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Investigating the Impacts of Retrofitted CNG Vehicles on Air Pollutant Emissions in Tehran

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ABSTRACT: The present study was conducted to investigate the impacts of retrofitted CNG vehicles on air pollutant emissions in Tehran over a 20 years period using available statistical data, precise automobile tests, data analysis, and LEAP Software. The obtained results revealed an increase in air pollutant emissions including CO (equal to 1030.77 thousand tons), NO_x (equal to 1030.77 thousand tons), THC (269.02 thousand tons) and CO_2 (equal to 38.43 thousand tons) resulting from utilizing retrofitted CNG vehicles within the studied period. Considering the obtained results, if the current trend of producing retrofitted CNG vehicles continues, a total cost of 435 million USD will impose on the environment, annually. According to the emission test results, by implementing retrofitted CNG vehicles policy, a higher emission rate of dual-fuel vehicles will be expected compared to their petrol-fueled counterparts. This is due to poor quality of the policy implementation such the use of substandard conversion kits and old technology of retrofit technologies.

Key words: Modeling, LEAP, Emission, Factors, Test, Retrofit, Vehicles, Natural gas

INTRODUCTION

Air pollution has been widely discussed as a controversial issue during recent decades (Fotouhi and Montazeri, 2012; Nejadkoorki and Baroutian, 2012; Zahran, 2013; Araizaga *et al.*, 2013; Shafie-pour and Tavakoli, 2013; Chianese *et al.*, 2012; Balabanova *et al.*, 2012; Barrera *et al.*, 2012; Katsura, 2012; Lee *et al.*, 2012; Zou *et al.*, 2011; Montero Lorenzo *et al.*, 2011; Halek *et al.*, 2010; Chiou *et al.*, 2009). Around 70% of deaths from respiratory and cardiovascular diseases in Tehran City occur due to severe air pollution (Gholizadeh *et al.*, 2009). As one of the main factors of air pollution hazard in Tehran, approximately 96.8% of CO emission is omitted by transportation sector (IEBSa, 2008). Nowadays, a special attention has been paid on the use of natural gas as an alternative to reduce air pollutant emissions of vehicles. Generally, the upward trend of fuel consumption and increased air pollutant emissions reveal the necessity of utilizing alternative fuels in transportation fleet (Karbassi and Qadyani, 2009). In a country like Iran, with abundance natural gas resources, the use of natural gas fuel, especially by automotive industries seems appropriate. Natural gas has been used an alternative fuel since 1920. However, the ease of consuming other liquid fossil fuels resulted in limited use of this fuel in certain countries (Karbassi and Qadyani, 2009). Iran, with more than three billion USD investment in substituting petrol with natural gas as the standard fuel of transportation fleet is one of the pioneer countries in substituting retrofitted CNG vehicles with gasoline-powered ones (Hamayesh Sanat Co., 2009). Over 1.8 million retrofitted CNG vehicles and more than 9.4 MCM of CNG consumptions in Iran (IHBS, 2009) prove the importance to study the emission of these types of vehicles and their imposed environmental costs. Apart from advantages of using natural gas, its consumption can be associated with some problems including air pollution, safety hazards, environmental costs, etc. the old dual-fuel technologies, old generation of conversion kits and no periodic monitoring and inspections creates doubt whether converted vehicles will be helpful in reducing air pollutant emissions or not. Literature reviews on air pollutant emissions of retrofitted CNG vehicles can

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be divided into two general categories. The first category is relevant to studies that generally consider retrofitted CNG vehicles beneficial or harmful to reduce air pollutant emissions while the second category studies separately examine emission factors to analyze the behavior of each of vehicles after converting them into a dual-fuel mode. The first group of studies is divided into two categories. The first category of studies confirms CNG as a clean fuel which can reduce emissions. In this regard, it can be referred to a study that compared NGVs (Natural Gas Vehicles) and gasoline-powered vehicles. They concluded that in spite of higher finished product price, NGVs would be an opportunity to achieve higher level of environmental standards (Di Pascoli, 2001). Engerer and Horn (2010) believed that CNG is a suitable alternative fuel for European automobiles. Lower emission of NGVs is the main reason for proposing such vehicles to European countries in order to reduce air pollution and comply with environmental standards. Korakianitis *et al.* (2011) declared that although numerous problems exist in the path of developing NGVs, the benefits of employing such vehicles are valuable. By comparing the emissions of diesel engine and CNG buses as well as investigating their environmental costs, Ari Rabl (2002) concluded that the use of CNG buses is cleaner and more cost-effective according to European standards. The latter category of the first group studies condemns retrofitted CNG vehicles due to increased air pollutant emissions. For example, Nguyen et al. (2011) measured the level of CO and CH4 emissions on a daily and seasonal basis, after execution of CNG vehicles production program in two urban and suburban districts within two periods; four years (1996-2000) and six years (2001-2007). The obtained results showed elevated levels of the emissions after executing NGVs produce. Ejaza *et al.* (2009) exposed mice to the exhaust outlet of vehicles consuming CNG fuel. The results revealed the risk of pathogenic diseases caused by the use of CNG vehicles that can cause cancer in a long term. The second group of studies attempt to examine different emission factors from retrofitted CNG vehicles in comparison with gasoline-powered ones. For example, in a research performed by Aslam *et al.* (2006) in Malaysia the emissions of CNG retrofitted and gasoline-powered vehicles were separately examined. They concluded that in spite of 30% increase in NOx emission and reduction of 15% of the vehicle power; NGVs release CO equal to 40-50% and HC equal to 35-50% less than the gasoline-powered vehicles. Dondero and Goldenberg (2005) carried out a research in Brazil as one of the pioneers in development of CNG retrofitted vehicles. They concluded that compared to gasoline-powered vehicles, utilization of third generation conversion kits in CNG retrofitted vehicles will result in reduction of CO emissions equal to 53%, non-methane hydrocarbon emissions equal to 66%, and CO_2 emissions equal to 20%. In contrast, HC and NO_x emissions were increased 162% and 171%, respectively. Jahirul *et al.* (2010) carried out a research on an automobile converted with an advanced conversion kit in 2 modes of petrol and CNG to measure the amount of emissions in two states (50% and 80% of throttle maximum is opened). The obtained results showed a significant reduction of unburned hydrocarbons, carbon monoxide, oxygen and carbon dioxide in the exhaust of NGVs set in CNG mode. Moreover, NO_x emission increased 41% when 50% of throttle maximum was opened. Approximately 38% of NOx emissions were increased in case of opening 80% of throttle maximum. In another study, Joseph (2010) made a comparison between some parameters of dual-fuel and diesel-fuel engines. The obtained results showed that NOx production rate at low engine speeds is much less than the single-fuel engines while at high speeds, the value is much higher due to high temperature. The CO and CO_2 levels show lower values in dual-fuel engines. Pourkhesalian (2010) examined the effect of alternative fuels including propane, butane, methanol, methane, petrol, and hydrogen on the engine output power, fuel consumption, SOx and CO emissions. The findings revealed that NO_x emission decreases respectively by consuming methane, hydrogen, petrol, propane, ethanol, and methanol at low engine speed. In a report presented by Nyulund and Lawson (2000) to the International Association of NGVs, it was emphasized that in order to use natural gas in automobiles, appropriate technologies must be employed. For example, the NO_x emission can greatly be reduced, if a suitable catalyst for NGVs is applied, otherwise, it will inevitably be increased. However, considering the unknown impacts of NGVs emissions and their environmental costs on air pollution of Tehran, it seems necessary to conduct a study focusing on the impact of NGVs.

