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Chapter

Road Transportation Industry Facing the Energy and Climate Challenges

Brahim Mebarki, Belkacem Draoui, Boumediene Allaoua and Abdelghani Draoui

Abstract

On a worldwide scale, vehicles, which constitute the transportation sector, play a major role in supporting the other productive sectors. In addition, the automobiles help promoting the living standards of human beings by satisfying the needs of most people in their daily activities. Nowadays, for the traction or repulsion of vehicles, the overwhelming majority of these automobiles are equipped with internal combustion engines (ICE); however, the automotive industry is moving steadily toward the adoption of new technologies because of the rapid depletion of fossil fuels and climate challenges caused by the transport sector, which accounts for the 27% of global energy consumption and for 33.7% of pollutant emissions and green house gas (GHG). For road transportation sector, the fuel-cell electric vehicle is one of the promising solutions advocated by car manufacturers and research entities to replace gradually conventional vehicles.

Keywords: energy and transportation, electric vehicles, fuel cell vehicles, battery

1. Introduction

The internal combustion engine is considered to be one of the greatest inventions in the human era. It is exploited in most road and rail transport solutions. This engine operates by burning products originating from fossil fuels. But due to the limited reserve of fossil fuels and because of the harming effects of burning these resources on the environment, the stakeholders of the automotive industries have opted for the development of efficient and high performance substitutions to this type of engines. Furthermore, the economic development and population growth experienced by the world during the last 15 years have led to a sharp increase in demand for energy in this sector, which will increase the rate of depletion of fossil fuels and lead to major air pollution and global warming. To address these concerns, transportation-related research and development focus on developing viable renewable and clean solutions.

2. Road transportation: energy and environmental challenges

The global transport sector will face a number of unprecedented challenges over the next four decades (2010–2050). It is expected that the world population will increase from 2.2 to 9.2 billion, with over two thirds of the population living in cities, compared to about half of today's population. In addition, it is expected that the number of megacities increased from 22 to between 60 and 100 megacities today in 2050. Many of these megacities, emerging mainly in Asia, Africa, and Latin America, will face high levels of traffic congestion, pollution, and noise. Furthermore, this effect will be amplified by the 2 or 3 billion cars and trucks that could be outstanding. During the same period, travel and road freight will at least double because of the increased demand for transport, as well as economic development and improvement of living standards [1].

2.1 World population, vehicle fleet, and mobility

To understand the evolution of the vehicle market, it is necessary to compare the increase in the world population. We start with the investigation on the growth of the world population. During most of human existence, population growth was so slow that it was imperceptible within a single generation. To achieve a world population of 1 billion people, it took until 1804 for those modern humans to appear on the world stage. To add the second billion, it was not until 1927, a little over a century. Thirty-three years later, in 1960, the world population reached 3 billion. Then the pace accelerated, since we added a billion every 13 years or more. In 2000, the worldwide population has reached 6 billion with 700 million vehicles; by the year of 2050, it has been estimated that the population will reach 10 billion with 2.5 billion vehicles (**Figure 1**) [2, 3].

Between 1950 and 1990, the number of road vehicles has increased ninefold in the world from 75 to 675,000,000. The vehicles predominantly for personal transport (cars and motorcycles) accounted for nearly 80% of all of them during these four decades. During the same period, the world population doubled from approximately 2.5 to nearly 5 billion. During the period 1990–2030, the number of registered vehicles increased from 675,000,000 to 1,624,000,000 and mileage driven 10.7 billion kilometers to 26.6 billion kilometers, most of this increase occurring in countries that do not currently belong to the Organization for Economic Co-operation and Development (OECD) (**Table 1**). This table shows that despite the already high levels of use of motor vehicle in the OECD countries, the number of vehicles and the amount of displacement is called to increase significantly over the coming decades [5, 6].

The study [5] summarized in **Table 1**, predicts that all indicators related to transportation via lightweight vehicles in OECD countries—at the exception of fuel consumption—will increase significantly between 1990 and 2030 [5].

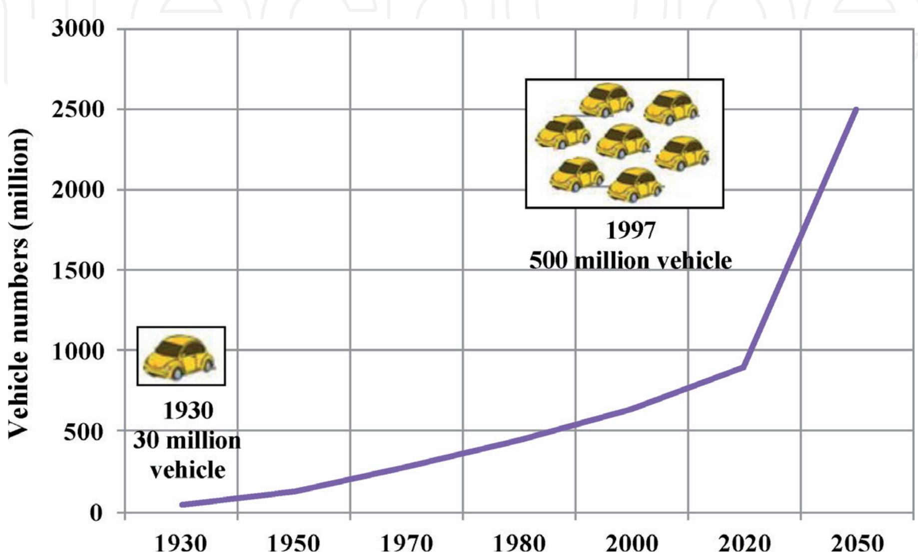


Figure 1.
Vehicle world fleet growth [4].

	Light vehicles			Heavy vehicles		
	Totals		Δ%	Totals		Δ%
	1990	2030		1990	2030	
OECD countries						
Number of vehicles (millions)	468	811	73	16	31	94
Mileage traveled (billion)	7.057	12.448	76	687	1.377	100
Weight of fuel consumed (megatons)	563	520	8	182	359	97
Other countries						
Number of vehicles (millions)	179	725	305	14	56	300
Mileage traveled (billion)	2.380	9.953	318	647	2.512	288
Weight of fuel consumed (megatons)	167	394	136	142	552	289
All countries						
Number of vehicles (millions)	648	1.537	137	30	87	190
Mileage traveled (billion)	9.437	22.400	137	1.334	3.889	192
Weight of fuel consumed (megatons)	730	914	25	324	911	181

Table 1.
Evolution of global fleet and the distance covered, 1990–2030 [5].

In order to avoid dramatic climate change, climatologists advised for aiming to reduce the emissions of greenhouse gases by 60% from current levels by 2050 [7]. These two predicted scenarios are completely contradictory: a significant increase in the number of vehicles creates a huge demand for fossil energy day after day, fossil energy, mostly originating from oil, which goes against environmental the objectives of mitigating the greenhouse gases emissions. So the dilemma to solve is how to reduce pollution through toxic emissions combined with a significant increase in the number of vehicles? [3].

2.2 Energy resources

2.2.1 Nonrenewable energy reserves

It has been stated that the rate of depletion of nonrenewable energies, namely oil, gas, and carbon, is faster than the time of regeneration [8]. Crude oil is a result of the transformation of organic (animal and vegetal) debris from marine populations, under great pressure and in the absence of oxygen. This waste, mixed with sediments and gradually buried by new layers which are deposited, undergoes molecular changes under the combined effect of an increase in temperature and pressure. It thus becomes a liquid or a paste made up essentially of hydrocarbons, molecules made of hydrogen, and carbon assembled in chains which vary in their degree of complexity; as well as hydrocarbons, variable proportions of sulfur, nitrogen, oxygen, and traces of various metals are present [9].

According to data reported in 2013 by British Petroleum Company, **Figures 2**–**4**, respectively, illustrate the reserves estimation of oil, gas, and coal at the end of 1992, 2002, and 2012. On aggregate, the reserves can be estimated to 1075 billion tons of oil equivalent (Gtoe).

Although new deposits of oil and natural gas are discovered regularly, with the ever increasing rate of consumption, it is predicted that the aforementioned reserves will be exhausted in the twenty-first century. Coal provides more distant prospects. In addition, it is an abundant and inexpensive resource compared to other fossil fuels. However, coal is also the most energy-emitting source of CO_2 gas, recognized for its harming effects on global warming, and this is the main issue related to its use [8–11].

Table 2 shows the ratio of energy reserves on consumption. It is calculated by dividing the remaining reserves at the end of a given year by the consumption of that year. The result represents exploitation duration at the current consumption rates.

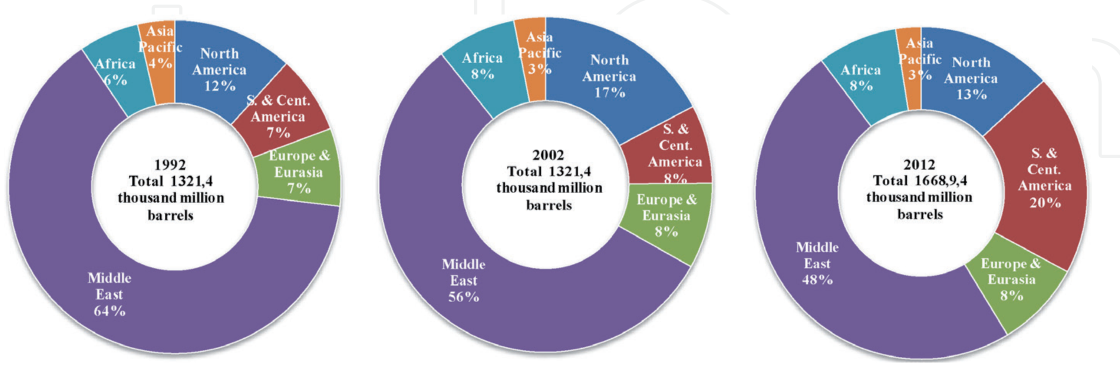


Figure 2.
Distribution of proven reserves for oil [10].

