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Estimation of carbon dioxide emissions using liquefied petroleum gas (LPG) in some Libyan cities as an alternative fuel

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ABSTRACT

This study assessed the use of liquefied petroleum gas (LPG) as an alternative fuel to petrol. in the transport sector, focusing on environmental and economic aspects and its potential application in certain Libyan cities. Liquefied petroleum gas is considered a relatively cleaner fuel, as it is characterized by lower emissions of harmful gases compared to petrol The practical aspect of the study involved comparing carbon dioxide emissions resulting from the use of petrol and LPG in a number of Libyan cities with high traffic density, namely: Tripoli, Benghazi, Misrata, Zawiya, Sabha, Al-Khums, and Tobruk. Emissions were calculated. on the assumption that each vehicle travels 100 kilometres per day, comparing the consumption of petrol and LPG and the emissions resulting from each. The results showed that the use of LPG reduces carbon dioxide emissions by approximately 22% compared to petrol, with emissions falling from around 15.525 kg CO_2 to 12.1kg CO_2 per 100 kilometres per vehicle. The study also indicated that a partial switch of up to 25% of the total vehicle fleet could achieve a significant reduction in emissions within Libyan cities. The study concluded that liquefied petroleum gas (LPG) represents a practical and phased option for reducing environmental pollution and cutting traditional fuel consumption in Libya, particularly given the availability of local oil and gas resources.

تقدير انبعاثات ثاني اكسيد الكربون باستخدام غاز البترول المسال في بعض المدن الليبية كوقود بديل

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الكلمات المفتاحية:
الغاز البترولي المسال(LPG)
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الملخص

قيّمت هذه الدراسة استخدام غاز البترول المسال كوقود بديل للبنزين في قطاع النقل، مع التركيز على الجوانب البيئية والاقتصادية وإمكانية تطبيقه في بعض المدن الليبية. يُعتبر غاز البترول المسال وقودًا أنظف نسبيًا، إذ يتميز بانخفاض انبعاثاته من الغازات الضارة مقارنةً بالبنزين. تضمن الجانب العملي للدراسة مقارنة انبعاثات ثاني أكسيد الكربون الناتجة عن استخدام البنزين وغاز البترول المسال في عدد من المدن الليبية ذات الكثافة المرورية العالية، وهي: طرابلس، بنغازي، مصراتة، الزاوية، سبها، الخمس، وطبرق. حُسبت الانبعاثات بافتراض أن كل مركبة تقطع 100 كيلومتر يوميًا، وذلك بمقارنة استهلاك البنزين وغاز البترول المسال والانبعاثات الناتجة عن كل منهما. أظهرت النتائج أن استخدام غاز البترول المسال يُقلل انبعاثات ثاني أكسيد الكربون بنسبة 22% تقريبًا مقارنةً بالبنزين، حيث انخفضت الانبعاثات من حوالي 15.525 كيلوغرامًا من ثاني أكسيد الكربون إلى 12.1 كيلوغرامًا لكل 100 كيلومتر لكل مركبة. أشارت الدراسة أيضاً إلى أن التحول الجزئي لما يصل إلى 25% من أسطول المركبات يمكن أن يحقق انخفاضاً ملحوظاً في الانبعاثات داخل المدن الليبية. وخلصت الدراسة إلى أن غاز البترول المسال يمثل خياراً عملياً وتدريجياً للحد من التلوث البيئي وخفض استهلاك الوقود التقليدي في ليبيا، لا سيما في ظل وفرة موارد النفط والغاز المحلية.

1.Introduction

Liquefied Petroleum Gas (LPG), a modern, clean-burning energy carrier consisting of propane and butane, is an energy source that is socially, economically, and environmentally crucial for fostering growth and has been recognized in the implementation plan of the United Nations World Summit on Sustainable Development. LPG offers numerous real and tangible benefits in supplying energy to rural and semi-urban areas. LPG can play an important role in providing energy to those who currently lack it, either as a direct

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energy source or as a backup to other energy sources, including renewable energy sources such as wind, solar, and biomass [1].

Liquefied petroleum gas (LPG) is a relatively clean energy source consisting of a mixture of propane (C_3H_8) and butane (C_4H_{10}). It has the advantage of being easily converted to a liquid state under moderate pressure, which reduces its volume by about 270 times, thereby facilitating its storage, transport, and distribution for domestic and industrial purposes and as a vehicle fuel [2.3].