MATERIALS & METHODS

Tehran Province with an area of around 18,814 m^2 consists of 15 townships, 37 counties, 56 cities, and 83 villages. It is situated between the longitude of 55° 10' E and latitude of 36° 21' N. According to 2006 Census announced by Statistical Center of Iran (SCI), the city has a total population of 13,422,366 inhabitants (IYCB, 2009). In this research, the required data on the study area, its socioeconomic structure as well as the number and characteristics of dual-fuel vehicles was initially collected and inputted into LEAP Software (Heaps, 2012). Afterwards, three scenarios were designed to examine the impact of retrofitted CNG vehicles on air pollutant emissions in Tehran.

The first scenario so called reference scenario assumes that the current production trend of dual-fuel vehicles will be continued while the second scenario supposes production freeze of these vehicles. The third scenario is based on Iran's Energy Demand Plan, known as Total Transportation Policy. Accordingly, in this research, the air pollutant emissions and environmental costs associated with dual-fuel vehicles in Tehran were investigated and compared through the mentioned scenarios.

-The following data were collected at first phase of the current research: Statistical information on the total number of produced petrol and retrofitted CNG vehicles (NIOC, 2009).

-The amount of emission factors omitted by zero-kilometer retrofitted CNG and gasoline-powered vehicles (in Gas and Petrol modes) (Table 1) (IFCO, 2011).The increasing trend of emission factors for gasoline-powered vehicles.

-An example of increasing trend of air pollutant emissions by Pride Vehicle is given in Fig. 1. These trends were entered into the LEAP in the form of linear and nonlinear coefficients to forecast the emission status of the vehicles in future (Fig. 1 a, b).

-Environmental costs due to air pollutant emissions (IEBS, 2008b).

a)Socio-economic information of Tehran Province including the current population, the population growth rate, GDP, inflation rate, interest rate, GDP growth rate, etc (TCTTSR Co., 2008).

-Other required input data for LEAP including worn out age, private vehicle mileage, taxi and pick-up, fuel price, income elasticity, and related regulations and standards (IFCO, 2010).

At this stage, using the normal distribution statistical method, a total number of 19 retrofitted CNG vehicles were selected as a statistical society (Table 2). For every one year of vehicle life, 20000 km ±%10 is added to the vehicle mileage. Emission tests were carried out in two credible laboratories of SAIPA Research Center and Iran Khodro Power Train Co. (IPCO) that are equipped with Emissions Testing Chassis Dynamometer (ETCD). The SAIPA Research Center is equipped with an analyzer from Austrian manufacturer AVL, and IPCO uses an analyzer from HORIBA, Japan. These tests are conducted based on European standards (91/441/EEC) in which automobiles are placed on a dynamometer chassis to go through a driving cycle. Finally, by collecting pollutants and transferring them to the analyzer, the precise amount of emission mass is calculated for three; urban, suburban, and combined cycles.

The air pollutant emissions calculated at this stage, along with emissions of zero-kilometer and dual-fuel vehicles were gathered in a comprehensive database called Emission Factor Profile (EFP).

Long-Range Energy Alternative Planning Systems (LEAP) is a scenario-based comprehensive modeling tool for energy, economic, and environmental analyses. Due to flexible data structure, LEAP provides the possibility of powerful analysis of technology specifications, details of final consumption and air pollutant emissions according to user selection. In this project, LEAP was employed to model the effects of policies promoting the use of natural gas as an alternative fuel on air pollutant emissions and its costs in a 20-year trend starting from the base year 2006. In this regard, three scenarios were considered. Table 3a represents main key assumptions of the present study. The first one so-called reference scenario estimates the pollution status and its environmental costs for the next 20 years, if the current trend of producing retrofitted CNG vehicles continues. The second scenario named as None CNG Scenario focuses on manufacture and conversion freeze of retrofitted CNG vehicles the main objective of this research to investigate, the effects retrofitted CNG vehicles on air pollutant emissions.

The third scenario was designed based on the country's Total Transportation Policy (TTP), in which the trend of changes in fuel and fleet is mainly emphasis on substituting petrol-fueled automobiles with light diesel engines (Table 3b).