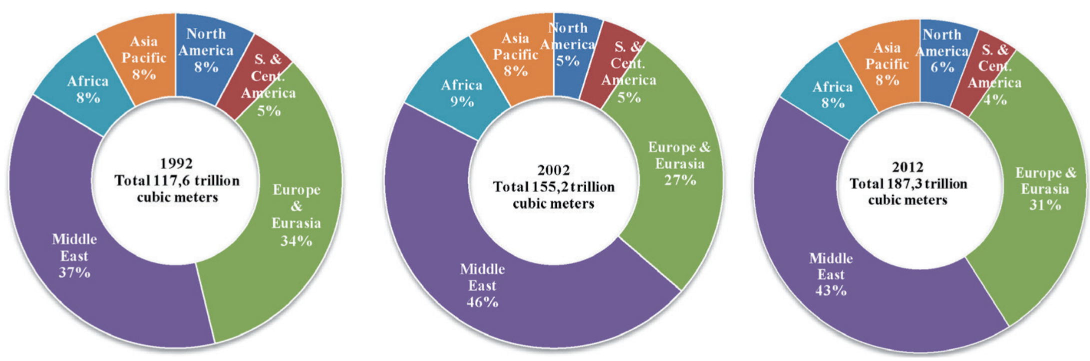


Figure 3.
Distribution of proven reserves for gas [10].

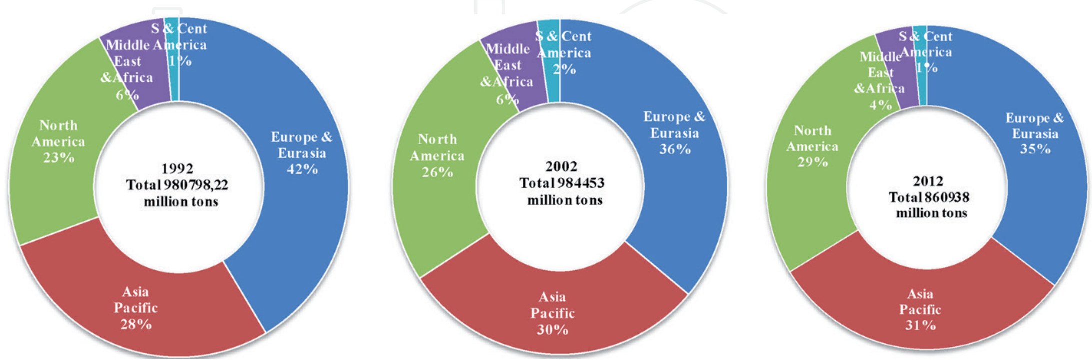


Figure 4.
Distribution of proven reserves for coal [10].

Fossil energy	Petrol	Gas	Carbon
Operating life	52.9	55.7	109

Table 2.
Operating life of fossil resources [10].

Regarding nuclear energy, according to the IAEA and the World Nuclear Association, the current uranium reserves can be exploited for 30 years provided that the price remains less than 40 \$ per kg of uranium and over 60 years, if the production cost rises to \$ 80 per kg. However, by adding all the proven reserves (not extracted today), the duration of exploitation is forecasted to have a slightly more than 200 years of consumption (depending on the price of uranium) [12].

Oil is the main source of energy, providing 33% of global demand, followed by coal (27%) and gas (21%). Renewables energies account for 13% of demand where 10% is supplied by hydraulic energy. The nuclear power contribution fluctuates around 6% [13].

The exploitation of the first three nonrenewable energies is due to the fact that these sources have a high specific energy density (around 40 MJ/kg for oil, 20 MJ/kg for coal, and 60 MJ/kg for methane). On the other hand, the oil has the advantage of being a liquid fuel, which makes it easy to transport, store, and use once refined; this explains its widespread use in many applications [14].

Given that oil resources are limited (**Figure 5**), leading to an increase in the cost of oil. A study showed that if the rate of discovery of fossil resources should continue at current levels and consumption were to increase, then the oil resources would be exhausted by 2038 [9].

2.2.2 Evolution of consumption

Historically, global energy demand has grown steadily over the last 40 years, starting from 5000 Mtoe in 1970 to 14414.4 Mtoe in 2015. It has tripled in size in 45 years, which corresponds to an average annual growth rate of about 2.22% [13–16]. This growth is slightly lower than the 2.22% observed between 2010 and 2015. However, given the difference in economic growth between the two periods, the energy intensity is expected to improve at a constant rate of 1.5% per year [16]. **Figure 6** shows that the primary energy consumption is expected to grow on average 1.7% per year by 2040 to 2050 to reach 20 billion tons of oil equivalent of which the share of developing countries (China, India, Brazil, etc.) will be over 70% [5]. More than 85% of the increase in global demand for energy from 2010 to 2040 occurs in developing countries outside the OECD [16].

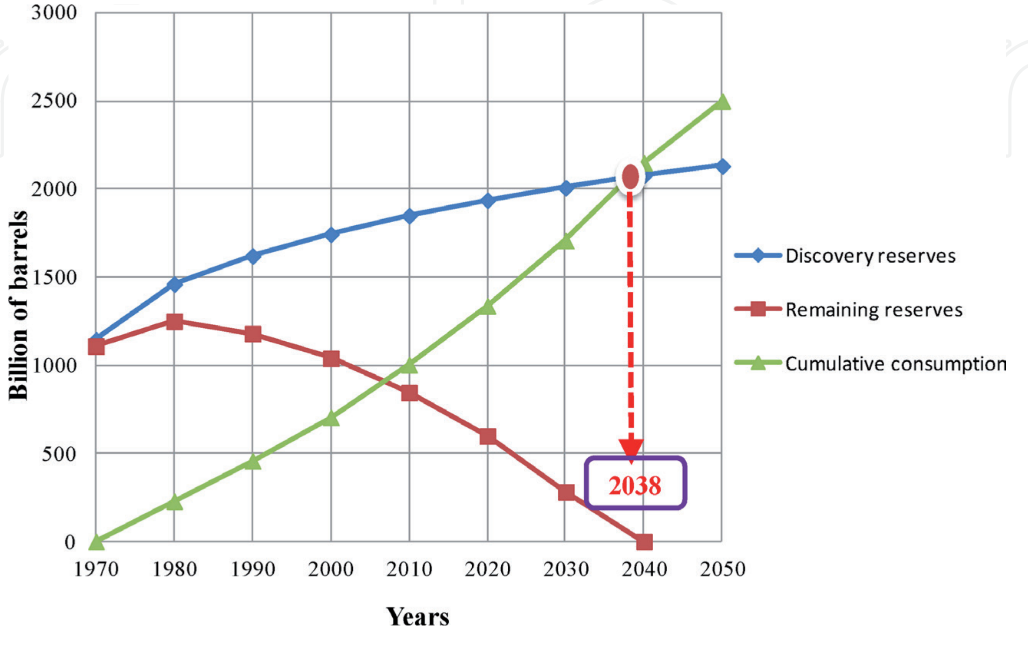
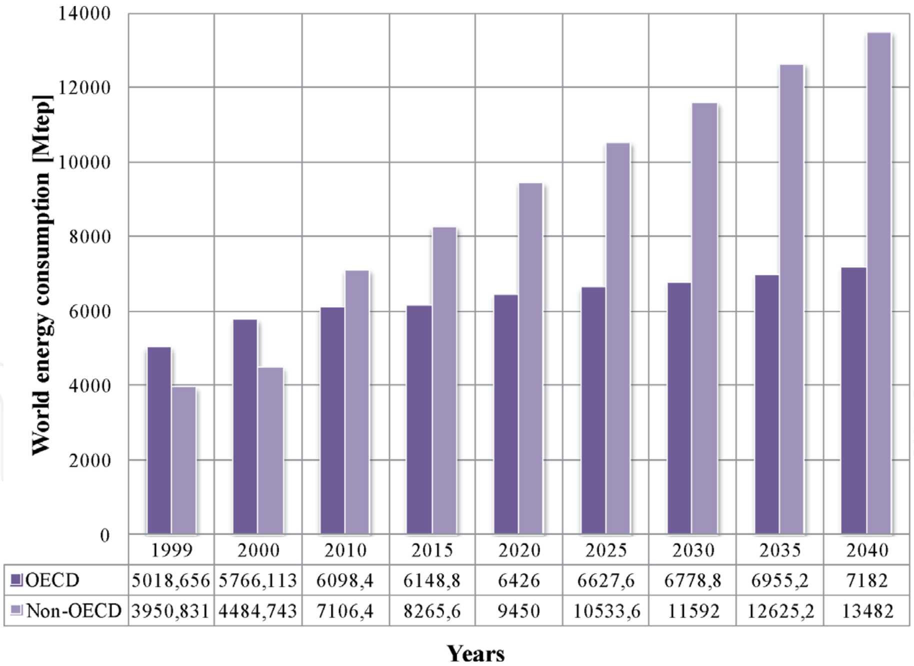


Figure 5.
World oil discovery, remaining reserves, and cumulative consumption [9–15].



