Comparative analysis of alternative fuels and powertrains for goods transport vehicles: A case study of Catalonia, Spain

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Abstract

By 2050, the European Union aims to cut greenhouse gas emissions to achieve carbon neutrality. Therefore, like other sectors, emissions from the goods transport sector need to be reduced as well. A proactive shift to cleaner vehicles with alternative propulsion systems to conventional systems is required. The environmental impact of various engine technologies is currently gaining traction when considering the purchase of goods transport vehicles. This study introduces various alternative fuels and powertrains in the context of Catalonia, Spain. However, the observations and discussions provided in this paper can be applied to other countries, with slight variations conforming to local markets. Apart from discussing the alternative options, a comparison including technical and financial evaluation, infrastructure evaluation, risks/opportunities evaluation, and emission evaluation is provided. The paper further enlists the risks and opportunities available for each alternative with a 15-year horizon, and lastly provides a SWOT analysis. This study not only offers a guidance to the goods transport operators regarding alternative fuels and powertrains but also provides the general readers with a broad understanding of the topic.

Keywords: Diesel; Electric, Gas, Hybrid, Hydrogen, Logistic Operators

1. Introduction

Efforts are underway to achieve carbon neutrality by 2050 in the European Union. To ensure the success of this commitment, the EU has set a target of reducing the net greenhouse gas (GHG) emissions by 55% (relative to 1990 levels) by 2030. Approximately 6% of all EU's carbon emissions come from diesel trucks, which transport 65-70% of inland freight currently. Decarbonizing heavy-duty road transport is essential for the EU as road freight is expected to increase by 55% by 2050 [1]. In Catalonia, the GHG emissions were estimated to be 38.5 million tonnes CO_2 equivalent in 2020 [2] (latest available). This represents an overall reduction of 12.4% compared to 2019 emissions. Road transport contributes 27% (10.4 million tonnes CO_2 eq) of GHG emissions. Similarly in the United States, the transportation sector adds 27% to total GHG emissions, the highest among all contributing sectors. Within the transportation sector, 26% of GHG emissions are attributed to medium and heavy-duty vehicles [3]. Furthermore, heavy-duty vehicles result in approximately 40-60% of NO_x and particulate matter (PM) emissions [4].

Heavy-duty vehicles (HDVs) account for a small portion of the total fleet (<15%), which is mostly made up of light-duty vehicles (LDVs), up to 70% [5]. However, having a greater share in total truck mileage, HDVs contribute disproportionally toward CO_2 emissions. For instance, in the EU HDVs account for only 4% of the on-road fleet but have a 30% share in on-road CO_2 emissions [6]. Likewise, CO_2 emissions (in million tons) by different logistic vehicle classes in various regions of the world are provided in Fig. 1 [5].

To achieve carbon neutrality, it is pertinent to reduce GHG emissions by HDVs, which itself is a difficult target. Since diesel-fueled vehicles make up most of the HDV sector (with a small share of petrol and natural gas), improvements in diesel technologies are estimated to bring about less than a 15% reduction in CO_2 emissions [7]. For that reason, the use of alternative fuels and powertrains (AFP) for HDVs is necessary and thus incentivized.

However, AFPs face several challenges including inadequate infrastructure (for instance, lack of enough electric charging points), and regulatory aspects. On top of these challenges is the uncertainty of the relevant technological evolution itself. Overall, this makes it difficult for the logistic companies to decide on the type of vehicles to be purchased. To address this issue, the Government of Catalonia requested proposals and subsequently awarded the authors this study to develop an all-inclusive methodology, based on sound comparative analysis, to assist logistic companies in deciding the type of vehicles to be purchased. This paper provides a comprehensive comparison of the various goods transport vehicular technologies available in Catalonia, Spain. It includes financial evaluation, infrastructure evaluation, risks and opportunities evaluation, and emissions evaluation. The inferences derived during this comparison are projected to a 5, 10, and 15 year horizon followed by a SWOT analysis.

2. Alternate Fuels and Powertrains

Conventional fuels include gasoline and diesel, which utilize an internal combustion engine (ICE) to generate energy for the vehicle. The use of these two types of fuels is different depending on the volume or payload for which they are dedicated: low or medium load trucks mostly use gasoline engines, especially in countries such as the United States, Canada, Russia, and China; while for larger heavy-duty trucks the preferred option is the diesel engine. This technology is present in all types of goods transport vehicles on the market. However, conventional fuels greatly add to environmental degradation.