RESULT & DISCUSSION

This type of information was obtained based on the methods and statistics. The air pollutant emission of retrofitted CNG vehicles analyzed based on three factors including NOx, CO, and HC are given in Table 4. In addition, the amount of CO_2 was measured to calculate environmental costs caused by greenhouse gas emissions. It is noteworthy that the obtained data are sorted according to the age of the vehicles. Finally, the obtained results were inputted into the software. Fig. 2 derived from Table 4, is an example of air pollutant emissions of Pride Car changing based on the vehicle mileage.

In this study, emission rates were predicted based on the proposed scenarios including reference scenario (which emphasizes on keeping the current trend), No-CNG Scenario focusing on production freeze of retrofitted CNG vehicles, and the scenario developed based on the country's Total Transportation Policy. In this study, emission changes were examined in a 20-year period from 2006 (as the base year) till 2026. The impacts of retrofitted CNG vehicles on air pollutant emissions are depicted in Figs. 3-6 through absolute and cumulative emission charts.

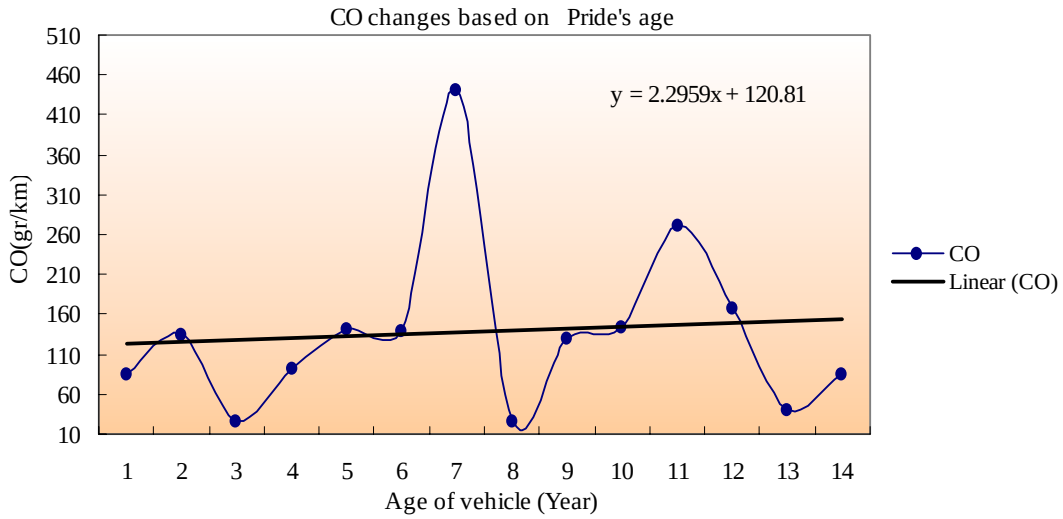


Fig. 1. (a) Increasing trend of CO emission in Pride vehicles

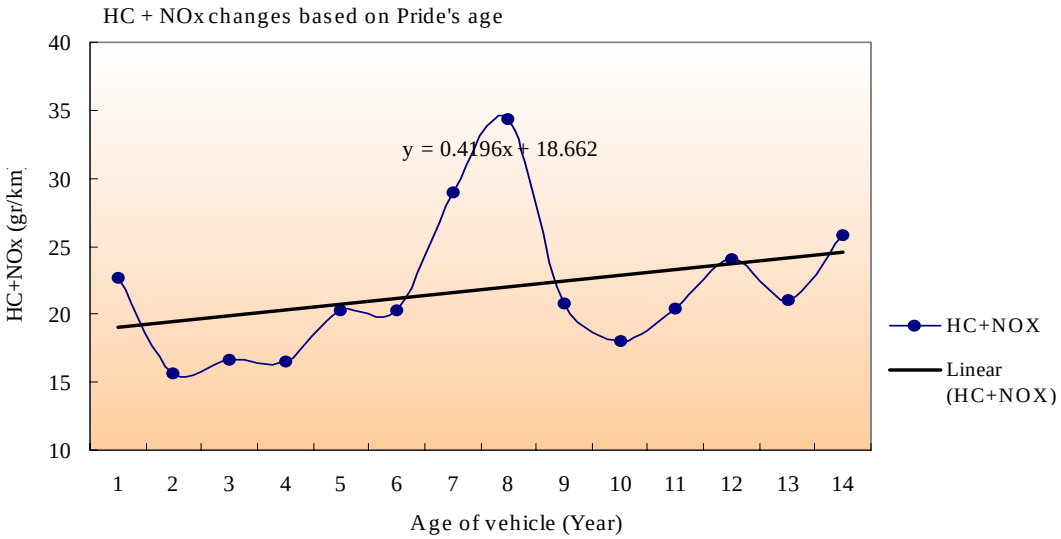


Fig. 1. (b) Increasing trend of HC + NOx emission in Pride vehicles

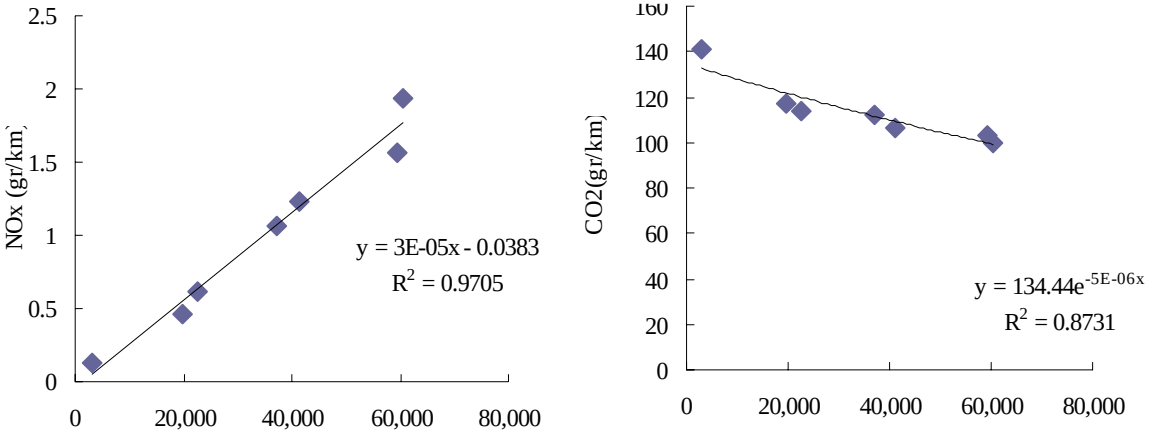
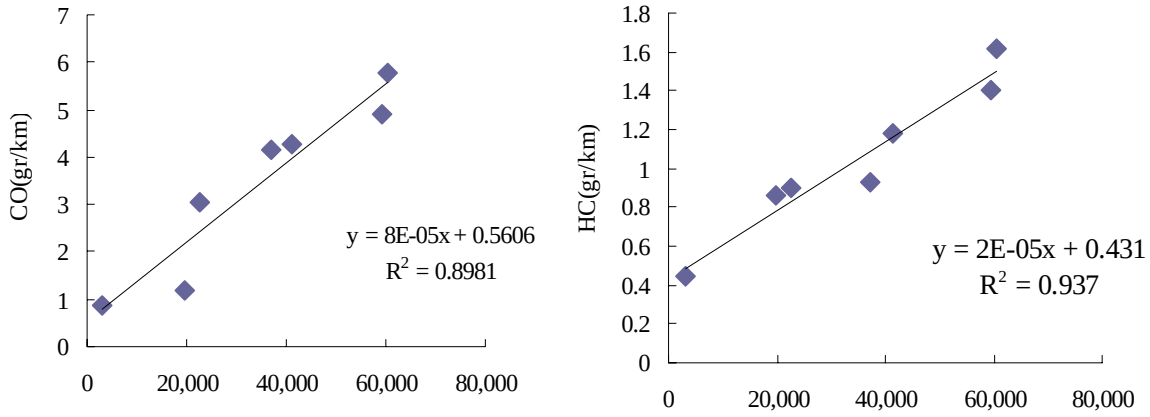


Fig. 2. changes in emissions against the distance travelled by Pride Car



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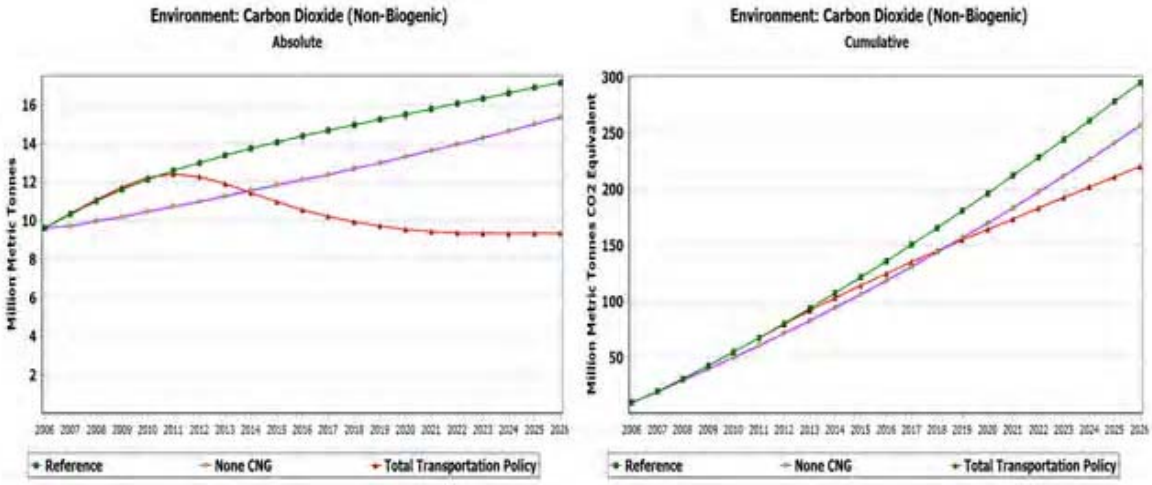

Fig. 3. Absolute and cumulative CO_2 trend as a global warming index in the proposed scenarios

