

*Part II*

**Energy and Land Transportation  
in the Atlantic Basin**



## Chapter Three

# Sustainable Mobility in the European Union: Alternative Fuels for Passenger Transport

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Transportation is responsible of 25 percent of global final energy consumption (2,800 Mtoe in 2016).<sup>2</sup> Some 60 percent of this global transport demand is passenger transportation (or passenger mobility), one of the fastest growing sectors in terms of energy consumption (with an estimated average annual growth rate of 1.5 percent projected to 2040).

Both travel and freight transport are expected to grow faster than any of the other end-uses for refined petroleum over the period to 2040. This is particularly relevant for electricity — which will see its consumption in transport triple over the same period — and for natural gas — the supply of which will increase by nearly 500 percent. This transportation growth will be driven mainly non-OECD countries, especially in freight transport (which is projected to grow by 30 percent between 2015 and 2040, while remaining relatively constant in OECD).<sup>3</sup>

This growth in freight transport will also multiply the possibilities for multimodal transportation, in parallel to increases in industrial production in developing countries, but not in OECD. In fact, more than a half of the increase in the world's freight transportation energy use, together with increasing demand for goods and services, will come from non-OECD countries.

Given the complexity and breadth of the total global transportation sector (which also includes freight and rail, shipping and aviation), this study focuses only on road passenger mobility, the largest segment of the transportation sector.

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1. The authors would like to thank Manuel Bravo for his suggestions.

2. This figure is estimated based on consumption in 2012 and assuming certain growth of global fuels consumption, and is based on Energy Information Administration, *International Energy Outlook 2016*, [https://www.eia.gov/outlooks/archive/ieo16/pdf/0484\(2016\).pdf](https://www.eia.gov/outlooks/archive/ieo16/pdf/0484(2016).pdf).

3. Energy Information Administration, “International Energy Outlook, 2017,” [https://www.eia.gov/outlooks/ieo/pdf/0484\(2017\).pdf](https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf).

To achieve sustainable mobility efficiency, both demand management and mitigation of environmental impacts must be considered. The automation of transportation, along with information and communication technologies (ICT), could contribute significantly to a sustainable transportation model in the future. Alternative fuels<sup>4</sup> in transportation, such as electricity or natural gas, are also essential for transportation sustainability because of their relatively low emissions.

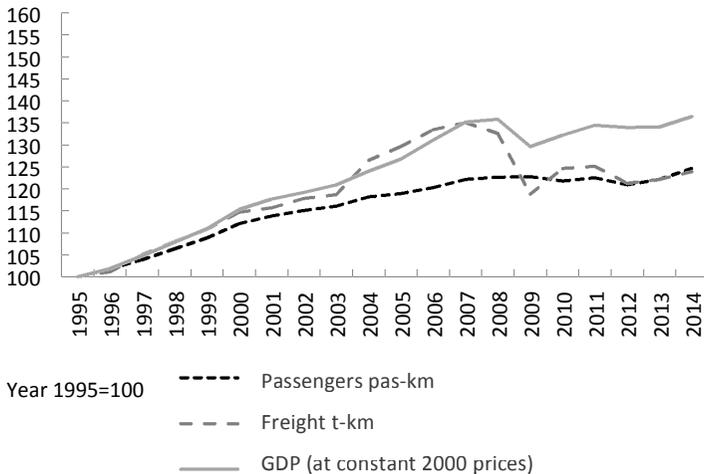
This chapter begins with a description of the current crossroads of energy and transportation in Europe, and an analysis of this economic and policy intersection over the last decade. Our attention then turns to the electric vehicle and its related issues, focusing the analysis on the leading European countries in electric mobility, and on France (due to its size and continental weight). A similar analysis of gas-fueled vehicles is then undertaken, centering on Italy, the most advanced European country in gas-fueled transportation. Electricity and natural gas are studied and considered as alternative energies for vehicle transportation both at the national level and within the European Union (EU) context. Finally, there is a presentation of the results and main findings of our recent study on passenger mobility in the Basque Country<sup>5</sup> of Spain.<sup>6</sup> The chapter ends with an analysis of the absolute and relative environmental and economic costs and benefits among these alternatives and other fuels available for use in passenger transportation in Europe (BEVs, PHEVs, conventional hybrids, CNG and LPG vehicles).