To minimize GHG emissions, alternative fuels – based on fossil fuels or renewables – may be utilized. Liquefied petroleum gas (LPG) composed largely of butane and propane, is liquefied at relatively low pressures of about 5 to 10 bar. Liquefied natural gas (LNG) is mostly made up of methane that is cooled down to 160 ºC for storage and transportation in liquid form. Conversely, compressed natural gas (CNG) is stored in a gaseous form under a pressure of 200 bar. A renewable alternative to natural gas is biofuel or biogas obtained from biowaste.

On the other hand, propulsion is achieved with the assistance of electric motors in the case of electrified powertrains. Battery electric vehicles (BEVs) utilize the electric energy stored in onboard batteries, which are recharged at electric charging stations. A more popular alternative in freight vehicles is hybrid electric vehicles (HEVs). These operate with two different powertrains, such as a diesel-powered engine and an electric motor. Then, there are fuel cell electric vehicles (FCEVs) that generate electricity within a fuel cell by utilizing hydrogen that is stored onboard.

Each of them is described in more detail below. process will affect the weighted average delivery time significantly.

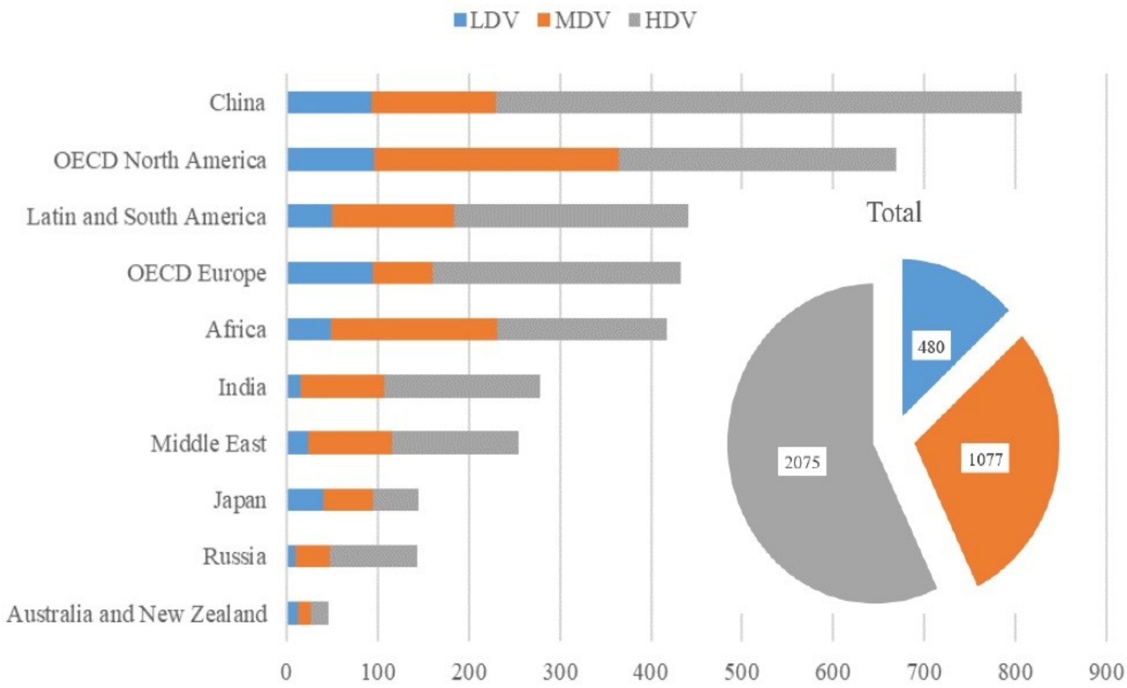

Fig. 1: CO2 emissions by road freight vehicles [5]

2.1 Gas

Engines that use gaseous fuel are engines that, like those that use liquid fuels such as gasoline or diesel, use an internal combustion chamber. These include the following:

Natural Gas: It is a source of fossil energy, consisting of a mixture of hydrocarbons, molecules made up of carbon atoms and hydrogen. There are two types i.e. Compressed Natural Gas (CNG), and Liquified Natural Gas (LNG).

Liquefied Petroleum Gas (LPG): It is a mixture of butane and propane with a composition, characteristics, and proportions that make it suitable for the automotive industry.

Both CNG and LNG can be replaced by so-called renewable natural gas, biogas. This gas is a fuel generated through the processes of degradation of organic matter (animal waste, plant waste, and wastewater) which, once clean, is transformed into biomethane, renewable fuel that is considered neutral to CO_2 emissions. This gas change does not require any modification or additional investment, both in infrastructure and in the engine.

Another type of engine that can be used for gas is the bi-fuel [8]. The bi-fuel engine is an internal combustion engine that uses alternately a liquid fuel (gasoline or diesel) and a gaseous fuel (LNG, LPG, or rarely hydrogen), stored in different tanks and selected by a control system of the vehicle or at the will of the driver. The engine can run only on fossil fuel but not just gas. The possibility of operating on diesel or gasoline would reduce concerns about not being able to find a gas station.