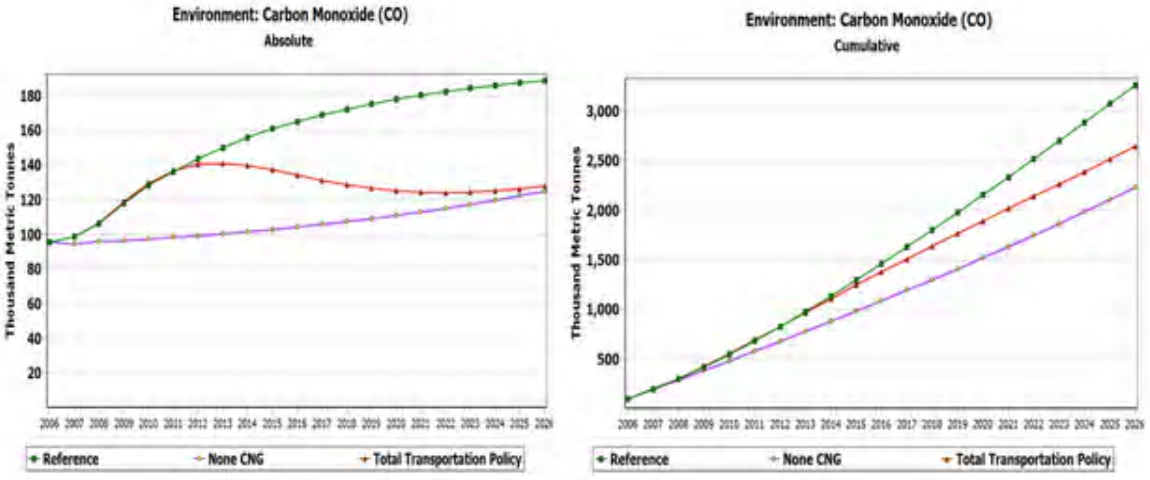

Fig. 4. Absolute and cumulative CO trend in the proposed scenarios

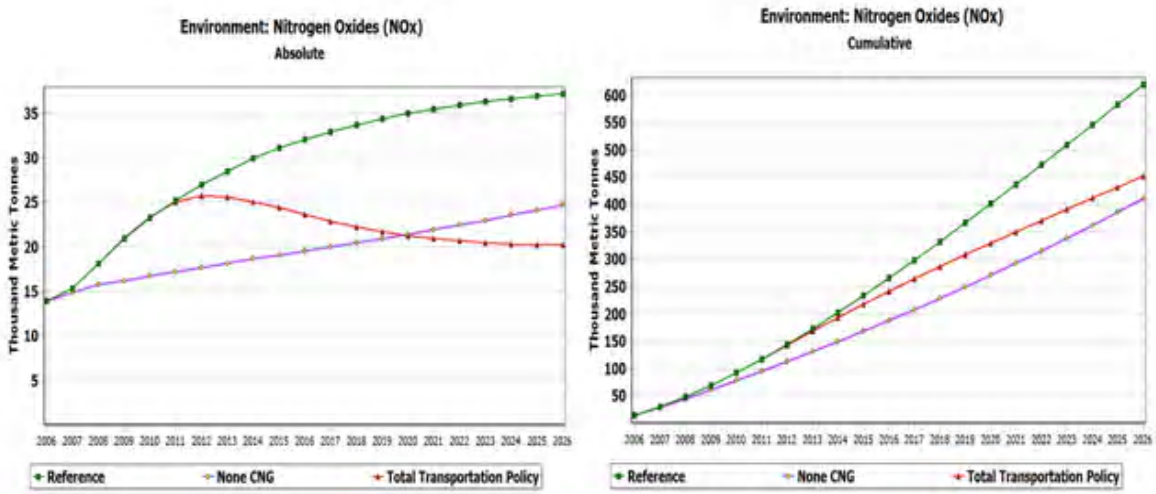

Fig. 5. Absolute and cumulative NO_x trend in the proposed scenarios

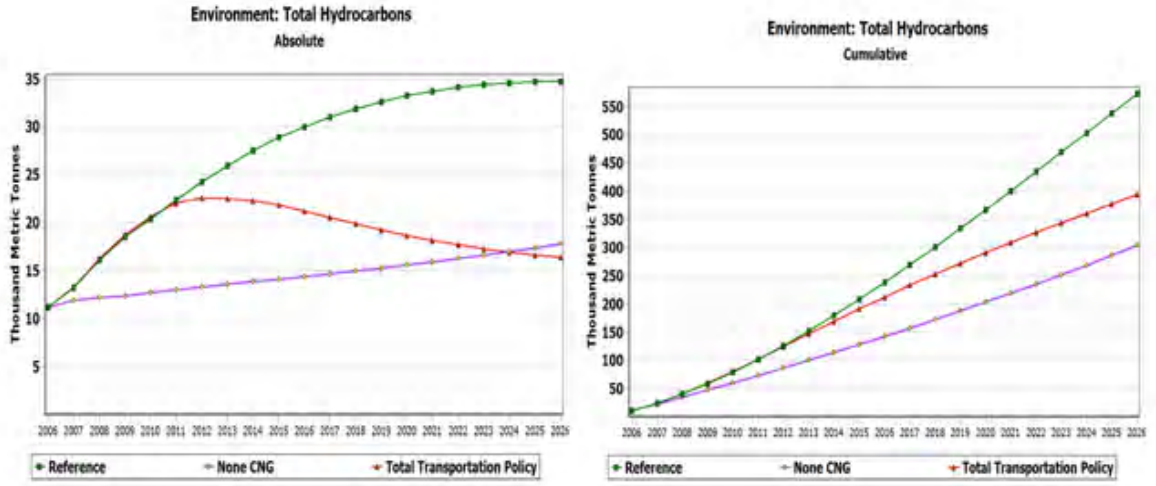

Fig. 6. Absolute and cumulative HC trend in the proposed scenarios

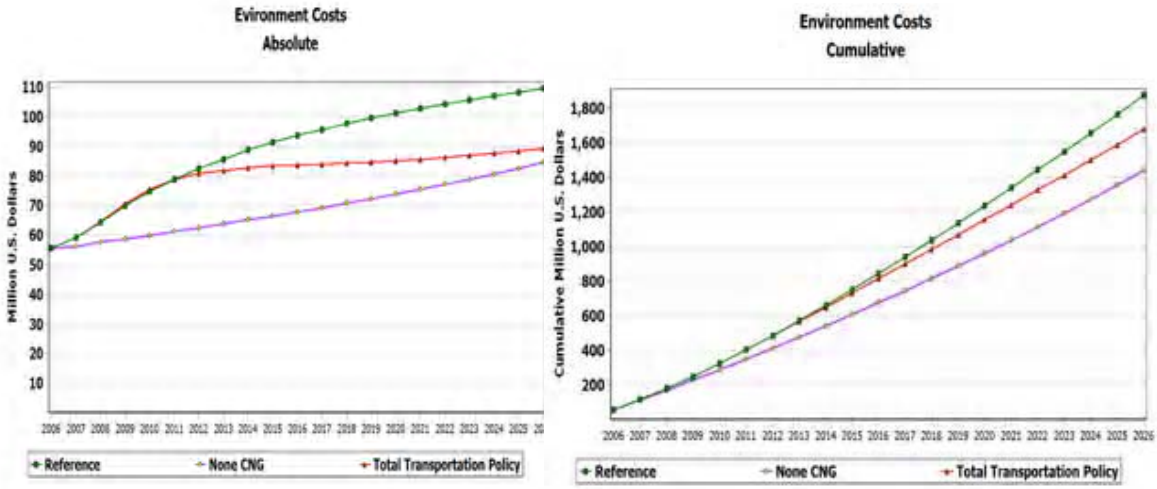

Fig.7. Absolute and cumulative trend of externality costs due to generated emissions based on the proposed scenarios

In this research, the data presented by World Bank, Department of Environment (DOE) and energy balance sheet of the year 2008 were collected to calculate the external cost of the proposed scenarios (Fig. 7).