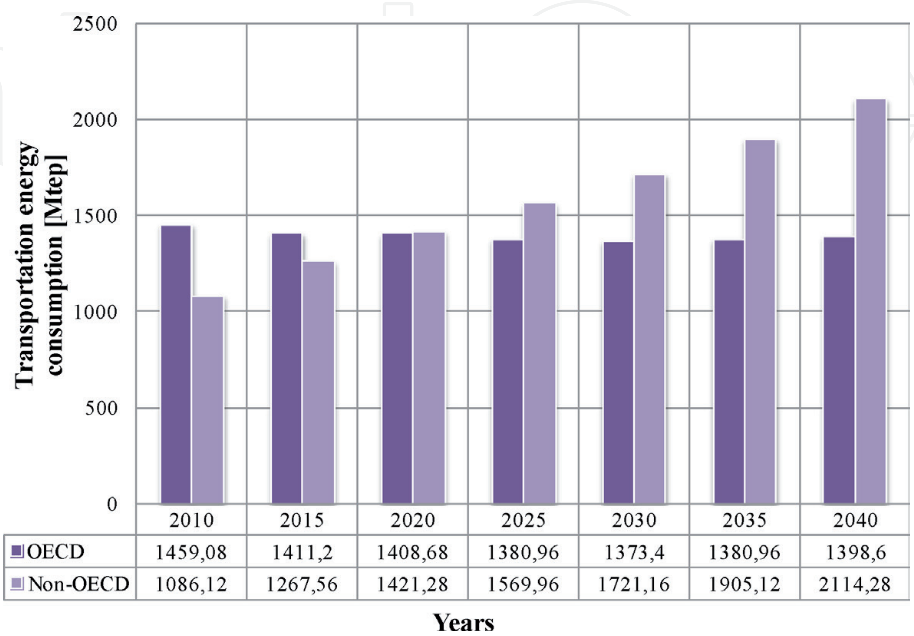
	1999	2000	2010	2015	2020	2025	2030	2035	2040
OECD	5018,656	5766,113	6098,4	6148,8	6426	6627,6	6778,8	6955,2	7182
Non-OECD	3950,831	4484,743	7106,4	8265,6	9450	10533,6	11592	12625,2	13482

Figure 6.
World energy consumption [16].

Among the factors explaining the growth of developing countries, there are of course the macroeconomic fundamentals: strong economic growth, driven by sustained industrial development and population growth, coupled with a broader access to energy sources, and in addition to this, in many developing countries, a policy of low energy prices and the frequent existence of subsidies.

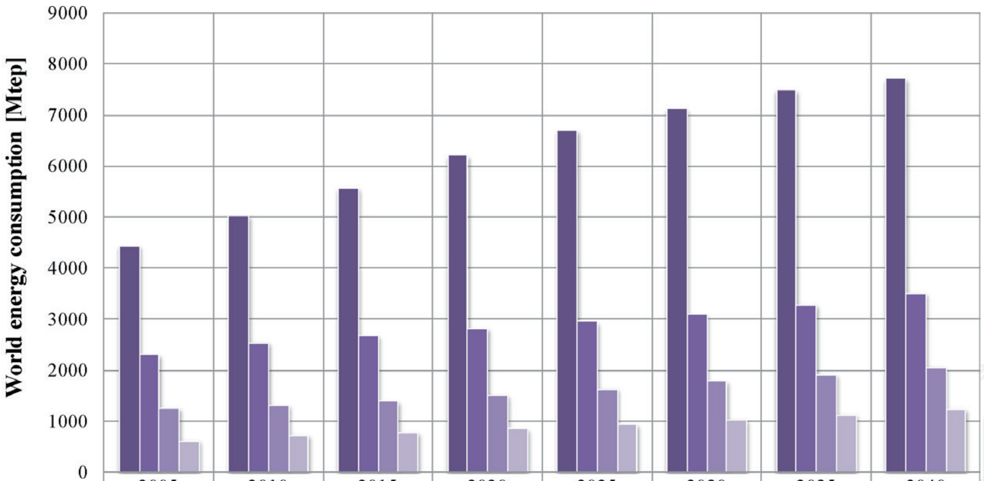
2.2.3 Energy consumption in the transportation sector

Energy consumption in the transportation sector includes energy used for the movement of people and goods by road, rail, air, and water. The latter has experienced a real explosion during this century and is increasing on average by 1.1% per year (**Figure 7**). Most of the growth in the use of energy transport is in non-OECD



	2010	2015	2020	2025	2030	2035	2040
OECD	1459,08	1411,2	1408,68	1380,96	1373,4	1380,96	1398,6
Non-OECD	1086,12	1267,56	1421,28	1569,96	1721,16	1905,12	2114,28

Figure 7.
Transportation sector energy consumption.



	2005	2010	2015	2020	2025	2030	2035	2040
Industrial	4450,2192	5040	5579,28	6216,84	6713,28	7144,2	7507,08	7733,88
Transport	2305,53288	2545,2	2676,24	2827,44	2948,4	3094,56	3286,08	3515,4
Residential	1260	1310,4	1388,52	1506,96	1638	1784,16	1922,76	2061,36
Commercial	616,59612	728,28	776,16	846,72	934,92	1030,68	1128,96	1234,8

Years

Figure 8.
World consumption by sector [16, 17].

countries that experienced strong economic growth at the same time, leading to improved living standards and a corresponding increase in personal and commercial travel request. Demand in these countries is almost doubled, from 43.1 quadrillion Btu in 2010 to 83.9 quadrillion Btu in 2040. That is to say, it increased by an average of 2.2% per year. On the other hand, the energy consumption of the OECD countries decreased on average by 0.1% per year, that is to say, 58 quadrillion Btu in 2010 to 56 quadrillion Btu in 2040 due to the relatively slow economic growth, improving energy efficiency, and stable population growth levels.

Compared to other economic sectors, transportation is ranked second after the industrial sector with a rate of 25.68% of final world consumption in 2015 [16, 17]. Under this scenario, the consumption will be reduced and will represent 24.16% of world consumption in 2040 [16] (**Figure 8**).

2.2.4 Transportation dependence on oil

Since its origins, the transport sector remains totally dependent on oil production. This results in an increased demand for the latter [9–18].

In 2015 the global transport sector consumes about 2,676,240,000 tons of oil equivalents of energy annually. Of this quantity, over 96% originates from oil, representing more than 60% of the total oil production in the world (**Figure 9**). Road transport accounts for the majority of this energy consumption. Light vehicles (LV) (including light trucks, light commercial vehicles, and minibusses) represent about 52% of the total means of road transportation, while busses and trucks represent a share of 4% and 17%, respectively. While the air and marine transportation account for about 10% of world consumption of transport energy, aviation is by far the most dynamic sector, with an increase in revenues-ton-kilometers of around 5.1% by year 2030. The railway sector represents only about 3% of the total energy consumption related to transportation [19].

However, the consumption patterns of industrialized and developing countries are very different (**Figure 10**). Oil consumption is almost three times higher in industrialized countries than in developing countries. Global demand will reach 106.5 million barrels per day in 2020 compared to 96 million barrels a day today.