The main advantages of CNG over conventional ones are:

- Allows a very good range combined with diesel in diesel-CNG hybrids.
- The fueling is very fast.
- CNG is lighter than the mixture of gases that make up the atmosphere, so it rises when spilled, which reduces the risk.

The main benefits of LPG are:

- Available in large quantities worldwide.
- Cheaper than gasoline and diesel in most cases. LPG is becoming the most affordable alternative fuel.
- Offers the longest running range of any alternative fuel option. Thanks to a higher octane rating and efficiency.
- LPG engines can use higher compression ratios, resulting in higher power and better fuel efficiency.
- With modern systems, the power and torque of LPG are greater than or equal to its gasoline equivalent.
- LPG is stored at lower pressures than CNG, making storage tanks lighter and cheaper.
- LPG tanks are 20 times more puncture resistant than gasoline or diesel tanks.

Bi-fuel engines have several potential advantages:

- Fuel flexibility.
- Higher compression ratio.
- Better efficiency.
- Easy conversion of existing internal combustion engines without major hardware modifications.

Both CNG and LNG vehicles are inspected or repaired at the official workshops of the manufacturers or authorized workshops, at a cost almost equal to or less than that of a diesel or petrol vehicle. In terms of maintenance frequency, CNG vehicles must be inspected every 5 years, while LNG vehicles must be inspected every 10 years. The characteristics and intervals of maintenance and safety operations of LPG vehicles are similar to CNG vehicles.

In terms of natural gas supply infrastructure, there are two types of facilities: those connected to the exclusive gas network of CNG suppliers, and those that purchase LNG to store in cryogenic tanks for distribution as LNG or CNG after regasification. The first is characterized by the infrastructure, which must be close to the CNG provider, as it is necessary to connect to the network. As a result, investment increases significantly the farther away the station is. In terms of refueling infrastructure, LPG charging does not involve a change in driving habits as the public outlets for this fuel are at the same conventional fuel stations and the downtime is similar.

The operational range of an LNG or CNG may vary depending on the model. In the case of LNG, they can reach 1,600 km. On the other hand, CNG is around 1,200km.

Gas is the technology that is emerging most prominently in the freight vehicle market, where most models can be found compared to conventional ones.

2.2 Hydrogen Fuel

Hydrogen vehicles run on an electric motor, where the energy to run it is obtained from stored hydrogen, which is converted into electricity by the fuel cell.

Electric batteries are ideal for low-weight vehicles and short-distance travel, while fuel cells are more suitable for heavy and long-distance vehicles.

The main advantage that manufacturers of fuel cell vehicles point out compared to BEVs is the time for a full refill. Brands say it's around five minutes, such as the Honda Clarity Fuel Cell or the newcomer Hyundai Nexo [9].

Refilling the hydrogen tank is a virtually identical task to refilling with traditional fuels, through a hose that is sealed in the tank.

The range of this type of vehicle is very similar to that of combustion vehicles. Hyundai's first generation of fuel cell reached almost 430 km, while this second generation, with the Nexo, the maximum range is estimated to be around 600 km.

There are currently no hydrogen battery freight vehicles in the Spanish market. However, there are some models marketed in the European market, such as some light vehicles.

2.3 Electric Vehicles

An electric vehicle is a vehicle powered by one or more electric motors, using electrical energy stored in rechargeable batteries. An electric motor is a rotary machine that transforms electrical energy into mechanical energy.

Lately, lithium-ion batteries are more in use, as they improve the performance of traditional lead or nickel batteries. This technology is developing at a rapid pace, intending to increase its electricity storage capacity and service life, and reduce its cost and weight.

The massive investment in this sector has led to a rapid increase in passenger electric vehicles (exceeding 2 million worldwide sales), electric city buses, and the emergence of heavy trucks.

Concerning recharging, there are four charging modes, which vary depending on the type of current, the charging speed, and the infrastructure required. These modes are normal charging point, semi-fast charging station, fast-charging station, and ultra-fast charging point. Some require the vehicle to have a high voltage electrical installation. Being able to opt for these four types depends on the charge control systems built into the vehicles and the capacity of the battery. It should be noted that light vehicles require a shorter charging time than heavy vehicles, as the battery capacity is much larger for heavy vehicles.

Currently, the range for this type of vehicle is between 200 and 300 km maximum. Two aspects need to be considered, on one hand, they require larger batteries, which means more weight on the vehicle, and on the other hand, the range directly depends on the load the vehicle carries. To make matters worse, the relatively heavier weight of electric vehicles results in 30-40% additional road wear compared to ICE vehicles [10].