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4. By alternative fuel we mean energy sources used to power alternative fuel vehicles, including the following: liquefied petroleum gas (LPG), natural gas (NG), biomethane, hybrid and pure electric energy, hydrogen, E85, biodiesel, biofuel, as stated by the European Commission (see EEA, “New passenger vehicles using alternative fuels,” 2017, [https://ec.europa.eu/transport/facts-fundings/scoreboard/compare/energy-union-innovation/alternative-fuel\\_nl](https://ec.europa.eu/transport/facts-fundings/scoreboard/compare/energy-union-innovation/alternative-fuel_nl)).

5. A number of characteristics make the Basque Country an appropriate case to study: its energy, transportation and environmental policies, its entrepreneurial initiatives for the development of electric vehicle penetration and other alternative fuels, as well as its industrial base which is relevant for transportation. Furthermore the size (7,000 km<sup>2</sup>) of the Basque Country and its highways and roads infrastructure are of an appropriate size for the practical development and deployment of electric and gas-fueled vehicles. Last but not least, a very detailed database on vehicle displacements between areas and zones within the Basque country allow for useful calculations and analysis.

6. This study considers some of the most relevant countries in terms of penetration and promotion of electric and gas-fueled vehicles in order to extract lessons for achieving a more sustainable passenger transportation sector. Spain is not among these countries; however it is considered when we analyze the impact of the penetration of alternative fuel vehicles in economic and environmental terms.

**Figure 1. Evolution of Transportation in the EU-28, 1995–2014**

Notes for Figure 1: 100 = respective levels in 1995. Passengers pas-km means passenger-kilometers (a passenger-kilometer is tabulated when a passenger is carried one kilometer: calculation of pas-km equals the sum of the products obtained by multiplying the number of revenue passengers carried on each passenger travel/transport stage by the stage distance). Freight t-km is a measure of freight carried by a mode of transport, like roads, railways, airways or waterways. It is calculated as T-km equal TLC (total load carried measured in tons) multiplied by TDC (total distance covered measured in kilometers). Source: Álvarez, E. y Menéndez, J., *Energías alternativas para el transporte de pasajeros. El caso de la CAPV: análisis y recomendaciones*. Energy Chair of Orkestra—Basque Institute of Competitiveness, 2017, <http://www.orkestra.deusto.es/es/investigacion/publicaciones/cuadernos-orkestra/1150-energias-alternativas-transporte-pasajeros>.

## Energy and Transportation in Europe<sup>7</sup>

Both as an economic sector and as an infrastructural network ranged across the map, over time European transportation has expanded in parallel with the growth of the European economy (in standard GDP terms). Although freight transport is more sensitive to the evolution and growth of the economy, passenger transportation has also become increasingly tied to economic growth (see Figure 1), and both were pro-cyclical during the last economic crisis.

7. For a deeper discussion of EU transportation strategy and policy with respect to infrastructure as well as alternative fuels see the section “EU Transportation Strategy,” in Chapter Seven of this volume “The Greening of Maritime Transportation, Energy and Climate Infrastructures in the Atlantic Basin: The Role of Atlantic Port-Cities,” by Joao Fonseca Ribeiro.

The most integrated and developed transportation infrastructures are the road and highway networks (even though some European countries, like France, have quality and competitive railways for passenger transportation). As a result, road transport is key within the EU; in terms of passenger-kilometers (pas-km, the standard measure unit employed by the sector), the road segment accounted for 82.5 percent of total EU passenger transport in 2012. As a result, private cars are the key lever within the energy and transport sectors simply because public transportation of passengers (i.e., by bus, train, etc.) is not very significant at the European level.

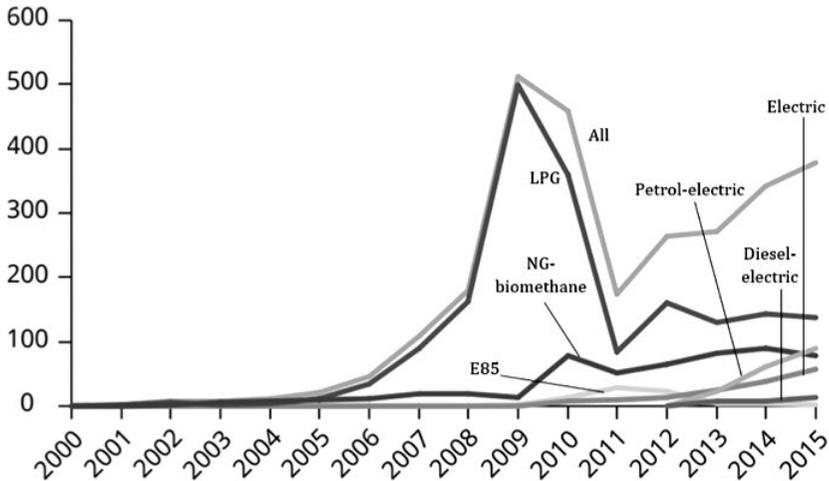
Transportation accounts for 96 percent of petroleum-derived fuel consumption in the EU. Because of this high level of oil dependency, the economic cost to import most of this crude oil, and the environmental and geopolitical risks associated with it, the EU has established objectives to reduce the weight of petroleum-derived fuels within the transportation energy mix. One way to reduce EU dependency on oil-based transportation fuels would be to reduce the activity of the sector. However, such fossil fuels should be phased out of transportation in a way that does not negatively affect other economic activities.