Although Iran has been one of the pioneers in converting gasoline-powered vehicles to natural gas vehicles (NGVs), however, the applied conversion kits are a far cry from international standards. European countries such as Italy, prior to Iran, have focused on the use of NGVs, and many conversion kits, currently used in Iran (or even in the world) have been developed by Italian companies. Other countries including Germany, France, and Japan have less experience than Iran in utilizing NGVs. However, the NGVs produced in these countries have a great technological superiority over the Iranian ones. These vehicles have much better performance than those manufactured by Iran.

The obtained results suggested that joining dual-fuel vehicles to Tehran's transportation fleet has adversely affected the air pollution status. By comparing the results of the proposed scenarios, Figs. 3 to 6 show clearly the negative impact of utilizing the conversion kits. In the year 2011, the difference in CO emission – as most important emission factor affecting human health– was approximately 105 thousand tons, which is expected to be raised to 1031 million tons by the year 2026. Moreover, the environmental costs of NGVs were approximately 53 million USD in year the 2011. This value expected to reach its peak of 435 million USD until the end of the year 2026, if the current trend of retrofitted NGVs production continues.

According to the emission test results, as the age of retrofitted NGVs increases, their air pollutant emissions goes up; higher than petrol-fueled vehicles. This is due to disregard for proper implementation of "dual-fuel vehicle" policy. The engine of NGVs must specially be designed for dual function. However, several parameters such as fuel intake system, quality of gas supplied in CNG fueling stations and engine design affect on exhaust emissions from NGVs which are separately be discussed in the followings.

One of the manifest differences between the technologies used in Iran, compared to their foreign counterparts is their fuel intake systems. The fuel intake system equipped with a mixer possesses include a major share of dual-fuel vehicles in Iran. Such a system is outdated and no longer used in other parts of the world. This elementary technology causing increased fuel consumption leads to increased emission rates. The scientific proofs for this issue are as follows:

-Fuel intake system with a mixer, which comprises first and second generation of conversion kits, does not have much control over fuel consumption. The amount of fuel entering the mixer is only determined based on relative pressure drop, which is a function of inlet airflow velocity. Therefore, there is no precise control over the amount of fuel and emissions from fuel consumption.

-The air and fuel mixer is composed of a venture to increase velocity and reduce relative air pressure. This creates a resistance on the path of inlet air to the engine and increases pumping losses. Therefore, the output power of such engines, even when working with petrol fuel, is less than similar petrol- powered engines. Accordingly, the excess fuel must be consumed to compensate the shortage caused by power drop. Accordingly, due to reduced engine volumetric efficiency, the output power is decreased once again when using the automobile in a gas mode. This will cause an increase in fuel consumption and consequently, lead to higher emission rates.

Benefiting from Gas Direct Injection (GDI) inside cylinders is a technology applied by foreign automakers. Considering the advantages, significant investment has been put on GDI. However, this technology is not applied in domestic manufactured products. High output power, as well as lower emissions and fuel consumption are some of the capabilities resultant from using this technology. Considering that natural gas is one of the strategic fuels of Iran's transportation system, investing on GPI will be useful in order to take advantage of NGVs in future.

Utilizing lean-burn technology applied turbochargers, can significantly increase output power, and reduce emissions to Euro 5 standard level. It seems that codification and development of turbocharged CNG engines has no place among domestic automobile manufacturers. Therefore, necessary measures should be considered in long-term development plans of Iran's automotive industry to enjoy the benefits of such motors.

Given the higher octane number of natural gas compared to the other common fuels; it is possible to use engines with higher compression ratio. Considering that the majority of domestic retrofitted CNG vehicles are converted from petrol-fueled vehicles (petroleum-based engines), their compression ratio has remained unchanged. Accordingly, it is not possible to benefit from the advantages of high octane gas. The output power will certainly be enhanced, if the possibility of raising the compression ratio on these engines is provided. In addition, any increase in compression ratio leads to a higher thermal performance. This, in turn, will directly decrease fuel consumption and air pollutant emissions. Therefore,

an increase in compression ratio will result in a higher performance with lower air pollutant emissions.

Unfortunately, the VVT Technology is not found in domestic vehicles. This feature enables the engine to change valve timing based on different loads and speeds. Hereby, it can keep the engine working conditions around the optimum point. Optimal functioning of the vehicle will also lead to increased efficiency and reduced air pollutant emissions.

Depending on selected engine (stoichiometric or lean-burn), rotation rate generated in the combustion chamber is of great importance. It influences on fuel quality and combustion by-products. Therefore, it is necessary to control the rotation speed in the cylinder in accordance with what is needed, by redesigning the form of piston bowl and entry manifold. These types of designs are not done on petroleum-based engines whereas their initial designing is just suited for gasoline fuel. This will affect the optimum function of engines.

Other effective parameters that could not be categorized under the previous items are as follows:

One of reasons resulting in reduction of output power in retrofitted CNG engines compared to similar petrol-fueled engines would be the increased engine weight due to overweight of high pressure cylinder tanks. By utilizing optimized manufacturing technologies and mass production, lightweight, high pressure cylinder tanks can be manufactured at lower prices. This will reduce the emissions by reducing the overall weight of the vehicle.