Electric vehicles are easier to maintain, as they do not have to carry out the periodic tasks related to internal combustion engines (spark plugs, oils, filters, etc.), therefore, the scheduled periodic maintenance actions required by an electric engine are relatively less frequent. As such, electric vehicles can be inspected or repaired in the same workshops where the other vehicles are inspected, at official dealerships, or in any mechanical workshop. In addition, training programs are being developed that allow other professionals (mechanics, emergency services, dealers, etc.) to obtain the qualification to handle these types of vehicles.

Conditions for Battery Electric Trucks (BETs) have changed dramatically since 2010 when lithium-ion battery prices were around € 675-900 / kWh. energy densities around 110 Wh / kg. Compared to 2018, prices have dropped by around a factor of four, and densities have more than doubled. In other words, the batteries are cheap and dense enough to be considered viable for usage in heavy vehicles.

Finally, electric vehicles comply with the same safety guidelines as conventional vehicles, so they are just as safe in the event of an accident.

Electric goods vehicles are still in short supply. It should be noted that although there are no heavy electric vehicles in the Catalan market, there are small vans.

2.4 Hybrid

They are governed by two types of motors: an electric motor and a thermal motor. They are two engines in charge of different tasks necessary for the operation of the vehicle. In this type of vehicle, it is the vehicle itself that autonomously makes the most efficient decision, on which engine to use at any given time, except in exceptional cases of specific functionalities of some vehicle designs.

There are two types of hybrids:

- "Traditional" hybrid vehicle (HEV): It is driven by an internal combustion engine combined with one or more electric motors that use the energy stored in the battery. The vehicle is charged using regenerative braking and an internal combustion engine.

- Plug-in hybrid electric vehicle (PHEV): It is a hybrid electric vehicle that can charge batteries by plugging the vehicle into an external source of electrical power, as well as by regenerative braking.

In urban traffic, where less power is needed, the car usually runs on batteries and recovers the braking energy, which makes these vehicles perform better than vehicles solely reliant on conventional fuel. On the other hand, for long-distance journeys, since the range of the electric motor is low for PHEVs and very low for traditional hybrids (HEV), therefore the diesel or petrol engine is usually used. Hence, the vehicle works like a conventional one.

Given the technological complexity of hybrid vehicles, the dependence on the official workshops authorized by the manufacturers was very visible at the beginning. Currently, the unofficial workshops have received training and are equally prepared. The maintenance cost is slightly lower than the maintenance of the vehicle with only internal combustion, as there is an electric motor that involves less frequent maintenance visits, along with less intensive use of the combustion engine.

Vans with hybrid technologies are currently in use, especially for urban routes since in such settings the hybrid vehicles provide better fuel economy. However, there is still no supply of hybrid heavy vehicles.

3. Infrastructure

One of the barriers to purchasing freight vehicles with alternative technologies is the availability of necessary infrastructure to recharge vehicles without accumulating empty miles. Since hydrogen recharging points are nonexistent in Catalonia, this section only explores the available gas refueling and electric recharging stations.

Fig. 2 provides the locations of electric charging points. Although 500 kW [11] recharging points are required to recharge a heavy vehicle, there are no such recharging points yet either in Spain or in Catalonia. Therefore, Fig. 2 only shows the points for light vehicles. Fig. 3 shows the CNG and LNG recharging points in Catalonia, where most of them are located near the city of Barcelona and the border with France.

4. Emissions

Emissions from land transport have a very significant contribution to the total emissions, as mentioned at the beginning of the paper. There are two major groups of gases: those that contribute to climate change (greenhouse gases, GHGs) and those that directly affect human health.

- Greenhouse gases: The main ones are: water vapor (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3).
- Gases harmful to health: The most important gases are: nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter (PM) among others.

Due to the harmful impacts of emissions, cities are increasingly restricting the entry of polluting vehicles in certain strategic areas, such as the Low Emission Zone Rondes de Barcelona.

Emission data for light vehicles (vans) and heavy vehicles (rigid and articulated) is provided in Table 1. Since CO2 emissions are affected by the speed of the vehicle, the average speeds of the vehicles have also been considered. As light vehicles travel more kilometers in urban areas, hence the average speed is 21 km/h, whereas for heavy vehicles it is considered 59 km/h.

5. Technology Comparison

A comprehensive summary of the comparison of various alternative technologies available in the market with reference to conventional vehicles is provided in Table 2.

6. Risks and Opportunities

One of the key elements in decision-making for the acquisition of a vehicle with alternative energy to fossil fuel is the uncertainty inherent in the future evolution of the aspects that influence decision-making, such as the existence of proper recharging infrastructure.