Liquefied petroleum gas (LPG) has a relatively high-octane rating compared to petrol. available at filling stations. Although the octane rating of LPG may vary depending on its composition, the higher the proportion of higher-order hydrocarbons than propane (such as butane), the lower the octane rating; and the opposite is true for lower-order hydrocarbons. Such as, methane and ethane, where the higher-octane rating of LPG compared to petrol offers advantages in performance and efficiency. It is also possible to use more advanced ignition timing and a higher compression ratio while reducing the likelihood of pre-ignition or knocking compared to petrol [4].

. Liquefied petroleum gas (LPG) is an alternative fuel used in road transport, with more than 27 million vehicles running on it globally in 2017, providing an immediate and tangible means of improving air quality, particularly in urban areas [5]. In terms of emissions of key regulated pollutants, Autogas is among the lowest-emitting motor fuels (6). Scientific studies indicate that LPG produces significantly lower levels of carbon monoxide, hydrocarbons, nitrogen oxides, and ozone precursors compared to petrol; this yields environmental and health benefits [2].

Around 17 million tons of liquefied gas were used on the roads in 2004, meaning that its share of transport fuel is estimated at around 1%. The total fleet of vehicles running on liquefied petroleum gas stood at more than 27 million vehicles globally in 2017, with gas use concentrated in specific markets. Five countries—Turkey, Russia, South Korea, Poland, and Ukraine accounted for nearly half of global automotive gas consumption in 2021 [5.6]. Poland has a high proportion of gas use in the transport sector. In 2019, LPG vehicles accounted for approximately 14.3% of all passenger cars in Poland [7].

Autogas plays an important role in mitigating the effects of climate change and global warming [6]. For example, on average, natural gas vehicles can produce 20% less carbon dioxide than petrol vehicles when total emissions from source to consumer are calculated, and when exhaust emission levels are tested, natural gas vehicles produce up to 15% fewer emissions [2].

By the early 2030s, alternative fuels will account for between 10% and 30% of vehicle fuel, depending on the policies adopted in this regard. This is because advanced biofuels are still in their early stages. There are three main drivers for the development of alternative fuels: the massive increase in demand for transport fuel in developing countries, the risk of oil running out sooner than expected, and the need to reduce greenhouse gas emissions by around 50% by 2050 [8].

Carbon dioxide is one of the main causes of emissions. The transport sector is considered the primary target for reducing carbon dioxide pollution with the aim of mitigating global warming, as this sector accounts for between 23% and 27% of total global carbon dioxide emissions (9). In particular, carbon dioxide emissions from the transport sector in developing countries are rising significantly, due to the substantial expansion in car use linked to rapid economic growth. Estimates suggest that carbon dioxide emissions from the transport sector in developing countries will increase significantly in the coming years, at an annual growth rate of 3.4%. [10]. Statistics from the World Health Organization show that these particulate emissions may be responsible for premature deaths and contribute to a number of health problems, such as cardiovascular and respiratory diseases and asthma [11,12].

1.1 Sources of LPG production

Liquefied petroleum gas is produced from two main sources: from natural gas processing, where approximately 60% of global production comes as a by-product during the separation of liquids from raw natural gas in gas plants. The remaining 40% is extracted during crude oil refining operations in refineries, particularly from distillation and catalytic cracking units [13.14].

1.2 Separation

The separation process is the first step, in which propane (C_3H_8) and butane (C_4H_{10}) are isolated from other components. In natural gas plants, LPG is separated as a by-product during the processing of raw gas, while in oil refineries it is extracted from the gases produced by atmospheric distillation and catalytic cracking units. Fractional distillation columns are used to take advantage of the different boiling points of the compounds [2].

From natural gas: Raw natural gas contains natural gas liquids (NGLs) comprising ethane, propane, butane, and pentane. In gas processing plants, the gas is cooled to very low temperatures to separate the NGLs, which are then fed into 'fractionation columns'. Separation is based on differences in boiling points: propane -42°C, butane-50°C

From oil refineries: LPG is produced during atmospheric distillation and in fluid catalytic cracking (FCC) and hydrocracking units. Refinery gas contains C3/C4 hydrocarbons and is sent to a Gas Recovery Unit for separation [2].