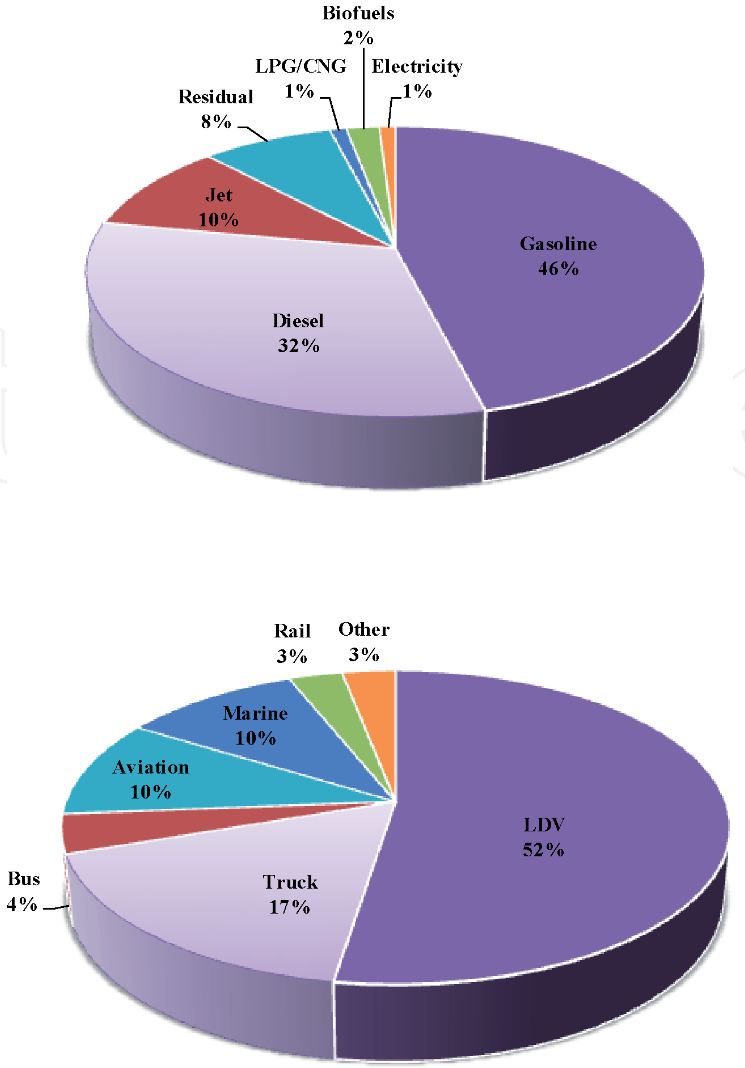
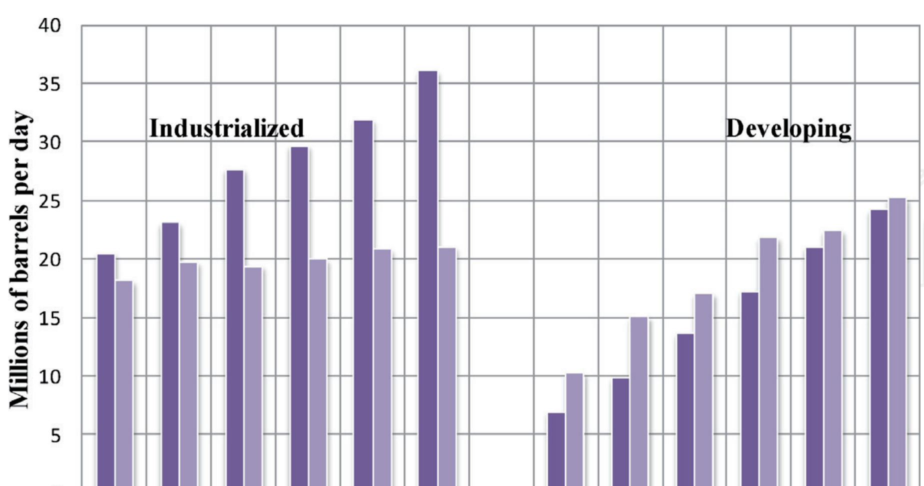


Figure 9.
Distribution of fuel consumption by source and mode [19].



	Industrialized 1990	1997	2005	2010	2015	2020	Developing 1990	1997	2005	2010	2015	2020
Transportation	20,46	23,07	27,66	29,68	31,89	36,09	6,859	9,85	13,63	17,22	21	24,19
Other	18,09	19,7	19,34	19,96	20,79	21,02	10,24	15,01	17,01	21,79	22,4	25,19

Years

Figure 10.
Increase in world oil demand, 1997–2020 [9].

In other sectors, oil consumption should stabilize or even decline in industrialized countries. Oil consumption will increase relatively slowly in all sectors for developing countries as compared to transportation sector. In developing countries, the transport sector also shows the highest expected growth in oil consumption. Currently, over 55% of the oil in the world (about 53 million barrels per day) will be consumed in the transport sector [9].

2.2.5 Consumption standards

Currently, only the United States and Japan have laws establishing fuel consumption standards. Across the Atlantic, the index of average consumption models is produced by the entity [Corporate Average Fuel Economy (CAFE)] and California standards for greenhouse gases. In Japan, the Top Runner program is adopted [20].

2.2.5.1 US standards

CAFE standards date back to the first oil crisis. They regulate the average consumption of constructors fleets on a combined city/highway use. Their initial goal was to double the energy efficiency of vehicles between 1975 and 1985. The first objective set for 1978 was to achieve a consumption of 18 miles per gallon (mpg) for cars or 13.1 l/100 km. In 1985, these latter were to reach a level of consumption of 27.5 mpg in 1985 (8.6 l/100 km). Subsequently, these standards have been facilitated. From 1990 and till the present time, the standard of 27.5 mpg has been re-applied [20].

In 2007, the US Congress set a new objective in the matter: 35 mpg (6.7 l/100 km) by 2020. In addition, the Department of Transportation (DOT) and the Environmental Protection Agency (EPA) have jointly proposed to apply this new standard on the period 2012—2016, which would allow, at national level, to meet the standards of all states. This program would save 5% of fuel per year, 1.8 million barrels of oil, and reduce CO_2 emissions to 950 million m^3 (1.8 million tons of the nearly 6000 produced) or 21% in 2030 compared to the situation that would prevail without the new standards [20].

2.2.5.2 Japanese standards

Japan is the country where the GHG emission standards are the most strict ones. According to the Top Runner program, introduced in 1999, emissions from gasoline light vehicles should be less than 22.8% of their 1995 level. For diesel vehicles, the goal was set at 2005 and the reduction achieved was 8.8% (the required improvement was, originally, 14.9%) [20].

2.2.5.3 European Union

In Europe, the European Automobile Manufacturers Association (ACEA) committed in 1998 to reduce CO_2 emissions from new cars to 140 g/km in 2008. Since 1998, the average reduction was 2.5% per year. Subsequently, in 2007, the European Commission proposed to limit to 130 g/km by 2012, and non-compliance of any car manufacturer would expose it to financial penaltiess. The goal is to eventually reach 120 g/km through complementary measures. However, reaching the threshold of 130 g/km has been delayed for 3 years, in 2014 [20].

3. Impact of transport on the environment

During the last decades, and with the industrialization of many countries, the world has experienced an increase in the number of individual vehicles in which their use is considered a good indicator of economic growth. But oil consumption used currently in a vehicle results in various impacts on the environment: emissions pollute the air and cause to climate change, noise causes harm and leads to health issues, and infrastructure affect landscapes and ecosystems. The further social impacts are as follows: hundreds of thousands of people are killed or injured each year in accidents, and congestion levels achieved in many densely populated areas are sources of wasted time. These problems today are important issues for governments and international organizations.

Pollutants are formed during the combustion of fuel in vehicles equipped with internal combustion vehicles. The products emitted by combustion vehicles are still the same; only the relative amounts vary with the type of combustion, the geometry of the engine, and the operating conditions of the vehicle [6–21].

The combustion of hydrocarbon liquids rejects pollutants called "primary" directly from the exhaust pipe and pollutants "secondary" formed by the chemical conversion of the first in the atmosphere. In addition to gas emissions, road transport is the source of emissions of pollutants in the form of fine particles, heavy metals, noise, etc. These pollutants have a direct impact on the public health and are responsible for climate change due to the greenhouse effect.

Pollutants from automobile exhaust are as follows [22]:

- Carbon compounds: CO, CO_2
- Nitrogen compounds: NO, NO_2 commonly referred to under the generic name of nitrogen
- Oxides NOx, N_2O, and more rarely NH_3, HCN, nitrosamines, etc.
- Organic compounds, volatile, irritating, or odor, such as hydrocarbons (HC), benzene, polycyclic aromatic hydrocarbons (PAHs), carbonyl compounds (aldehydes, etc.), carboxyl (organic acids)
- The sulfur compounds, particularly SO_2 and SO_3 and rarely H_2S
- Halogenated compounds, mostly in leaded fuels disappearing over
- Metal compounds, especially the fuel lead and zinc lubricants associated with its impurity cadmium
- Volatile organic compounds (VOC) and soot appointed as particulate matter (PM_{10}, $PM_{2.5}$), derived almost exclusively diesel engines

3.1 Climate change and air pollution

The potential harms of climate change is well established. Average temperatures on the surface of the earth and the oceans have risen, causing climatic disturbances that are already present in almost all regions of the world. At the global level, it is estimated that average temperatures have risen by 0.7°C over the twentieth century. The last decade (2001–2011) was also the warmest ever recorded by meteorological services, and the current warming is accelerating [23, 24].

Climate change is already resulting in a multitude of visible and measurable phenomena: the gradual disappearance of Arctic ice cover in summer accelerated melting of glaciers, ocean acidification, etc. Climate models predict a substantial increase in sea levels, which then lead to disastrous consequences for low-lying coastal areas and island states, and in the near horizon for the youngest among us are living the consequences. Greater frequency of extreme weather events such as floods and droughts is also anticipated. Climate change will directly affect ecosystems, infrastructure, economy, and well-being of people worldwide. Emissions of GHG in the past, present, and future will destabilize the climate system for a long time. This means that even if global emissions were reduced and stabilized now, climate change will continue to affect us for several more decades. Beyond the gradual effects approached due to the increase in average global temperatures, the Intergovernmental Panel on Climate Change (IPCC) estimates that a global warming of more than 2°C above the temperature of the preindustrial exposes us to the risk of abrupt and irreversible changes (tipping points) in the functioning of the climate system. To limit global warming to a maximum increase of 2°C, the IPCC estimates that global GHG emissions must be stabilized by 2015 and be reduced by half by 2050. In summary, there is still time to act but the time window in which we can do it quickly narrows [24, 25].

3.1.1 Greenhouse effect and global warming

The greenhouse effect is a natural phenomenon of partial retention of solar radiation and the earth's heat in the atmosphere, described in 1827 by the physicist Jean Baptiste Fourier. This phenomenon essential to our existence gives an average temperature of 15°C on earth. If it did not exist, the average surface temperature of the earth would be −18°C. The water is in ice and life would probably never appear on earth. What is dangerous is not the phenomenon itself, but its rapid increase due to human activities is worrying [18–26, 27].