Considering the habitual use of private vehicles, the automobiles are used for a relatively long time in Iran. Obviously, it is necessary to make certain modifications over time on the hardware and software of automobiles especially NGVs. Some of the modifications are minor so that there is no need for fundamental changes in the systems of existing vehicles. Therefore, by applying these minor modifications, their fuel consumption can easily be optimized making public announcements for summoning NGVs through authorized representatives of automobile manufacturers, minor modifications including adjustment or replacement of parts or upgrading ECU software can be made.

As the result suggests, poor quality of gas being used in NGVs is one of the factors increasing the level of air pollution in Iran. The result of the current study confirms the claim. The main reasons for the poor quality of fuel are lack of adequate supervision on gas compressing stations as well as improper repair and maintenance. According to studies conducted by IFCO (2010), water content in CNG stations in Tehran City is about four times higher than the standard levels (50ppm for CNG stations and about 200ppm for delivered fuel). The amount of oil in the samples was approximately 20 times higher than the standard level. This is due to no regular evacuation of filters specified to this operation. According to the standards presented by National Iranian Gas Company (NIGC), the amount of solid particles in the gas delivered from the refinery is to be zero. Nonetheless, it is 50 times above the standard in some stations throughout Tehran. This is due to lack of on-time periodic maintenance of these stations and gas transmission lines. As mentioned earlier, there are a bunch of studies that consider NGVs suitable in terms of environmental issues. However, it is clear that utilizing this type of vehicles requires fulfillment of certain conditions. As have already been mentioned in literature reviews, some studies confirm the finding. Based on the obtained results, the following solutions are proposed to mitigate air pollutant emissions in retrofitted CNG vehicles:

-Development of domestic manufacturing of CNG vehicles can be considered an inflection point in the country's automobile manufacturing industry. This type of engines are specifically designed for natural gas and do not have many of the problems facing the present retrofitted CNG vehicles.

-It should be noted that all measures required to manage vehicle emissions are not limited to the engine. Therefore, by applying advanced technologies used by other automobile manufacturers, the emissions can be reduced to the level of international standards.

-The conversion of the vehicles in miscellaneous companies must be halted. The environmental costs due to air pollutant emissions of such vehicles are far more than the cost of employing these technologies. Therefore, upgrading converting kits in the country is considered one of the effective solutions in achieving this goal.

-Allocation of a part of the consumed fuel and applied technologies used to the cleaner ones would be another executive solution to mitigate air pollutant emission levels. For example, utilizing light-duty diesel vehicles as a strategic technology can greatly assist in reducing emissions from the transport fleet.

The significant point is that the abundance of this energy source should not be a reason for its improper consumption. The results show that such improper use of energy can cause irreversible damages.

CONCLUSION

Although the use of natural gas as a strategic fuel is economically feasible in Iran, however, it is quite necessary to pay enough attention to the fuel quality and the applied technology of retrofitted CNG vehicles. Reduction of air pollutant emissions including CO (equal to 1030.77 thousand tons), NOx (equal to 209.52

thousand tons), THC (equal to 269.02) and CO2 (equal to 38.43) as a result of production freeze of dual-fuel vehicles in Tehran reveal that this strategy has failed to meet expectations. This malfunction is due to the reasons such as failure to use appropriate technology, poor quality of fuel and lack of repair and maintenance of refueling stations and NGVs. Application of superior technologies to retrofit vehicles with a natural gas conversion system, proper supervision and periodic auditing of fuel stations and retrofitted CNG vehicles would be amongst effective strategies mitigate undesirable impacts caused by improper use of this technology in Tehran.

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REFERENCES

Araizaga, A. E., Mancilla, Y. and Mendoza, A. (2013). Volatile Organic Compound Emissions from Light-Duty Vehicles in Monterrey, Mexico: a Tunnel Study. Int. J. Environ. Res., **7 (2)**, 277-292.

Aslam, M. U., Masjuki, H. H., Kalam, M. A., Abdesselam, H., Mahlia, T. M. I. and Amalina M. A. (2006). An experimental investigation of CNG as an alternative fuel for a retrofitted gasoline vehicle. Fuel, **85**, 717–724.

Balabanova, B., Stafilov, T., Šajn, R. and Baèeva, K. (2012). Characterisation of Heavy Metals in Lichen Species Hypogymnia physodes and Evernia prunastri due to Biomonitoring of Air Pollution in the Vicinity of Copper Mine. Int. J. Environ. Res., **6 (3)**, 779-794.

Barrera, V. A., Miranda, J., Espinosa, A. A., Meinguer, J., Martínez, J. N., Cerón, E., Morales, J. R., Miranda, P. A. and Dias, J. F. (2012). Contribution of Soil, Sulfate, and Biomass Burning Sources to the Elemental Composition of PM10 from Mexico City. Int. J. Environ. Res., **6 (3)**, 597-612.

Chiou, P., Tang, W., Lin, C. J., Chu, H. W. and Ho, T. C. (2009). Comparison of Atmospheric Aerosols between Two Sites over Golden Triangle of Texas, Int. J. Environ. Res., **3 (2)**, 253-270.

Chianese, E., Riccio, A., Duro, I., Trifuoggi, M., Iovino, P., Capasso, S. and Barone, G. (2012). Measurements for indoor air quality assessment at the Capodimonte Museum in Naples (Italy). Int. J. Environ. Res., **6 (2)**, 509-518.

Dondero, L. and Goldemberg, J. (2005). Environmental implications of converting light gas vehicles: the Brazilian experience. Energ. Policy, **33**, 1703–1708.

Ejaza, S., Chekarova, I., Ahmad, M., Nasir, A., Ashraf, M. and Woong Lim, C. (2009). Pollution dilemma in Asian population: CNG and wound healing. Environ. Toxicol. Phar., **28**, 323–332.