1.3 Purification

After separation, the gas undergoes a purification process to remove impurities that affect its quality and safety in the gas recovery unit. These impurities include water, hydrogen sulfide (H_2S), carbon dioxide (CO_2), and mercaptans. Purification is carried out using desulfurization units and glycol drying units or molecular sieves until the product meets international fuel specifications.

1.4 Liquefaction

The propane-butane mixture is liquefied by compressing it to approximately 8 to 10 bar at ambient temperature. This process reduces the volume of the gas by about 270 times, making it economical to transport and store [15]. The mixing ratio between propane and butane depends on climatic conditions: the proportion of propane increases in colder regions due to its higher vapor pressure [16]. Pressure: At 20°C, propane liquefies at 8.4 bar and butane at 2.2 bar [17]. The mixture is therefore typically stored at 8–10 bar [18]. Volume reduction: Liquefaction reduces the volume by approximately 1/270 compared to the gaseous state, making transport by sea and road cost-effective [15].

Control of blending ratio: European standard EN 589 specifies summer blends of 60% butane and 40% propane, and winter blends of 70% propane and 30% butane to ensure suitable vapor pressure in cold conditions.

Table 1: LPG Composition as Automotive Fuel in some Countries [19].

LPG Composition (% by volume)		
Country	Propane	Butane
Belgium	50	50
Denmark	50	50
France	35	65
Greece	20	80
Ireland	100	-
Italy	25	75
Netherlands	50	50
Spain	30	70
Sweden	95	5
United Kingdom	100	-
Germany	90	10

1.5 Storage and distribution:

Stored in spherical or cylindrical tanks and distributed to consumers via 71,000 refueling stations worldwide. The global market for LPG and CNG is estimated to reach $3.1 billion by 2025 and is expected to reach $5.8 billion by 2034, with a growth rate of 6.98%. The Asia-Pacific region is projected to account for 38.2% of the global market by 2025 [2.6]. The current trend points to continued growth in gas production and consumption due to advancements in LPG technology, changes in government emissions policies, and expansion in Eastern European and CIS markets. However, countries such as Australia, Japan, South Korea, and Germany saw a 17%

decline between 2013 and 2017 due to the proliferation of diesel and electric vehicles. The European Union is actively planning to phase out LPG as a vehicle fuel from 2030 as part of its emissions reduction policies [2].

1.6 Economic and market significance

The market for compressed natural gas (CNG) and liquefied petroleum gas (LPG) vehicles has seen significant growth, with the global market size estimated at US$3.1 billion in 2025 and projected to reach US$5.8 billion by 2034, at a compound annual growth rate (CAGR) of 6.98%. The Asia-Pacific region dominates the market with a share of over 38.2% in 2025 [2.11]. There are approximately 27 million LPG-powered vehicles in operation worldwide, known as 'Autogas' [20]. Distribution is uneven and concentrated in three main regions. Key countries: In Asia, particularly cities in South Korea, a global leader in LPG-powered taxis and buses. China: 18% of the Asia-Pacific market. India, Japan, Indonesia: Rapid growth due to urban expansion and pollution [21]. Europe—the largest in terms of vehicle numbers: 29% of the global market. Leading countries by vehicle numbers: Poland: world leader with 3.46 million vehicles running on LPG; Italy: 2.6 million vehicles; Germany: 0.38 million vehicles; and the United Kingdom: 5% of the European market [20]. North America—Largest by market value: 32% of the global market. Reason: Tighter CO_2/NO_x regulations and widespread use in commercial truck fleets [22.23].

Other regions: South America: Brazil and Argentina are active markets. Middle East and Africa: The fastest-growing, but with a total share of 9%. Nigeria, South Africa, and Saudi Arabia have expansion projects. Small countries: Macedonia 11,960 vehicles, Slovenia 11,240, Kazakhstan 4,070 [24].

1.7 Future trends in Libya

Several trends point to continued growth in the use of Autogas globally, driven by developments in LPG vehicle technology, changes in government emissions policies, and the potential expansion of the market in the Commonwealth of Independent States and Eastern Europe [2]. In contrast, developed countries such as Australia, Japan, South Korea, and Germany saw a 17% decline between 2013 and 2017 due to the proliferation of diesel and electric vehicles [17]. The European Union has also begun planning to phase out LPG as a vehicle fuel from 2030.