The Intergovernmental Panel on Climate Change predicts an average warming of 1–3.5°C by 2100. This would raise the sea level by 15–95 cm. This threatens to flood completely some islands in the Pacific and Indian oceans and it will amplify the frequency and severity of weather events such as floods and droughts [28–31].

3.1.1.1 Greenhouse effect mechanism

The climate is governed by the heat balance of the earth. The essential energy source for the planet is the incident solar flux (short wavelength) whose absorption or not by the earth system depends primarily on the constituents of the atmosphere that absorb and reflect about 50% of the flow incident (H_2O, CO_2 and O_3, aerosols and clouds) (**Figure 11**). The other half of the incident flux is absorbed by the land surface and is re-emitted to the atmosphere as infrared wavelengths (IR, wavelengths). The greenhouse gases absorb IR and retransmit them to the surface of the earth and into space. So, greenhouse gases act like the glass in a greenhouse; increasing the concentration of these gases in the atmosphere causes an increase of the temperature of the greenhouse.

3.1.1.2 Gas contributing to the greenhouse effect

Gases contributing to the greenhouse effect are mainly water vapor, carbon dioxide, methane, and nitrous oxide. Industrial greenhouse gas includes fluorinated compounds, namely, hydrofluorocarbons or CFCs, perfluorocarbons or PFCs, and sulfur hexafluoride or SF6; these gases are also responsible for the degradation on the ozone layer. These are the six gases covered by the Kyoto Protocol (**Table 3**). The gases do not all cause to the same intensity to the green house effect. Indeed,

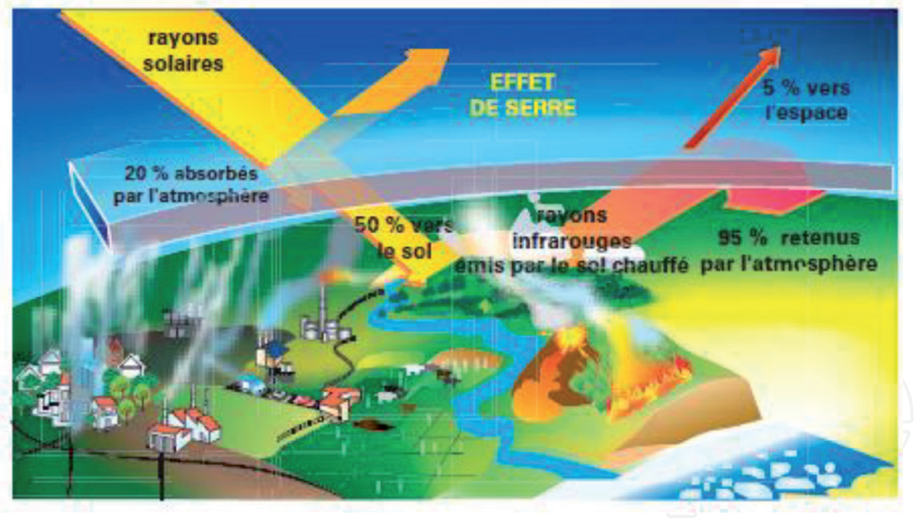


Figure 11.
Greenhouse effect mechanism.

Greenhouse gas		Chemical formula	GWP	Atmospheric lifetime (years)
Carbon dioxide		CO_2	1	200 (variable)
Methane		CH_4	25	12
Nitrous oxide		N_2O	298	114
Fluorochemicals	Dichlorodifluoromethane (CFC-12)	CCl_2F_2	10,900	102
	Chlorodifluoromethane (HCFC-22)	$CHClF_2$	1810	12,1
	Perfluoromethane	CF_4	7390	50,000
	Sulfur hexafluoride	SF_6	22,800	3200

Table 3.
Length of stay and global warming potential of greenhouse gases [32, 33].

some have a greater warming potential than others and/or length of stay (residence) longer.

It is noted that the duration of stay in the atmosphere of the different green house gases varies widely: 12 for CH_4, approximately 200 years for CO_2 and more than 50,000 for CF_4. This means that the carbon dioxide produced today will still affect in a century.

The contribution to the green house gas effect of each gas is measured by the Global Warming Potential (GWP). The global warming potential of a gas quantify the radiative forcing (i.e., the power that radiative greenhouse gas returns to the ground) accumulated over a period of 100 years (that is how we increase the greenhouse when it emits one kilogram of the gas). This value is measured in relation to CO_2. If 1 kg of methane is emitted into the atmosphere, it has the same effect on a century if we had issued 25 kg of carbon dioxide. If 1 kg of sulfur hexafluoride is emitted in the atmosphere, it has the same effect on a century if we had issued 22,800 kg of carbon dioxide. That is why greenhouse gases are measured in carbon equivalent. By definition, 1 kg CO_2 contains 0.2727 kg carbon equivalent, i.e., the weight of carbon only in the carbon dioxide compound. For other gases, the carbon equivalent is given by the equation:

$$\text{Carbon Equivalent} = 0.2727. \text{GWP relative} \quad (1)$$

Greenhouse gases are not very abundant naturally. But because of the human activity since the Industrial Revolution, the concentration of these gases in the atmosphere has changed significantly. According to the IPCC, if no measures are taken, the CO_2 content in the atmosphere rose from 260 to 400 ppm today to 1000 ppm at the end of the century, leading to a rise in temperature between 2 and 6°C [34].

The following figure shows the concentration of CO_2. First observed seasonal net CO_2 concentration. It varies in the range of 2% per year, with a maximum in month of May (at the beginning of the growing season) and a minimum in October (end of season) [34].

Global emissions of greenhouse gases are increasing steadily, despite various policy initiatives such as the Kyoto Protocol. The situation varies considerably from one sector to another.

In the reference scenario IEO 2013 [16], global emissions of carbon dioxide produced from burning fossil fuels increased by 31.2 billion tons in 2010 to 36.4 billion tons in 2020 and 45.5 billion tons in 2040 (**Figure 12**).

The increase in CO_2 emissions was 40% from 1990 to 2010, reaching 31.7 billion tons of carbon dioxide in 2012. The increase of 1.3% in CO_2 emissions worldwide is largely caused by 300 million tons of emissions in China and 70 million tons in Japan (since the Fukushima disaster in 2011, Japan uses more fossil energy). The United States and some European countries reduced their emissions. Much of the increase in emissions is attributable to developing countries that are non-OECD members who continue to rely heavily on fossil fuels to meet the fast pace of growth in energy demand. Regarding emissions from non-OECD countries, it is predicted to reach 31.6 billion tons in 2040, or 69% of the world total, in comparison to emissions from OECD countries which would be around 13.9 billion tons in 2040 or 31% of the world total (**Figure 13**).

CO_2 emissions from transportation modes, should, if no action is taken, continue to rise at current rates. The graph in **Figure 14** shows the evolution observed and projected

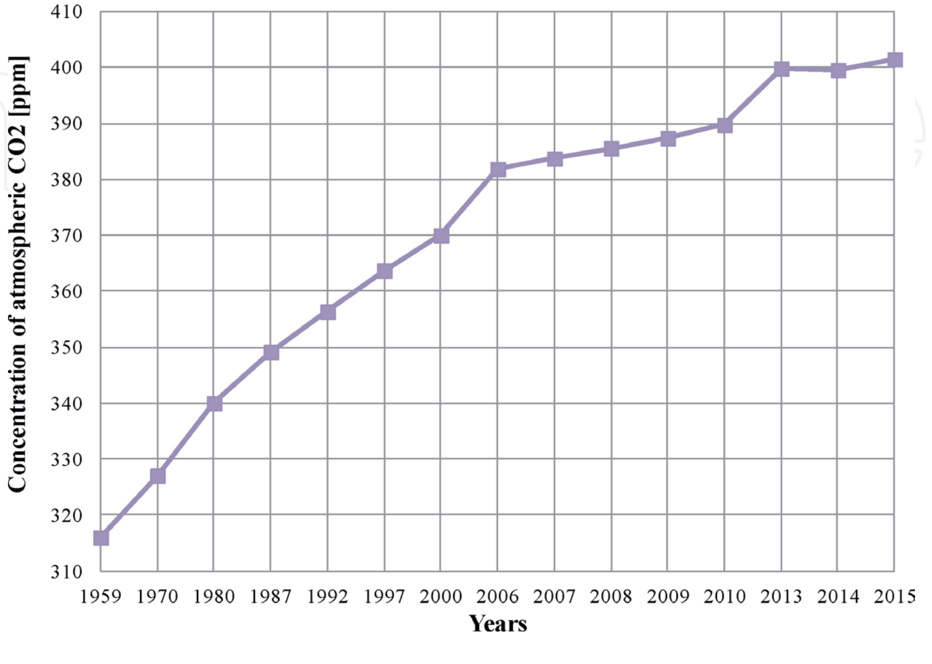
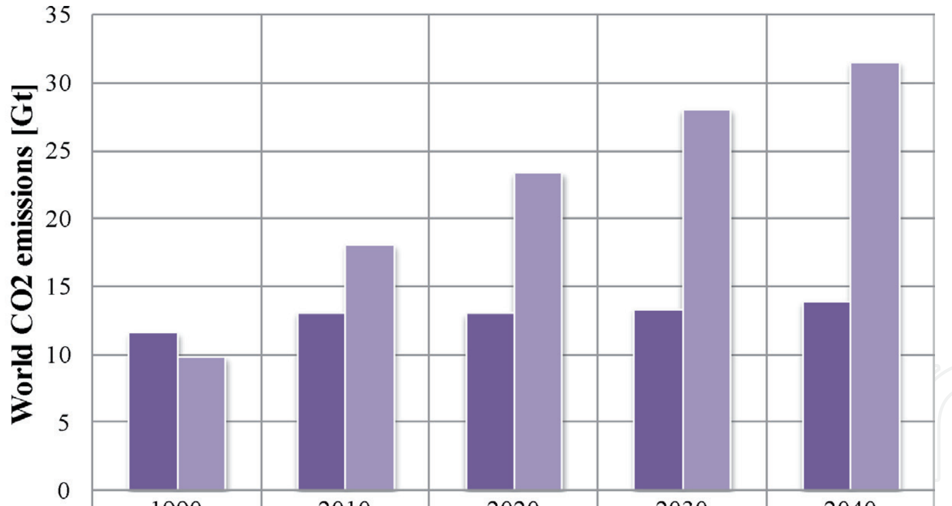


Figure 12.
Global CO_2 concentration [34, 35].