Indeed, there is a need to move towards sustainable mobility. There is no single definition of sustainable mobility, although many have been proposed. The most widely accepted meaning is that it meets the mobility needs of the present without compromising the ability of future generations to meet their own needs. Other definitions are based on specific conditions such as the satisfaction of demand at affordable prices, facilitated citizen access, or lower energy and material resources consumption.

Since the beginning of the century, but particularly since the COP 21, the EU has committed itself to reducing greenhouse gases (GHG), including CO<sub>2</sub> emissions, and to decreasing oil consumption. The development of new and more efficient vehicles, along with cleaner fuels, has characterized this European aspiration. Among the various technological developments currently restructuring the European vehicle fleet, alternative vehicle fuels should be considered a viable policy option.

The European Commission has developed legislation—some binding and some merely indicative—to address the energy and climate change challenges (including EC directives on air quality [2008], and the promotion of renewables [2009]). The European Commission's *Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles* must be transposed

**Figure 2. Trends in Total Registrations of AFVs, 2000-2015 (Thousand Vehicles)**



Source: European Environment Agency (EEA), "Monitoring CO2 emissions from new passenger cars and vans in 2015," <http://www.eea.europa.eu/publications/monitoring-emissions-cars-and-vans>.

to member state legislation. For example, in Spain this was done through the Sustainable Economy Act.

But given that the penetration of alternative energy into the transportation sector (see Figure 3) must be increased and intensified, the role of the EU Directive 2014/94/EU (on the *Deployment of Alternative Fuels Infrastructure*, or DAFI) has become the key baseline for the implementation of a National Framework for Action on Alternative Fuel in Transport in each European member state. In this sense all the countries had to prepare a National Framework for Action for the Promotion of Alternative Fuels by the end of 2016.

Despite the development of such rules and others at the European level, the evolution of alternative fuel vehicles has been limited and inconsistent (see Figure 2). In any case, the penetration of alternative fuels must also be supported by the development of new strategic infrastructure, which the EU promotes. Nevertheless, infrastructure costs remain a barrier to development.

## Electric vehicles

The penetration of electric vehicles (EV) is not yet significant across the world. However, the global EV fleet surpassed the two-million-unit barrier in 2016, only a year after it had reached the first one million mark in 2015.<sup>8</sup> At the current stage of technological development, high EV price and unmet charging infrastructure requirements remain the main causes behind this still relatively low penetration rate. In addition, the relative differences between electricity and conventional fuel prices must still be seriously considered. However, some European countries are making important efforts to accelerate the rate of EV penetration. Norway and the Netherlands are perhaps the most outstanding countries in this regard. However, for the purposes of this analysis, France is highlighted, due to the relative weight of its economy within Europe and because of some distinctive features of the country and certain challenges it faces in order to increase the penetration rate of EVs. Nevertheless, further references are also made to other relevant European countries such as Germany and Sweden, as well as to the Netherlands and Norway.

### *France*

Some distinctive features distinguish France from most of its European partners: (1) the size of its economy and population; (2) the notably low CO<sub>2</sub> emissions generated by its electricity sector (100 g/kWh) mainly due to the penetration of nuclear (76.5 percent) and renewables (17.4 percent) in the electricity generation mix;<sup>9</sup> (3) the strong French automotive industry; and (4) clear French policies supporting EV deployment.

Since 2009–2010 France has implemented significant regulations for promoting alternative fuels in transportation. Electric mobility has been given a noticeable boost by the National Action Framework and the Energy Transition Law. Furthermore, the various pieces of legislation that since 2009 have pursued cleaner air and lower GHG emissions are also important, as they have supported the development of electric vehicles and recharging infrastructure.