The purpose of this section is to identify uncertainties and/or opportunities that may influence the decision to acquire vehicles. These uncertainties were collected in the form of a matrix and projected over time horizons of 5, 10, and 15 years in the form of a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats).

The matrix of risks and opportunities considers 7 main characteristics to study for each of the technologies, that is to say: legislation, current technologies, economy, infrastructures, cost of energy, efficiency, and emissions.

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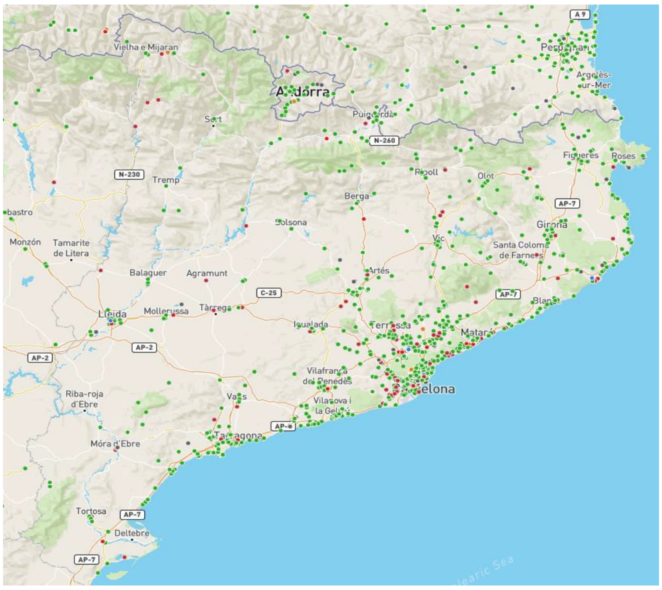

Fig. 2: Electric vehicle charging points in Catalonia. Source: electromaps [12]

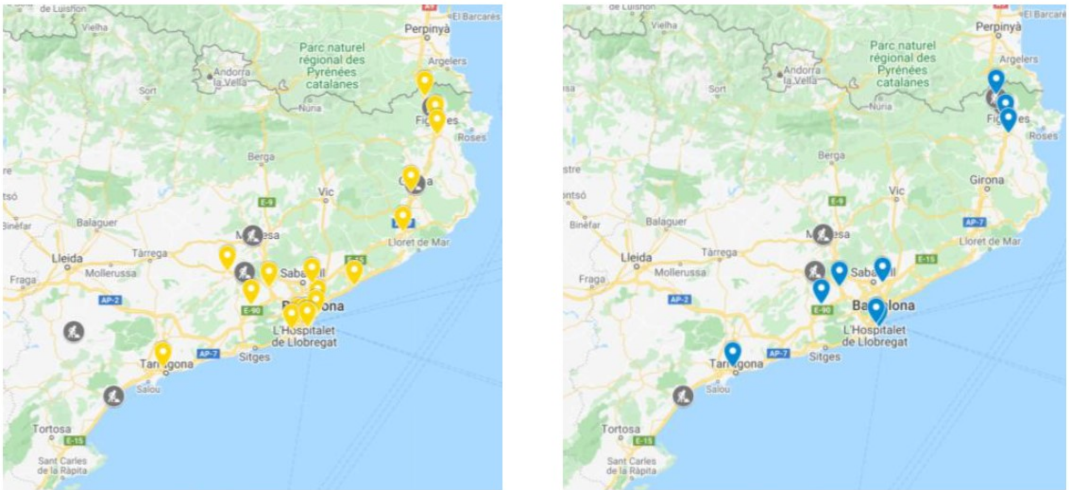

Fig. 3: CNG (left) and LNG (right) recharging points in Catalonia. Source: Gasnam [13]

Table 1: Emission values for logistic vehicles [14], [15]

Vehicle	Emissions	Diesel Euro VI	Gasoline Euro VI	Gas CNG/LPG Euro VI	Electric
Van	CO_2 eq. g/km (21 km/h)	245.65	332.92	235	0
	NO_x g/km	0.480	0.014	0.07	0
	PM_{10} total g/km	0.021	0.022	0.022	0.020
Rigid Truck	CO_2 eq. g/km (59 km/h)	407.6	Not available	Not available	0
	NO_x g/km	0.0987	Not available	Not available	0
	PM_{10} total g/km	0.0692	Not available	Not available	0.0666
Articulated Truck	CO_2 eq. g/km (59 km/h)	564.08	Not available	Not available	0
	NO_x g/km	0.1229	Not available	Not available	0
	PM_{10} total g/km	0.0845	Not available	Not available	0.0813