	1990	2010	2020	2030	2040
OECD	11,6	13,1	13	13,4	13,9
Non-OECD	9,8	18,1	23,4	28,1	31,6

Years

Figure 13.
Global CO_2 emissions.

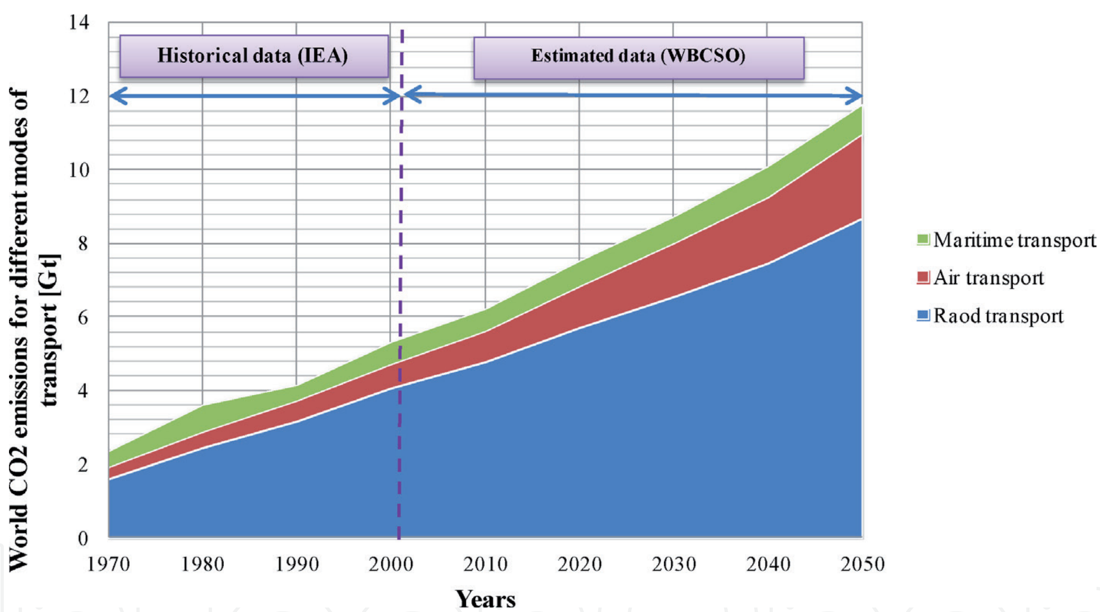


Figure 14.
Evolution observed and projected global CO_2 emissions in different modes of transport [36].

of emissions from different transport modes between 1970 and 2050. CO_2 emissions from transport are expected to double between 2000 and 2050, the largest part of the increase being related to road and air transport. Freight transport has grown faster than passenger transport, and progression seems set to continue in the future [36].

Globally, the transport sector is the second largest emitting sector with 7 Gt of CO_2 emitted in 2011, behind the energy sector, comprising the production of electricity and heat. According to projections by the International Energy Agency, these emissions will continue to rise, reaching 18 Gt in 2050 in the baseline scenario [37].

Beyond this overall finding, disparities are hiding across geographical areas. According to the reference scenario of the International Energy Agency, while the CO_2 emissions of the transport sector in developed countries will grow steadily in 2050, the same emissions in developing countries will, in turn, grow exponentially. At the head of these, China and India contributions reach, respectively, 4 and 1.5 Gt in 2050 (against 0.332 Gt and 0.1 Gt in 2005, respectively) [38].

3.2 Local pollution

Unlike greenhouse gases, local pollution has a direct impact on the health and comfort of the car users and others. The impact is most noticeable in areas of heavy traffic, especially in cities. Pollutants are due to fuel combustion or simply the running of the vehicle, such as the following:

- **Fine particles:** Rated PM for particulate matter, they are inorganic or organic particles or a mixture thereof [39]. They are classified according to their size; finer less than 2.5 μm named PM2.5 and coarser that have a diameter between 2.5 μm and 10.mu.m called PM10 [40, 41]. In 2007 in France, road transport occupied the fourth place of emission sources of these two types of particles, with 12% and 11%, respectively [40]. Tests on a vehicle "light" diesel, produced according to the European procedure (cycle Motor Vehicle Emissions Group (MVEG)), measured emissions of 1010 particles/km much higher than the limit (6106 particles/km) specified in the standard EuroV 2009 [42].

- **Heavy metals:** Other fine particles of heavy metals such as copper (Cu) and lead (Pb) are also issued by the transport sector. Copper is linked to the wear of brake pads for road vehicles, but it mainly comes from the wear of overhead lines in rail transport. Copper emissions are continuously increasing with the growth in traffic. As for lead, it is due to the use of leaded petrol and consumption of part of the "engine" oils containing traces of lead. Lead emissions are related to its content in the fuel [43]. Upon the arrival of unleaded gasoline, emissions have dropped drastically. Since 2000, road transport contributes 4% against 91% in 1990 of total Pb emissions in France [42–44].

- **Noise:** Noise pollution from transport, contrary to releases of gases and particles, has little adverse impact on public health. However, they represent a source of annoyance for 40% of French and 25% of the European population. 17% of these noises are caused by cars [45]. In fact, emissions of conventional cars are measured at an average intensity of 70dBA9. The electric vehicle emits the same intensity noise than conventional vehicles beyond 30 km/h. Nevertheless electric vehicles fell by 10dBA and 6.5dBA for speed 5 and 10 km/h, respectively [46]. Knowing that the noise is characterized by its intensity and duration [41], people in urban areas are the most affected, and the noise reduction can be one more argument for the electrification of transport [47–49].

The traffic noise has multiple negative effects on health. The World Health Organization recognized the ambient noise, especially the noise originating from car traffic, as a serious public health issue. The traffic noise has various kinds of harm. The most common effect is a mere annoyance, but it seems also proven that traffic noise causes serious health problems, including sleep cycle disturbances affecting cognitive function (especially in children), and helps in the emergence of certain cardiovascular diseases. It also seems increasingly obvious that it raises blood pressure. It has been estimated that over 245,000 people in the European Union acquired every year cardiovascular disease attributable to traffic noise. Some 20% of these patients (nearly 50,000 people) are victims of a heart attack, leading to their premature death. There are no comparable estimates for other parts of the world, but there is no reason not to think that much of the population suffers from traffic noise elsewhere [36].

Pollutant emissions are a source of health costs, damage to buildings and materials, crop losses, and other damage to ecosystems (biosphere, soil, water). Each impact is driven by one or more types of pollutants [36]:

- Impact on health: this impact comes from inhaling fine particles ($PM_{2.5}$/PM_{10} and other air pollutants). The particles contained in the exhaust gas may be considered the most important of these pollutants. Ozone (O_3) also affects health. The impact essentially translates into a worsening health problems for people with respiratory diseases and an increased risk of contracting these diseases.

- Degradation of buildings and materials such as damage mainly consists in two aspects: the first in the form of dirt and other surfaces of the facades of the buildings due to particles and dust and the second largest in the form of degradation due the corrosive action of acidic air pollutants such as NO_x and SO_2.

- Losses of crops and impacts on the biosphere: acid rain, ozone, and SO_2 damage crops, forests and other ecosystems.

4. Regulatory and technological aspects

Since the 1970s, the issue of preserving the environment has become a concern. International authorities have begun to take concrete steps to reduce the discharge of pollutants. The Kyoto Protocol adopted in 1997 is one of these measures. It had set a target average 5.2% reduction in greenhouse gas emissions of industrialized countries. And, although all sectors are concerned, the emissions from transport and automotive in particular have been the target of regulatory mechanisms put in place by governments. Thus, automakers are constantly forced to improve their technologies while maintaining low costs.

4.1 Regulatory aspects

The regulatory framework for emissions is different from one country to the other. However, all standards adopted by industrialized countries such as the European Union and its member states, the United States and Japan, are aimed at limiting emissions of CO, NO_x, HC, and PM (**Figure 15**). Each standard is based on specific test procedures. For information, the Tier-2 standard adopted in 1999 in the United States does not distinguish between fuels, while the Japanese standard takes into account the state (hot or cold) of the vehicle. **Figure 15** shows a comparison of these standards. It may be noted that Japanese standards are the strictest. They are followed by the European standard Euro V applied from 2009 and finally in US standards. European standards are, like all standards, whenever revisited and emission thresholds are revised continually declining.