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8. International Energy Agency (IEA), *Global EV Outlook 2017. Two million and counting*, International Energy Agency, 2017 <https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf>.

9. Réseau de transport d'électricité, *Power Generation by Energy Source, 2016*. <http://www.rte-france.com/en/eco2mix/eco2mix-mix-energetique-en>. Only Norway and Sweden have electricity mixes with lower percentages of CO<sub>2</sub> emissions.

In October 2016 Ségolène Royal, the Minister for Ecology, Sustainable Development and Energy, announced that the EV car stock in France has surpassed 100,000 units. By June 2017, France represented one third of the EU's pure or battery electric (BEV) vehicle stock, while Germany accounted for one sixth. Indeed, in terms of pure electric (or BEV) vehicles, France leads the European Union.<sup>10</sup> However, if one were to compare national levels of pure electric *plus* plug-in hybrid electric vehicles (i.e., BEV+PHEV<sup>11</sup>), France would still account for one fifth of all the EVs in the EU (although, in this case, France would trail the Netherlands, and Germany would be right behind it.)<sup>12</sup> Although such levels of EV penetration might seem significant, it should be noted that registered EVs account for only 1.1 percent of the total French vehicle fleet in the Paris region.

However, the development of EV charging infrastructure in France has been unequalled in Europe and highly concentrated in some areas. As with all EU countries, there are clear differences between regions within France. While most analyses of EVs are country-focused, a regional philosophy should be considered, as there can be important differences inside a country.

Since 2014, the number of charging points has increased significantly — four-fold between 2014 and 2015 (compared to a three-fold increase in Norway and a doubling in Germany and Sweden). This same growth is paralleled in the EU as a whole: the greatest increase of charging points in Europe occurred during the 2014–2016 period. In 2016, there were more than 14,360 charging points in Europe (up from 1,800 in 2012), of which more than 468 were fast charging points.

The EU-financed Corri-Door project has facilitated the installation of 180 fast charging points (with 80 km between each charging point). The French Energy Transition Law for Green Development established the objective of one million charging points by 2030. In fact, France has since raised the target to seven million charging points by 2030.

This rapid rollout of EV infrastructure is at least partly due to the fact that France has a strong incentive system that provides up to 10,000 euros (€) for the purchase of an electric vehicle, among other benefits. Furthermore, the vehicle manufacturing industry wields significant influence over the promotion and rollout of electric vehicles. The leading model in France

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10. At the broader European level, Norway would stand out with the greatest stock of EV.

11. PHEV means plug-in hybrid electric vehicle.

12. EAFO, *European Alternative Fuels Observatory*, 2017, <http://www.eafo.eu/>.

in terms of sales—the Renault ZOE—is also the leader across the continent, including in the EU, EFTA and Turkey.<sup>13</sup>

### *Norway*

Despite the EV numbers of France, no EU country matches the electric vehicle stock of Norway. If we consider the EU and Norway together, Norway would make up 20 percent of all electric vehicles in this broader Europe while France would represent 15 percent. The main difference between Norway and France is that the former accounts for only 1 percent of the total population and 1 percent of the total passenger car fleet of Norway+EU, and France 14 percent and 13 percent, respectively.

Norway is therefore the leading European country in terms of the penetration share and size of its EV fleet (with 133,260 electric vehicles in 2016). This significant EV deployment is the result of a long trajectory that began in the 1990s and has continued to enjoy a consensus of political support among national parties since then. This trend is set to continue, given that from 2025 all new vehicles in Norway (such as private cars, city buses and light vans) must be zero-emission vehicles, while GHG emissions from transportation must be cut by 50 percent by 2030, according to Norwegian national legislation.

Norway is not, however, a member state of the EU. As a consequence, Norway does not have a National Framework for Action on Alternative Fuels in Transport. However, it does belong to the European Economic Area (EEA) through which Norway can participate in the EU market. The creation of this broader market space, together with the articulation of several EU northern policies, has forged a close link between EU and Norwegian policies. In Norway, therefore, the relevant equivalent to the member states' National Framework for Action on Alternative Fuel in Transport is the National Transport Plan (NTP), which has been organized in two distinct phases: the NTP 2014–2023 and the NTP 2018–2029.