Despite its significant domestic use in Libya across various sectors, such as cooking, and given that it is a hydrocarbon, LPG is often overlooked because it does not explicitly fall into the category of renewable energy sources; it is cleaner than other fossil fuels and is a suitable fuel to support intermittent renewable energy sources such as solar and wind power [25].

Because it has a considerable drop in greenhouse gas emissions when compared to other commercially accessible fossil fuels like coal, light and heavy petroleum fuels, and natural gas in some applications, LPG can help with the shift to a low-carbon economy. Compared to traditional fuels used for cooking and household heating by billions of people in the developing world, such as biogas, kerosene, charcoal, animal dung, and wood, LPG emits considerably less greenhouse gas. Governments in developing nations should therefore make a strong case for supporting the LPG industry. Particularly given the positive contribution this fuel can make to more sustainable energy use. Government policies and measures can have a significant impact on the development of the LPG market.

Libya is among the countries with domestic LPG production, but the infrastructure for filling stations is limited. The government has been encouraging the switch to reduce consumption of subsidized petrol. However, this poses a direct challenge regarding public acceptance of the idea of switching to alternative energy sources to preserve a clean environment and save money; yet the matter remains on the back burner unless there is an effective implementation policy and a move away from the idea of subsidized fuel and the waste of money on petrol and diesel. Libya remains an oil-producing country, but it must move towards clean energy that serves the state, promotes sustainable development, and puts into practice the slogan of a clean environment with less pollution [3.26].

Libya is an oil and gas producing country with domestic liquefied petroleum gas (LPG) resources. However, research assessing the environmental benefits of using LPG as an alternative transportation fuel under Libyan conditions remains limited. Most previous studies have focused on technical performance or global experiences, while quantitative assessments of potential CO2 emission reductions in Libyan cities are scarce. Therefore, this study aims to estimate the potential reduction in CO2 emissions resulting from replacing gasoline with LPG in selected Libyan cities. It also evaluates different conversion scenarios (100%, 50%, and 25% of the vehicle fleet) to assess the environmental feasibility of a gradual transition to cleaner transportation fuels.

2. Materials and Method

Although liquefied petroleum gas (LPG) is primarily used in passenger vehicles such as taxis, it can also be used in other types of vehicles such as vans, private cars, and buses. LPG-powered lorries are widespread in the United States, and there are buses running on this fuel in Spain and South Korea. Buses make up the majority of LPG-powered vehicles in Vienna. Low maintenance costs are one of the main reasons behind the widespread use of propane in delivery lorries, taxis, and buses. The properties of propane—namely, its high-octane rating (104 to 112 compared to 87 to 92 for petrol), low carbon emissions, and reduced oil contamination—have contributed to engine lifespans being twice as long as those of petrol engines (26).

A comparison of gas use was carried out, primarily in terms of carbon dioxide emissions and also from an economic perspective, and this concept was applied to certain Libyan cities congested with private cars, where most people carry out their daily work and travel in their own cars, as Libya is not a country that relies on public transport or modes of transport that reduce congestion and provide daily travel.

The reduction in carbon dioxide emissions was compared and assessed against those of conventional fuel (petrol). Fuel economy and reduced environmental impact will be key objectives of the study.

3. Emissions Calculations and results

Some types of petrol-powered cars produce approximately 167–143.5 grams of carbon dioxide per kilometer. Meanwhile, other types powered by liquefied petroleum gas produce approximately kilometer. 120–122 grams of carbon dioxide per kilometer [27].

The calculations in this study were based on the following assumptions:

Only private vehicles were considered.

Each vehicle was assumed to travel 100 kilometers per day, representing the average daily commute in Libyan urban areas.

An average gasoline consumption was assumed to be 8 liters per 100 kilometers.

An average LPG consumption was assumed to be 9.5 liters per 100 kilometers, due to the lower volumetric energy density of LPG.

Carbon dioxide emissions coefficient for gasoline was set at 2.31 kg/L, while for LPG it was set at 1.65 kg/L, based on the emissions coefficients issued by the US Environmental Protection Agency.

Vehicle numbers were obtained from traffic department statistics for each selected city.