CO_2 emissions have been subject to a voluntary agreement between the European Community and the European Automobile Manufacturers Association. This agreement aimed to reduce emissions from passenger cars to 120 g/km by 2012 and 95 g/km by 2020. To achieve this, France and other countries have imposed, since May 2006, car manufacturers labeling their classes 10 new vehicles to encourage the purchase of less polluting models. Financial incentives to buy cleaner vehicles were also implemented through environmental taxes such as the Bonus/Malus ecological established in France since January 2008.

4.2 Technological aspects: alternative to the internal combustion engine

The scarcity of oil coupled with increasing demand (primarily bound to the development of emerging countries) causes an inevitable increase in the price of oil. This increase in oil prices gives researchers and industry the opportunity to

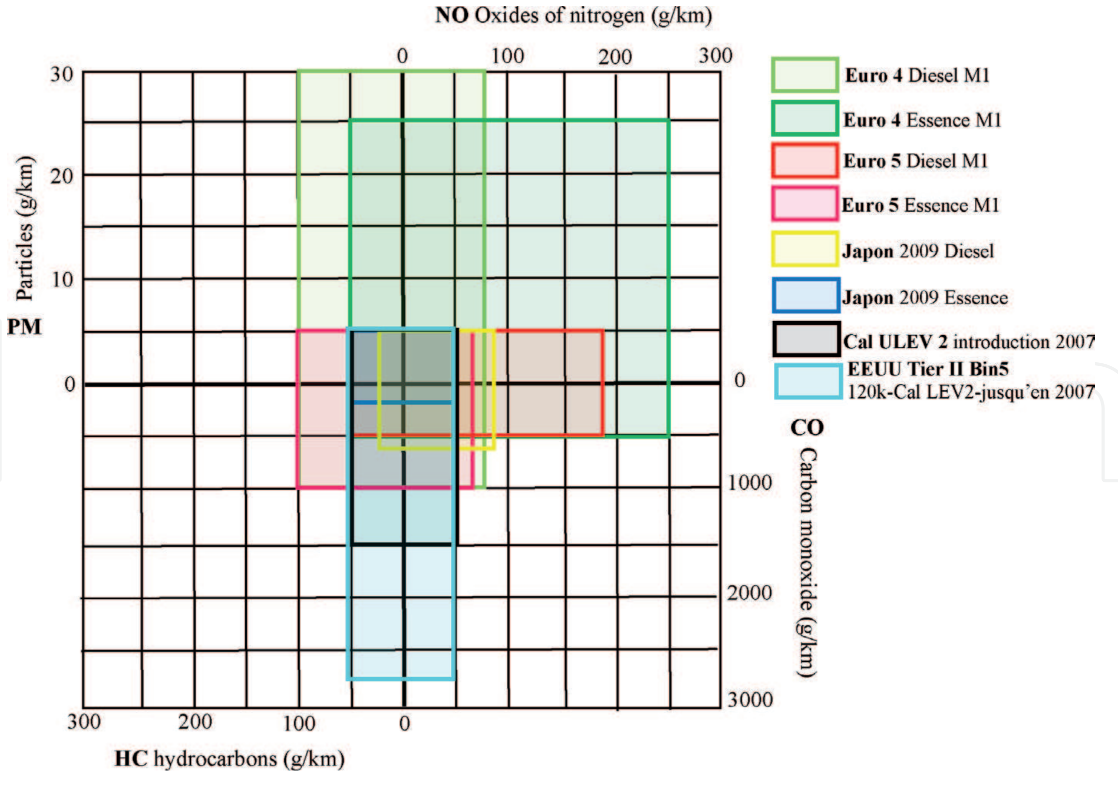


Figure 15.
Comparison of car emission limits in the European Union, Japan, and the United States.

explore new technological avenues that were not possible before. In this context, the return of investment on these technology is almost guaranteed. The era of the post-oil is actually launched. The urgent need to reduce CO_2 emissions worldwide, combined with the rise in oil prices, requires decision-making advocated by new political commitments. New commitments lay the foundations for a new global orientation in terms of energy management. The goal is to enable research and commercialization of new solutions, which involve the following:

- The optimization of combustion engines (improved technologies used currently in vehicles):
- Improving the efficiency of engines (downsizing, supercharging, injection, post processing, aerodynamics, etc.)
- Hybridization (electrical and thermal) and electrification of the drive train
- The use of new energies (diversification of energy sources used for traction vehicles)
- Biofuels
- Liquefied Petroleum Gas (LPG)
- Natural gas vehicles (NGV)
- Hydrogen (a few decades)

4.2.1 Biofuels

They were encouraged by the government following the two oil shocks in the 1970s. Today, after over 20 years of industrial development, these plant-derived fuels have their place in the energy mix. The European Union has set a particular incorporation target of 10% of renewable fuels in road transport by 2020 [50]. The two large biofuel production chains are the petrol sector and the diesel industry.

- The biofuel sector includes fuel ethanol and ethyl tertiary butyl ether (ETBE). The ethanol to be supplied to cars with gasoline engine is derived mostly from sugar plants (beet, sugar cane), wheat, or corn. It is mostly used in Brazil and the United States. It can be mixed with gasoline at concentrations ranging from 5 to 10% for the conventional vehicles and added at higher rates for adapted vehicles.

- The diesel biofuel sector corresponds to fatty acid methyl esters (FAME), which are made from vegetable oils from rapeseed or sunflower (Europe), animal fats, or recycled used oil and soy (United States). Biodiesel can be incorporated into the diesel fuel in amounts up to 7%. This rate can rise to 30% for certain fleets.

To increase the availability of biofuels, new biofuel production chains are being studied. They are used as feedstock lignocellulosic biomass, agricultural residues (corn stalks, cereal straw), and forestry, including dedicated poplar crops and organic waste such as sewage sludge. Ethanol processing by the biochemical pathway is studied. Similarly, for diesel, the transformation of this synthetic liquid fuels from biomass by the Fischer-Tropsch process is the subject of ongoing R&D around the world. These channels have many advantages: potentially lower costs, no competition with the food chain, and no limits to production volumes, no co-products to sell. But research is still needed for their development. LPG is a mixture of 80% butane (C_4H_{10}) and 20% of propane (C_3H_8) and heavier than air. It can directly come from stripping operations (oil extraction) during production on fields or crude oil refining. Its use has advantages compared to diesel fuel to reduce [51, 52]:

- 50% of nitrogen oxide emissions

- 50% those of carbon monoxide

- 90% of those hydrocarbons and particles

LPG is mainly distributed in gas cylinders for domestic heating, cooking food, and chemical industry, transport representing only a minority share of its consumption. Currently, It is consumed in significant quantities for the automobile only in few European countries and Australia, but China is a growing market, and the United States is considered to be a potential consumers in the years to come. If it is in the gaseous state at ambient conditions, LPG is usually stored in liquid format a pressure of 10 bars [52]. Currently, vehicles using this fuel are mostly equipped with a "dual-fuel" system (operation on petrol or LPG), which allows to adapt to the refueling station density available. This approach involves the LPG as an added feature to the existing petrol vehicles and makes operation in fuel optimal [50].

4.2.2 GNV/GNL

The largest deposits of natural gas (methane), whose reserves are larger than those of oil, are in the following countries: the Unites States, Russia, Canada, Iran and Qatar, Algeria, Nigeria, South Africa, Argentina, Australia, etc. It is fed by a major pipeline network or, alternatively, at high cost to the liquid, chilled to −162°C between very specific terminals special water (LNG); it gives the appellation liquefied natural gas (LNG). For automotive applications, called NGV. Methane is stored on board with a pressure of 200 bars in the tanks, the volume of which corresponds to 5 times that of a fuel tank of equivalent energy content. A distribution network already exists in some cities, but a compression facility is necessary for refueling stations because the pressure of the network generally does not exceed 30 bar. The acceptability of the presence of reservoirs and the specific filling operation are also issues to consider [52].

NGV can be easily fitted to a motor provided to run on gasoline. It reduces by nearly 25% the emissions of greenhouse gases. The engines used offer good energy efficiency (greater than 10 to 15% that of a gasoline engine) combined with a very low potential for regulated toxic emissions. Its exhaust will emit no sulfur oxides, lead, or particles [50–52]. 11.3 million CNG vehicles are circulating in the world. These are mostly light and commercial vehicles; trucks and busses do in fact represent only 5–6% of the park. The park is primarily developed in the following areas: Pakistan (20% of global NGV fleet), Argentina (16%), Iran (15%), and Brazil (14.5%). These four countries alone account for 2/3 of global NGV fleet. In Europe, CNG has developed mainly in Italy (6% of global NGV fleet) [50].

4.2.3 Synthetic fuels

Synthetic fuels are liquid fuels made from natural gas, coal, or biomass. They are called gas to liquids (GTL), coal to liquids (CTL), and biomass to liquids (BTL). Their production takes place in two steps:

- Conversion of the synthesis gas energy source formed by a mixture of carbon monoxide and hydrogen
- Chemical conversion of synthesis gas (process “Fischer-Tropsch”) into liquid hydrocarbons

4.2.3.1 Fuels from natural gas (GTL)

They can be integrated into “fuel pool” current and distributed through existing channels. The fuels produced are of excellent quality. They contain no sulfur or aromatics and result in net reductions in particulate emissions, unburned hydrocarbons, and CO (carbon monoxide). The cost of production has been reduced in recent years, and a new generation of catalysts is used to maximize yields. This sector accounts for natural gas, an outlet which in the future could become major.

