improve the technology. It assumes that the technology used in CNG-fueled private cars will improve via government investment and technology advancement. As a result, the amount of consumed CNG will reduce along with the cost of maintaining CNG-fueled vehicles and CO₂ emissions.

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**Fig. 11.** Normal share of CNG vehicles in all policies and sub-policies under low-carbon scenario and BAU scenario.

**Fig. 12.** CNG consumption in all policies and sub-policies under low-carbon scenario and BAU scenario.
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The second sub policy aims to make CNG fuel price competitive with other fuel prices, in which case the CNG price growth is assumed to be relatively lower than gasoline. As a result, it will increase the CNG consumption and the share of CNG-fueled private cars.

The second policy is the support by the government for public transport (taxi and bus fleet) to increase CNG fuel share in this sector. In this policy, it is assumed that all the taxis and buses will have used CNG by the end of 2030 as long as they are supported by the government. The third policy is a combination of the first and second policies.

As shown in Figure 10 and the previous section, during the execution of different policies under low carbon scenario, the share of CNG-fueled private cars will increase compared to the BAU scenario. The biggest increase in the shares of these cars is in the synthetic policy that shows a growth of more than fourfold, i.e. it rises from 6.2% in 2019 to 29.45% in 2030.

As shown Figure 11, CNG’s competitive fuel price sub-policy after the synthetic policy will have the most effect on the share of CNG private cars growth in which the share will reach 20.22% in 2030. In the technology improvement sub-policy, this share will reach 11.31%.

Resultantly, the most effective policy in increasing the share of CNG-fueled private cars will be the synthetic policy and the sub-policy that make the CNG’s price competitive.

In the whole transport system, the CNG consumption policies were organized in order of effectiveness, the synthetic policy, the sub-policy of making CNG’s price competitive, the policy of expanding CNG in the public transport and finally, the sub-policy of the technology improvement.

Given that CNG has been widely used in the public transport sector in recent years with government support –so that 76% of taxis and 42% of urban buses have used CNG, the potential of decreasing emission by boosting the use of CNG fuel in this sector is lower than in the private car sector—only 6% of private cars—and this is obvious in comparing the first and second policy as shown in Figure 12.

In the discussion of reducing CO$_2$ emissions as a result of implementing Technology Improvement, CNG Competitive Price, Government support for CNG fuel for public Transport sector and Synthetic policies, the amount of CO$_2$ emissions in each of these policies respectively is 10.78, 10.94, 11.22, 9.99 million tons in 2030 as shown in Figure 13.

Compared to the BAU scenario, CO$_2$ emissions shows the greatest reduction under the synthetic policy and under low carbon scenario as shown in Figure 13. The technology improvement sub-policy will have the greatest effect on reducing CO$_2$ emission after synthetic policy. Although this sub-policy is less effective on increasing the share of CNG-fueled private cars than the CNG competitive price sub-policy, it has greater impacts on reducing CO2 emissions, because it affects not only the CNG replacement but also the reduction of CO2 emissions in each car. So, it reduces the emission of carbon dioxide in two ways”.

According to Iran’s commitment to the Paris Agreement, the emission of CO$_2$ in Iran should normally be reduced by 4% in 2030 compared to its amount in the BAU scenario. As seen in the previous section, by applying the combination of the first and second policies, namely the implementation of the synthetic policy, CO$_2$ emission will decrease by 11.42% in 2030 compared to the BAU scenario in this year. Therefore, in the transport sector, Iran can rapidly fulfill its obligations only by replacing gasoline and diesel fuel with CNG. In addition, Iran has pledged to reduce its CO$_2$ emissions by another 8% under conditions such as lifting sanctions against Iran, international financial and technological support. Given the reduction of CO$_2$ emissions in the synthetic policy, Iran could also fulfill its additional commitment in the transport sector. Whilst, with the
lifting of sanctions against Iran and international financial and technological support, the technology will be much easier to improve.

CONFLICT OF INTEREST
The authors declare that no conflict of interest.

REFERENCES