Three fleet conversion scenarios were analyzed:

Full conversion (100%)

Partial conversion (50%)

Partial conversion (25%)

Statistics were compiled on private cars in each city based on data from the traffic departments in each city and were as follows:

Table 2: Number of Vehicles in Libyan cities

City	Number of Vehicles
Tripoli	550,000
Benghazi	340,000
Misrata	195,000
Al-Zawiya	100,000
Sabha	64,000
Al-Khums	59,000
Tobruk	49,000

3.1 Calculation Equations

1. Gasoline emissions

$$CO2=N \times FC_g \times EF_g$$

2. LPG emissions

$$CO2=N \times FC_{LPG} \times EF_{LPG}$$

Where:

- N = number of vehicles
- FCg = fuel consumption gasoline
- FC_{LPG}= fuel consumption LPG
- EF = emission factor

Savings = 3.425 kg CO_2 per 100 km = 22% less

These quantities are for a single car; if the total number of cars is taken into account, the results will vary between the carbon dioxide emissions from petrol and liquefied petroleum gas, as illustrated in the table below:

Table 3: amount of carbon dioxide emissions

City	Number of Vehicles	g of Co2/100km by benzene	g of Co2/100km by LPG	Savings
Tripoli	550,000	8539	6655	1884
Benghazi	340,000	5279	4114	1165
Misrata	195,000	3027	2360	667
Al-Zawiya	100,000	1553	1210	343
Sabha	64,000	994	774	220
Al-Khums	59,000	916	714	202
Tobruk	49,000	761	593	168

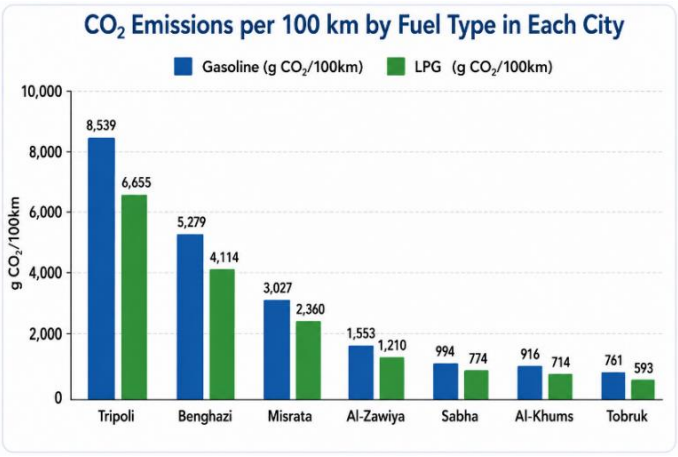


Fig. 1: CO_2 emissions by city: Gasoline vs LPG (100% vehicle conversion scenario)

These quantities are based on the assumption that all vehicles are converted, but if assumed that the proportion of converted vehicles is not 100%, but rather 50% or 25% of the total.

Table 4: amount of carbon dioxide emissions

City	Number of Vehicles 50%	g of Co2/100km by benzene	g of Co2/100km by LPG	Savings
Tripoli	275,000	4,269.5	3,327.5	942
Benghazi	170,000	2,639.5	2,057	582
Misrata	97,500	1,513.5	1,180	334
Al-Zawiya	50,000	776.5	605	171
Sabha	32,000	497	387	110
Al-Khums	29,500	458	357	101
Tobruk	24,500	380.5	296.5	84

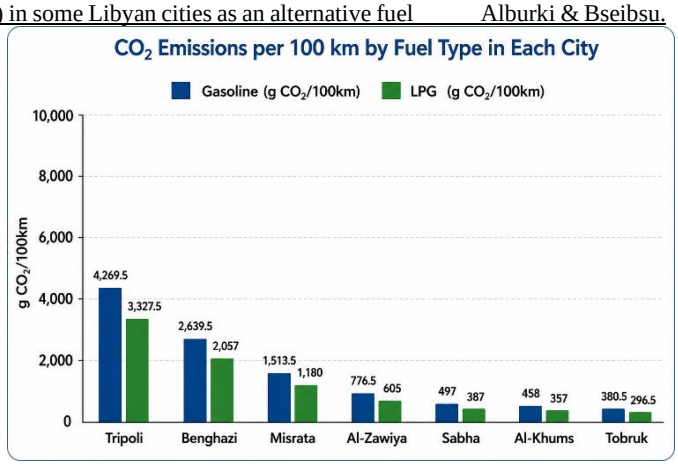


Fig. 2: CO_2 emissions by city: Gasoline vs LPG (50% vehicle conversion scenario)