4.2.3.2 The path from coal (CTL)

More expensive, it is interesting for countries with large coal resources (China and India). Research efforts are still needed and the problem of CO_2 emitted must be paid by his capture and geological storage.

4.2.3.3 The solution biomass (BTL)

Liquid fuels made from it, in this case, lignocellulosic biomass: agricultural residue (stalks, straw) and forestry, including dedicated poplar crops and organic waste such as sewage sludge. This solution has two advantages: reduced energy dependence and reduced CO_2 emissions. But the costs are still high because the sector is still at the stage of research and development. New technologies are expected in 2015.

4.2.4 Hydrogen (H_2)

Hydrogen is the most abundant element in the universe. On our planet, it is mainly found in water and in hydrocarbons which are the sources of industrial

Hydrogen	Natural gas	LPG	Coal
34 kWh/kg	17 kWh/kg 11 at 12 kWh/m^3	13 kWh/kg	7.2 kWh/kg
Fuel	**Gasoline**	**Wood**	**Natural uranium**
11,6 kWh/kg	12 kWh/kg	2 at 4 kWh/kg	120.10^3 kWh/kg

Table 4.
The average energy values of PCI main fuels [54].

hydrogen. It is widely used in the chemical industry and oil refining, among others. Due to its clean combustion, it is also considered as one of the energy vectors of the future [53]. The H_2 gas is about 8 times lighter than methane and must be compressed at very high pressure or liquefied for storage in significant amounts: under 700 bars, 1 kg of H_2 still occupies a volume of 23 l. Its liquefaction for cryogenic storage at −253°C consumes at least 30% of the initial energy content of the hydrogen, but it allows to concentrate 1 kg in a volume of 14 l [52]. A kilogram of hydrogen releases about three times more energy than a kg of gasoline and fuel oil (**Table 4**).

Indeed since hydrogen does not exist on earth, it took and it will in the future develop less expensive methods and more profitable products. Here are the different ways to produce hydrogen; now some have already reached technological maturity, and others are still in development and study.

- We can create it from fossil fuels (several methods): steam reforming and partial oxidation.
- But also from the electrolysis of water (commonly called crack water), electricity would come from renewable energy.
- From biomass.

4.2.4.1 Production of hydrogen from fossil fuels

It is the most prevalent currently. But this technique is not a viable solution because hydrocarbons have a limited lifespan. There are two different methods for this style of manufacture:

4.2.4.2 Steam reforming

Steam reforming or steam reforming is to convert hydrocarbons by reaction of synthesis gas with water vapor and in the presence of a nickel catalyst, at high temperature (840–950°C) and moderate pressure (20–30 bar). The fillers conventionally used are light hydrocarbons which include natural gas, LPG, and naphtha to boiling points of 200–220°C. Alcohols such as methanol or ethanol may also be used. Natural gas, however, is the reference load [55–56]. The steam reforming of the general reaction is:

$$C_nH_m + 2nH_2O \rightarrow (m/2 + 2n)\,H_2 + nCO_2 \tag{2}$$

4.2.4.3 Partial oxidation

The partial oxidation is to transform the hydrocarbon by oxidation synthesis gas formed in the presence of oxygen. This reaction takes place at high temperature

(1200–1500°C) and high pressure (20–90 bars) and does not require the presence of a catalyzer [53]. The chemical reactions may be summarized in the case of hydrocarbons by the following formulas:

$$C_nH_m + (n/2)\,O_2 \rightarrow nCO + (m/2)\,H_2 \tag{3}$$

$$nCO + nH_2O \rightarrow nCO_2 + nH_2 \tag{4}$$

The reaction is exothermic, for example, the enthalpy of the reaction with methane is −35.7 $kJ.mol^{-1}$. The advantage of the partial oxidation reaction is its exothermic (unlike the steam reforming reaction) for assisting catalysis (temperature rise). The main drawback lies in the fact that the H_2 percentages are lower than those obtained by steam reforming, due to the majority presence of the nitrogen from the air. In addition, it is possible to obtain NOx.

4.2.4.4 The water electrolysis

Electrolysis of water, if it covers only a few percent of all hydrogen produced [57–59] is nevertheless of great interest because it represents a fashion own production (especially if the electricity is nuclear, hydro, solar, and wind) which provides high purity hydrogen [53]. This technology works by passing an electric current through water to obtain the dissociation of water molecules into oxygen and hydrogen gas. The electrolysis of water involves two chemical reactions taking place separately on two electrodes. At the cathode, the electrolysis of water occurs according to Eq. (1), and at anode, the oxidation of hydroxide ions occurs according to:

$$2H_2O + 2e^- \leftrightarrow H_2 + 2OH^- \tag{5}$$

$$2OH^- \leftrightarrow 1/2O_2 + H_2O + 2e^- \tag{6}$$

The global reaction is written as:

$$H_2O \rightarrow H_2 + 1/2O_2 \tag{7}$$

There are other means of hydrogen production, some of which are still under study. There are particular biological processes set works by algae or microorganisms (digestion, photosynthesis).

The hydrogen can be used either as:

- Heat engine
- Fuel cell

4.2.5 The hydrogen combustion engine

Internal combustion means combustion of engine motors (commonly called “explosion”) which, according to Beau de Rochas’ Otto cycle or Diesel cycle, operates from the combustion of petrol, diesel or gas coal, natural gas, or distillates derived from fermentation of organic matter. All internal combustion engines can be converted to operate on hydrogen. Precautions are to be taken to avoid a flashback to the intake manifold. The loss on the power level is 20–25% compared to a gasoline engine of the same capacity, but the energy efficiency is equivalent. There is more need to select suitable materials for hydrogen (corrosion, lubrication). Such engines do not emit CO_2 but only few nitrogen oxides; they are well suited to hybrid gasoline-hydrogen as are biofuel prototypes developed since 1979 by the German manufacturer BMW. The BMW manufacturer who has subsequently improved its engines by the adopting the technique of direct injection of hydrogen at high pressure [60] has now abandoned this type of hydrogen thermal engine. Other manufacturers such as MAN, Ford, Mazda, and Quantum have also conducted research on these types of hydrogen thermal engines and have built prototype cars (cars, vans, and busses) [61], but eventually, these manufacturers has stopped at the prototyping phase. For its part, Mercedes has designed an engine operating with a mixture of hydrogen and natural gas [62].

4.2.6 Fuel cell

Car manufacturers seem to focus more on the torque hydrogen/fuel cell for the long term. The couple hydrogen/fuel cell appears, indeed, in principle, as a strong candidate to succeed the torque petroleum fuel/combustion engine. Hydrogen is then used to power a fuel cell which generates electricity to enable operation of an electric motor which will move the vehicle. Hydrogen is by definition the best energy carrier for the cell: no CO_2 emissions and better performance for the battery, including a performance about twice a petrol engine urban cycle. Fueled by a mixture of air and hydrogen, the cell converts the chemical energy of hydrogen into electrical energy according to the reverse principle of electrolysis. By reacting hydrogen with oxygen on the electrodes, fuel cells can produce electricity without programming other than water vapor. The idea dates back to 1839! It has long been used to generate electricity onboard rockets. The proton exchange membrane fuel cells (PEMFC) are best suited as a carrier. It is this type of battery that automakers concentrate most of their research.

4.2.7 Hybrid vehicles

It is a vehicle equipped with a system of thermal/electric motorization mixed and two energy storage systems: a fuel tank and a battery. The main advantage of the hybrid car is to get to optimize the integration of the two types of engines to make the most of each of them. Any kind of combinations is theoretically possible, the combustion engine can be used both for charging the batteries for the vehicle drive and the electric motor can be used both to move the vehicle to retrieve his braking energy. The dual petrol (or diesel)/electricity allows the optimization of energy use in the vehicle, reducing emissions of pollutants, including CO_2, and a consumer economy (10–50% depending the degree of hybridization).

4.2.8 Electric vehicles

The electric car will appear environmentally as "zero emission" solution. The electric vehicle has a reduced autonomy and a time of significant recharge, which could limit its use (on relatively short trips or for captive fleets) and its commercial development. The current batteries offer only a hundred kilometers of autonomy against nearly 1000 km for diesel vehicles. Though, a good progress is made in this research area. Advanced lithium ion or lithium polymer batteries, offered by Dassault and Bolloré groups, will enable a range of approximately 250–300 km (always with several hours cooldown). However, some manufacturers now positioning their electric vehicles as urban perished vehicles with a modest autonomy (between 80 and 160 km), which is no longer a handicap for commuting home/work. There is, in addition, a quick battery charging solutions for use in an emergency; these refills would restore in minutes between 50 and 80% of autonomy to allow the vehicle to return to its final destination.

5. Conclusion

The all-electric vehicles have again become a topical issue that seems to be the modern answer to deal with the explosion in the price of oil and environmental constraints, including increased green house gas emission effect linked to road transport especially automotive. Moreover, these means which are independent of fossil fuels and friend to the environment itself have many other benefits; they are silent, featured with relatively constant consumption and have good overall energy efficiency.

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