Engerer, H. and Horn, M. (2010). Natural gas vehicles: An option for Europe. Energ. Policy, **38**, 1017–1029.

Fotouhi, A. and Montazeri, Gh. M. (2012). An Investigation on Vehicle's Fuel consumption and Exhaust Emissions in Different Driving Conditions. Int. J. Environ. Res., **6 (1)**, 61-70.

Gholizadeh, M. H., Farajzadeh, M. and Darand, M. (2009). The connection between Tehran's pollution and mortality. Hakim Res. Mag. **12**, 269-272, in Persian.

Halek, F., Keyanpour, M., Pirmoradi, A. and Kavousi, A. (2010). Estimation of Urban Suspended Particulate Air Pollution Concentration, (2010). Int. J. Environ. Res., **4 (1)**, 161-168.

Hamayesh Sanat Co. (2009). Official website of the 33rd Seminar and Exhibition for CNG and dependent industries, Tehran, Iran.

Heaps, C. G. (2012). Long-range Energy Alternatives Planning (LEAP) system. [Software version 2011.0043] Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org

IEBS, (2008a). Iran Energy Balance Sheet, pp. 269, Ministry of Power, Tehran, Iran.

IEBS, (2008b). Iran Energy Balance Sheet, Ministry of Power, pp. **272,** Tehran, Iran.

IFCO, (2010). Energy demand modeling in transportation sector, Iranian Fuel Conservation Organization, Tehran, Iran.

IFCO, (2011). Emission and fuel consumption of transportation fleet. Iranian Fuel Conservation Organization, Tehran, Iran.

IHBS, (2009). Book of Iran's Hydrocarbour Balance Sheet, Ministry of Power, Tehran, Iran.

IYCB, (2009). Iran's Yearly Census booklet, Statistical Centre of Iran, Tehran, Iran.

Jahirul, M. I., Masjuki, H. H., Saidur, R., Kalam, M. A., Jayed, M. H. and Wazed, M. A. (2010). Comparative engine performance and emission analysis of CNG and gasoline in a retrofitted car engine. Appl. Therm. Eng., **30**, 2219-2226.

Karbassi, A. and Qadyani, N. (2009). Natural Gas and Automobiles, Automotive Industry Magazine, **135**, 66-70.

Katsura, H. (2012). The Effect of Latitude on Carbon, Nitrogen and Oxygen Stable Isotope Ratios in Foliage and in Nitric- oxide ions of Aerosols, Int. J. Environ. Res., **6 (4)**, 825-836.

Korakianitis, T., Namasivayam, A. M. and Crookes, R. J. (2011). Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions. Prog. Energ. Combust., **37**, 89-112.

Lee, J. G., Lee, K. H., Choi, H. I., Moon, H. I. and Byeon, S. H. (2012). Total Dust and Asbestos Concentrations during Asbestos-Containing Materials Abatement in Korea, Int. J. Environ. Res., **6 (4)**, 849-852.

Montero Lorenzo, J. M., Garcia-Centeno, M. C. and Fernandez-Aviles, G. A. (2011). Threshold Autoregressive Asymmetric Stochastic Volatility Strategy to Alert of Violations of the Air Quality Standards, Int. J. Environ. Res., **5 (1)**, 23-32.

Nejadkoorki, F. and Baroutian, S. (2012). Forecasting Extreme PM10 Concentrations Using Artificial Neural Networks. Int. J. Environ. Res., **6 (1)**, 277-284.

NIOC, (2009). National Iranian Oil Company, vehicles Statistics, Tehran, Iran.

Nylund, O. N. and Lawson, A. (2000). Exhaust emission from natural gas vehicles. A report prepared for the IANGV Technical Committee, Tehran, Iran.

Pascoli, S. D., Femia, A. and Luzzati, T. (2001). Natural gas, cars and the environment. A (relatively) 'clean' and cheap fuel looking for users. Ecol. Econ., **38**, 179–189.

Pourkhesalian, A. M., Shamekhi, A. H. and Salimi, F. (2010). Alternative fuel and gasoline in an SI engine: A comparative study of performance and emissions characteristics. Fuel, **89**, 1056–1063.

Rabl, A. (2004). Environmental benefits of natural gas for buses. Transport. Res. D-TR E, **7**, 391–405.

RIPI, (2010). Monitoring and quality control of compressed natural gas (CNG), gasoline and diesel. Research Institute of Petroleum Industry (RIPI), Tehran, Iran.

Shafie-Pour, M. and Tavakoli, A. (2013). On-Road Vehicle Emissions Forecast Using IVE Simulation Model. Int. J. Environ. Res., **7 (2)**, 367-376.

TCTTSR Co. (2008). Tehran Comprehensive Transportation and Traffic Studies and Research Company, Tehran's transportation and traffic at a glance, Tehran, Iran.

Thi Nguyen, H., Kim, K. H., Ma, C. J., Cho, S. J. and Ryeul Sohn, J. (2010). A dramatic shift in CO and CH4 levels at urban locations in Korea after the implementation of the Natural Gas Vehicle Supply (NGVS) program. Environ. Res., **110**, 396–409.

Yusaf, T. F., Buttsworth, D. R., Saleh, Kh. H. and Yousif, B. F. (2010). CNG-diesel engine performance and exhaust emission analysis with the aid of artificial neural network. Appl. Energ., **87 (5)**, 1661–1669.

Zahran, E. M. M. (2013). A Novel Approach to Improve the Air Quality Predictions of Air Pollution Dispersion Modelling systems. Int. J. Environ. Res., **7 (1)**, 205-218.

Zou, B., Zhan, F. B., Zeng, Y., Yorke, Ch. and Liu, X. (2011). Performance of Kriging and EWPM for Relative Air Pollution Exposure Risk Assessment, Int. J. Environ. Res., **5 (3)**,769-778.