Table 5: Amount of carbon dioxide emissions

City	Number of Vehicles 25%	g of Co2/100km by benzene	g of Co2/100km by LPG	Savings
Tripoli	137,500	2,134.8	1,663.8	471
Benghazi	85,000	1,319.8	1,028.5	291.3
Misrata	48,750	756.8	590	166.8
Al-Zawiya	25,000	388.3	302.5	85.8
Sabha	16,000	248.5	193.5	55
Al-Khums	14,750	229	178.5	50.5
Tobruk	12,250	190.3	148.3	42

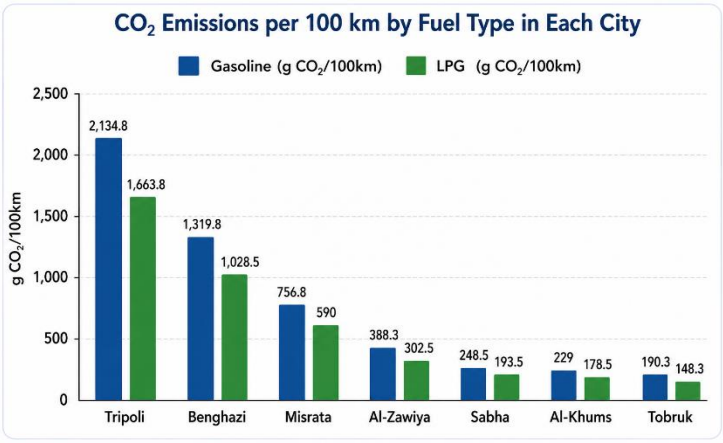


Fig. 3: CO_2 emissions by city: Gasoline vs LPG (25% vehicle conversion scenario)

All the preceding figures show that replacing gasoline with liquefied petroleum gas (LPG) as fuel leads to an average reduction in carbon dioxide emissions of approximately 22.1% in all selected Libyan cities. The consistency of this savings indicates that the environmental benefit of adopting LPG is not significantly affected by city size and is primarily related to the lower carbon intensity of LPG compared to conventional fuels.

4. Conclusion and discussions

Results indicate that replacing gasoline with liquefied petroleum gas (LPG) could reduce carbon dioxide emissions by approximately 22% across all conversion scenarios. This reduction is consistent with previous studies that reported emission reductions of 15% to 25% for passenger vehicles powered by LPG [5.6].

This reduction across all selected Libyan cities suggests that the environmental benefit is primarily due to the lower carbon content of LPG, rather than the number of vehicles. Consequently, larger cities

like Tripoli and Benghazi achieve greater reductions in absolute emissions due to their larger vehicle fleets.

These findings are consistent with previous studies conducted in Poland and Turkey, which concluded that LPG can be an effective transition fuel for cleaner transportation systems by reducing greenhouse gas emissions while maintaining relatively low fuel costs.

From a future perspective, the idea of adopting liquefied petroleum gas (LPG) has additional economic advantages, given that Libya produces LPG domestically. However, implementation will present challenges in expanding the refueling infrastructure, encouraging vehicle conversion, and raising public awareness of the environmental and economic benefits.

5. Recommendations:

Based on the results and a comparison of liquefied petroleum gas (LPG) with petrol in terms of emissions and cost, the following recommendations can be made:

1. Expand the use of LPG as an alternative fuel in the transport sector, particularly in taxis, light vehicles, and buses within Libyan cities with high traffic density.
2. Encourage a gradual switch from petrol to LPG through government support policies such as reduced conversion costs.
3. Establishing appropriate infrastructure, including LPG refueling stations in major cities and on key routes, to facilitate its adoption.
4. Raising awareness among drivers and vehicle owners of the benefits of using LPG in terms of reducing operating costs, lowering harmful emissions, and improving engine life.
5. Conducting broader, long-term studies to measure the environmental and economic impact of a full or partial switch to LPG in various Libyan cities.
6. Support the introduction of modern vehicle conversion technologies to ensure the highest efficiency and safety when using gas compared to conventional fuels.
7. The transition to clean energy... Diversification of clean energy sources such as solar power, green hydrogen, and electricity.

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