Table 2: Comparison Summary of Alternative Technologies

Technologies	Conventional (reference line)	Gas	Electric	Hybrid	Hydrogen
Purchase cost		Similar to conventional	Twice as conventional. Depends on batteries' capacity	Higher as they have an electric motor	About twice as conventional
Maintenance cost		Similar to conventional. Additional inspection every 5 years for CNG and every 10 years for LNG	About half the conventional	Lower than conventional	No experience
Refueling infrastructure		111 (CNG) and 76 (LNG) gas stations in Spain. 23 (CNG) and 13 (LNG) gas stations in Catalonia	> 5,000 LVs recharging points in Spain > 900 LVs recharging points in Catalonia	Similar to electric	6 hydrogen generators in Spain. 0 in Catalonia
Additional investment in infrastructure		Yes (Changes in conventional infrastructure)	Yes	Yes	Yes
Range		1000 - 1600 km	Depends on the load. Max. 200 - 300 km. For greater range, larger batteries are required.	Fully electric drive up to 50 km	400 - 600 km
Route Flexibility				Better than electric ones, due to diesel engine	Few recharging points
Energy Security		Risk of an explosion, but lower than hydrogen	A lower risk	Similar to conventional	Risk of an explosion when in contact with air
Emissions (CO_2, NO_X, PM)		Similar levels of CO_2	No CO_2, no local emissions	-50% emissions	0 emissions
Noise (dB)		Same, as they use the same type of engine	80% noise reduction in the city and 35% in the countryside	Lower than conventional	
Fuel cost		CNG is much lower than LPG	About 80% less than conventional	About 15% less than conventional	Similar to conventional, as the market is not extensive

the technologies, that is to say: legislation, current technologies, economy, infrastructures, cost of energy, efficiency, and emissions.

The SWOT analysis will serve to identify in the time horizons at 5, 10, and 15 years which internal and external factors are favorable and unfavorable for each of the technologies.

6.1 Risks

Based on various types of information such as interviews, reports, etc., this section presents a description of the risks that currently exist for each of the technologies that are the subject of this study.

6.1.1 Legislation

- Conventional: Laws already exist in cities such as London (Ultra Low Emission Zone), Paris (diesel vehicles will not be allowed in 2020 and electric vehicles will have free parking), or Hamburg (partial restrictions on specific routes for non-compliant vehicles Euro VI standards) to reduce the number of vehicles that emit a higher concentration of pollution. In Barcelona, for example, the low-emission zone (LEZ) is applied to goods vehicles since 2021.
- Electricity: Lack of recycling capacity and uncertainty surrounding the economy shows that the current regulatory framework urgently needs reform. The Commission has already published the revision of the 2006 EU Batteries Directive.
- Gas: There are currently no legal restrictions on gas vehicles.
- Hydrogen: Regulations currently limit the development of a clean hydrogen industry (called green hydrogen) for two reasons: high production cost and inefficient production. Government and industry must work together to ensure that existing regulations are not an unnecessary barrier to investment.

6.1.2 Current Technologies

- Electric: The main performance considerations of batteries designed for the use of electric trucks are the gravity and density of volumetric energy, the specific power (in watts per kg), the durability, and the number of cycles (battery life). One of the problems of batteries is the weight and volume, as a greater range implies the growth of these two variables.
- Gas: Investing in biomethane as a transport fuel. Biomethane has lower carbon emissions compared to gasoline or diesel due to the lower carbon content of the fuel.
- Hydrogen: Currently 95% of hydrogen production is produced through the Steam Methane Reforming (SMR) process.

6.1.3 Economy

- Electric: Electric vehicles are priced higher than conventional ones. While the electric vehicle does not require routine maintenance, the average life of an electric battery is still unknown due to lack of experience.
- Gas: The cost of maintaining gas vehicles is higher, as mandatory inspections by law must be performed every 5-10 years.

6.1.4 Infrastructure

- Electric: A recharging point must be installed in the area where the vehicle is parked, at an associated cost. This type of operation requires excessive investment in infrastructure and generally results in higher electricity prices.
- Gas: There are currently 90 stations in the country, 42 of which are public.
- Hydrogen: There are currently 5 hydrogen stations in Spain, while none in Catalonia. The development of hydrogen infrastructure is slow, but it has been widely accepted as one of the possible technologies that will slow down climate change.

6.1.5 Energy Cost

- Conventional: In general, European economies apply high rates on gasoline and diesel with some exceptions among Eastern European countries that adopt intermediate taxes.
- Gas: the price of CNG is slightly higher than the conventional one, although it depends on the volume and purchasing power.
- Hydrogen: Producing hydrogen from low carbon energy is currently expensive.