The NTP adopts the concept of the zero-emission vehicle. As a result, the NTP does not support any particular concrete technology (such as electric vehicles), but rather aims to cut transportation emissions by allowing different kinds of vehicles to be developed. This is similar to the philosophy underpinning European policy, as expressed in the 2014/94/EU Directive (which allows for different kinds of alternative fuels, including liquified

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13. EAFO, *op. cit.*, 2017.

petroleum gases, or LPG), although the Norwegian objectives are more rigorously in line with the objective of a low carbon economy.

Among the main incentives for the implementation of the NTP, the Norwegian Government has exempted BEVs (including fuel cell vehicles, or FCVs) from the vehicle registration tax. There is also a reduced property tax for BEVs and FCVs, along with an exemption from the value-added (VAT). Direct exemptions amounted to nearly 40 percent in 2015, when EVs accounted for some 23 percent of total vehicle sales.

By 2030, a 30 percent sales rate for EVs is expected to be in effect in Norway, and a 250,000-strong EV fleet is projected for 2020.<sup>14</sup> In anticipation, the Government has launched a public funding plan to set up two multiple-mode charging points every 50 kilometers on major highways.

### *Germany*

Because of its automotive industry, Germany is especially relevant to any discussion of European mobility. Nevertheless, the country's penetration rate has not been high enough to place Germany's EV fleet among the leaders in Europe. In 2016, the country had a stock of only 72,730 EVs. The EV market share in 2017 was only 1.26 percent, and is not expected to exceed double digits by 2020, unlike France and the Netherlands.<sup>15</sup>

However, Germany needs to develop an EV market in order to retain its position as a leading automotive supplier (see Chapter One). The Alliance of German Car Manufacturers (BMW, Daimler AG, Volkswagen and Ford) has set targets for what would be Europe's largest network of Combined Charging System (CCS) fast charging points. By the end of 2017, 400 charging points are to be put in place across Europe (and several thousand by 2020).<sup>16</sup>

With a time horizon to 2020, Germany has instituted a program of support for electric vehicle development, with a total budget of €1.2 billion (of which the Federal Government contributes half).<sup>17</sup> The Federal Government

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14. Ibid.

15. IEA, *Global EV Outlook 2016: Beyond one million electric cars*, International Energy Agency, 2016 [https://www.iea.org/publications/freepublications/publication/Global\\_EV\\_Outlook\\_2016.pdf](https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf).

16. IRENA, *Electric vehicles: Technology Brief*, International Renewable Energy Agency, 2017 [http://www.irena.org/DocumentDownloads/Publications/IRENA\\_Electric\\_Vehicles\\_2017.pdf](http://www.irena.org/DocumentDownloads/Publications/IRENA_Electric_Vehicles_2017.pdf).

17. BMWi, *Fifth "Energy Transition" Monitoring Report: The Energy of the Future, 2015 Reporting Year*, German Federal Ministry for Economic Affairs and Energy, 2016 <https://www.bmwi.de/Redaktion/EN/Publikationen/monitoring-report-2016.html>.

has dedicated €300 million of this budget to improving the charging infrastructure. This program also includes direct incentives of €4,000 for the purchase of BEVs and €3,000 for PHEVs. In addition, for those vehicles registered before December 31, 2015, there is a property tax exemption for ten years, and for five years for those registered between that date and December 31, 2020.<sup>18</sup> Such taxes vary with engine power and CO<sub>2</sub> emissions.<sup>19</sup>

Other incentives for BEVs include free car parks (or reserved parking spaces) and legal access to bus lanes,<sup>20</sup> although some of these are applied differently, depending on the Länder (or regional government).<sup>21</sup> Another priority objective of the German Government is to reduce administrative obstacles to the installation of private charging points.

### *The Netherlands*

In the Netherlands, there were 112,010 EVs registered in the transportation fleet in 2016, along with 26,700 charging points (mainly standard ones, as opposed to fast charging outlets). These relatively high numbers are partly due to an important political pact in the Netherlands: the National Energy Agreement for Sustainable Growth, organized with the participation of 40 organizations, including public institutions and private market agents, with the aim of reducing CO<sub>2</sub> emissions in transport by 17 percent in 2030 and 60 percent in 2050. The agreement includes a specific chapter for mobility complemented by the Sustainable Fuels Vision, which states that by the year 2035 all new vehicles sold in the country must be emissions-free.<sup>22</sup>

Vehicles with zero emissions are exempt from registration tax. There is a progressive tax system that varies with the CO<sub>2</sub> emissions of the vehicle. There is no aid for the purchase or installation of infrastructure at national level but there is in certain regions.