6.1.6 Efficiency

- Gas: less efficient than conventional ones.

6.1.7 Emissions

- Conventional: High. Diesel fuel is not only a fossil fuel but has a mixture of biofuel content derived from sources such as palm oil and rapeseed oil that can generate higher emissions due to land use change. Fossil-based diesel from traditional wells can have associated production emissions. The International Agency for Research on Cancer recognizes that the exhaust gases of diesel engines are carcinogenic at high levels of exposure.

- Electric: An analysis of long-distance battery electric trucks in the EU concluded that the long-distance electric batteries of electric vehicles are between 51% and 67% cleaner than those of equivalent vans powered by fossil fuels.

6.2 Opportunities

Regarding the opportunities observed for the technologies that are the object of this study, it can be indicated that:

6.2.1 Legislation

- Conventional: The next step will be to develop, through testing, appropriate regulatory frameworks, and operational practices to allow exclusively fit Heavy Goods Vehicles (HGVs) on public roads.
- Electric: Several countries have implemented fuel utilization standards for heavy-duty trucks (including MFT and HFT). In addition, the European Commission has confirmed its intention to revise the 2006 EU Batteries Directive. This would be an opportunity to make batteries an integral part of the circular economy.

6.2.2 Current Technologies

- Gas: Spain has just recently initiated the production and distribution of Biomethane. In Europe, 25% of gas stations already supply biomethane.
- Hydrogen: Many manufacturing companies are investing in fuel cell vehicles.

6.2.3 Economy

- Conventional: Differentiated taxation on the purchase of vehicles, also known as "feebates" (combination of fees and discounts), already applies to light vehicles.
- Electricity and gas: Differentiated taxes and “feebate” can be designed to tax not only inefficient and high-emission vehicles but also use the proceeds from these taxes to subsidize the purchase of vehicles with a superior fuel economy or low pollutant emissions. Further, the maintenance costs of electric vehicles are reduced by around 50% compared to conventional ones.

6.2.4 Infrastructure

- Conventional: The current infrastructure is for conventional vehicles.
- Electric: The challenge for truck electrification, particularly for HGV, is how to reduce battery needs by supplying electricity to moving vehicles. Electric Road Systems (ERS) are based on vehicles that can receive electricity from the energy transfer facilities along the road where the vehicles run. In addition, vehicles using ERS can be hybrid vehicles so that short disconnections from ERS may be accommodated.
- Gas: The creation of stations is on the rise, with Spain being the country with the most LNG stations in Europe.
- Hydrogen: Due to the lack of infrastructure, there will be a large investment in the coming years. The existing gas infrastructure may be utilized to transport new clean hydrogen supplies.

6.2.5 Energy Cost

- Electric: low prices.
- Gas: LNG is cheaper than conventional, as it is a liquid phase fuel that does not require compression. Economic savings of between 25% and 50%, depending on the solution adopted.
- Hydrogen: Fuel cells, fuel equipment, and electrolyzers (which produce hydrogen from electricity and water) can benefit from mass production.

6.2.6 Efficiency

- Electric: When driving on an uncontrolled road, a modern truck can achieve up to 30% efficiency from the engine to the wheel, while electric trucks can reach an efficiency of up to 85% or more.
- Hydrogen: is a fuel with a higher energy density per unit mass: 1 kg of hydrogen releases almost three times as much energy as 1 kg of diesel, gasoline, or natural gas. Tank-to-wheel 43-60%.

6.2.7 Emissions

- Electric: no CO2 or NOx.
- Gas: Light vehicles emit 5% less CO2 and 85% less NOx than diesel. In the case of heavy vehicles, no data is available to state the same. Using biomethane will further reduce emissions.
- Hydrogen: Zero CO2 and NOx emissions.

Based on the above discussion, the risks and opportunities matrix is provided in Table 3.

6.3 15-Year Projection

Based on the hypotheses adopted, the information gathered in the previous sections, and other studies, a forecast is made for the next fifteen years for each technology, summarized in Tables 4-6 as follows.

6.4 SWOT Analysis

The SWOT analysis serves to identify the strengths, weaknesses, opportunities, and threats of each of the technologies for the next 15 years. The following Table 7 is the SWOT matrix for all technologies.

7. Final Considerations

In this study, different freight vehicle engine technologies have been explored in reference to operational characteristics, emissions, and costs. The ultimate goal is to help logistic operators make decisions about buying goods vehicles with alternative energy to fossil fuels.

Table 3: Risks and Opportunities Matrix

Technologies	Conventional	Electric	Gas	Hybrid	Hydrogen
Legislation	Low Emissions Zone. Other measures to promote alternative fuels	Incentives for the sale of low / zero-emission vehicles			
		Legislation to recycle batteries	Regulatory development		
Current Technologies	Autonomous vehicles	Battery performance/ autonomy	Investments in improvements to this technology (biomethane)		Investments in hydrogen vehicles
Economy	High maintenance cost	Feebates (fees and discounts)			
		50% reduced maintenance cost	Higher maintenance cost due to frequent inspections	50% reduced maintenance cost	
Infrastructure	Extensive	Recharge point cost. Few charging stations	Few charging stations		There are no hydrogen generators
		ERS (electrical road systems) Investment potential	Investment potential		
Energy Cost	High rates	Low cost	High cost (CNG) / Low cost (LNG)	Low cost	High cost
Energy Efficiency (%)	10 - 20%	85%	Less efficiency	More efficiency depends on the use of the electric motor	43 - 60%
Emissions	High	No emissions	5% less CO_2 and 85% less NO_x than diesel	-50%	No emissions

Table 4: Projections for Electric Vehicles [16]

Variable	5 years	10 years	15 years
Infrastructure	Construction of > 8,500 new recharging points in Spain		
Price	Vehicle prices will go down.		
Maintenance cost	There will be no changes		
Range	The range of the vehicles will increase, with the improvement of the efficiency of the batteries		
Recharging	Fast recharge 90 minutes	Recharge time will be shorter	
Efficiency	Higher	Engine improvements over the next decade could lead to fuel savings of approximately 4% (for service/delivery vehicles) to 18% (for long-haul trucks)	
Battery	Bigger and less bulky	Macrobatteries will be developed to accumulate energy in the transformers and allow a higher load of power	
Tolls/taxes	Maintain fuel taxes		
Subsidies	Subsidies will be reduced		

Table 5: Projections for Hydrogen-fueled Vehicles [17]

Variable	5 years	10 years	15 years
Price	It will be reduced	It will be reduced by more than half compared to 2015	
Maintenance cost	0.11-0.12 € / km (costs will be reduced by 80% less than in 2015)		
Energy production cost	The IEA (International Energy Agency) analysis finds that the cost of producing hydrogen from renewable electricity could fall by 30% by 2030		

Table 6: Projections for Gas-fueled Vehicles [18]

Variable	5 years	10 years	15 years
Price	The cost of dual fuel vehicles will increase (due to the price of diesel). The price of gas-only vehicles will be reduced, but it all depends on the demand		
Maintenance cost	0.16-0.17 €/km	0.15-0.16 €/km	
GHG Emissions	Reduction up to 4%	Reduction up to 5%	Reduction of up to 8% (emissions will decrease with the use of biomethane)
Tolls/taxes	If renewable gas is not used as fuel, vehicles' access to gas will be restricted to reduce emissions		
Efficiency	Improvements over time		
Infrastructure	There will be up to 250 refueling points (Catalonia)		
Market share	15-25%	25-30%	35%

Table 7: SWOT Analysis

SWOT	Conventional	Gas	Electric	Hybrid	Hydrogen
Strengths	Experience in technology Extensive refueling infrastructure	Low acquisition cost	Only PM_{10} due to tire wear on the pavement		Only PM_{10} due to tire wear on the pavement
Weaknesses	Fossil fuel High emissions	Fossil fuel	Large size of the batteries (range) Extensive charging infrastructure	Large size of the batteries (range)	Extensive charging infrastructure
Opportunities		Use biogas Creating recharging points	Creating recharging points Reduction of the acquisition cost Battery weight reduction (Range)	Battery weight reduction (range) Creating recharging points	Creating recharging points Reduction of the acquisition cost Fuel cost reduction
Threats	Tax increase Restrictions	High emissions (if no biogas is used)	High battery price High acquisition cost	High battery price	High acquisition cost High fuel cost

Finally, and as a summary, some relevant final considerations on freight vehicle engine technologies:

- Diesel vehicles are the cheapest in terms of vehicle acquisition cost. Moreover, with the latest Euro VI technology, emissions have been drastically reduced.
- Gas vehicles are available from different manufacturers. For light vehicles, the emissions are lower than diesel-fueled alternatives, however, no emission data is yet available for heavy vehicles.
- Electric vehicles, with a promising future, still have the problem of battery life and weight, especially on long-distance journeys. Furthermore, significant investment is required to develop the required infrastructure.
- Hydrogen vehicles are an encouraging option, although they are in the experimental phase. Similar to electric vehicles, substantial investment is necessary regarding refueling infrastructure.
- In terms of emissions, electric and hydrogen vehicles are most suitable to achieve the goals of reducing pollutant emissions.

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