Tax incentives have been the main driver for electromobility in the Netherlands since 2015. Between 2017 and 2020 further major changes in the

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18. EAFO, 2017.

19. Tietge, U., Mock, P., Lutsey, N. and Campestrini, A., *Comparison of leading electric vehicle policy and deployment in Europe*, White Paper, The International Council on Clean Transportation (ICCT), 2016 [http://www.theicct.org/sites/default/files/publications/ICCT\\_EVpolicies-Europe-201605.pdf](http://www.theicct.org/sites/default/files/publications/ICCT_EVpolicies-Europe-201605.pdf).

20. EAFO, op. cit., 2017.

21. IEA, op. cit., 2016.

22. EAFO, op. cit., 2017.

Dutch tax system are expected; such changes would mainly affect PHEVs, the tax benefits of which would be progressively reduced towards the level of conventional vehicles.

### *Sweden*

With 29,330 EVs and 2,738 charging points (nearly half of them fast), Sweden is aiming for a 70 percent reduction of CO<sub>2</sub> emissions in the transport sector by 2030.<sup>23</sup> To this end, in 2015, SEK 1.925 billion (approximately €202 million) was earmarked for local climate change investments between 2015 and 2018. These policies will be strengthened by the end of 2017 with the *Klimatklivet* program, which in total will contribute SEK 1.6 billion by 2020. The government also supports the installation of 40 percent of the charging points, with investment in 3,849 points to date.<sup>24</sup>

Sweden provides a premium aid (*Supermiljöbilspremie*) of SEK 20,000 (approximately €2,100) for PHEV purchases, provided CO<sub>2</sub> emissions do not exceed 50 g/km and SEK 40,000 (approximately €4,200) for the BEV.<sup>25</sup> The government expects to revise this program in 2018. However, some uncertainty hangs over this program, given that there have occurred some interruptions of the incentives which have had a considerable impact on the penetration ratio of Swedish EVs. Nevertheless, this incentives policy has driven Sweden into one of the best EV positions among European countries: in 2016 Sweden accounted for 3.41 percent of EV registrations, just behind Norway and the Netherlands.

There is also an exemption to the payment of the annual circulation tax for five years.<sup>26</sup> Since 2011, it has also been possible for municipalities or the Transport Administration to create parking spaces dedicated exclusively to electric vehicles.<sup>27</sup>

The current situation in these five emblematic European countries is summarized in Table 1.

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23. Tietge, op. cit., 2017.

24. Government of Sweden, *Sveriges handlingsprogram för infrastrukturen för alternativ drivmedel i enlighet med direktiv 2014/94/EU*, 2016 <http://www.regeringen.se/informationsmaterial/2016/11/sveriges-handlingsprogram-for-infrastrukturen-for-alternativa-drivmedel-i-enlighet-med-direktiv-201494eu/>.

25. EAFO, op. cit., 2017.

26. Ibid.

27. Government of Sweden, op. cit.

**Table 1. Energy and Transportation in Europe, Selected Data from Selected Countries**

	France	Germany	Netherlands	Norway	Sweden
Share of EV registrations over total registrations (%)	1.46	0.73	6.39	28.76	3.41
EVs stock	84,000	72,730	112,010	133,260	29,330
Total public available charging points	15,843	17,953	26,700	8,157	2,738
Targets for share of EV registrations over total registrations (%)	20	6	10	30*	-
EVs stock per charging points	5.3	4	4.2	16.7	11.1

Source: Álvarez et al., 2017, based on EAFO, 2017; Tietge et al., 2016; IEA, 2017 and 2016. Note: registration targets represent an average for the period 2016-2020. (-) data not available. (\*) objective for 2030.

## Penetration and Other Relevant Ratios

The wide variety of policies and results in each country reveals great differences, but no clearly obvious relationship among the various factors that can lead (or not) to higher EV penetration. To identify the circumstances that most stimulate the development of electric mobility, the economic, social, environmental and technical characteristics of each country should be analyzed and compared.

One leading economic driver is the provision of incentives. Given their relevance for the development of electric vehicles, Table 2 presents the level of incentives provided as a percentage of the vehicle final price, along with the country's relative position in terms of incentives and EV penetration. The position of Norway stands out, as the relative incentives of the other countries have not achieved an apparently proportional level of penetration.

The level of GDP per capita (adjusted for purchase power parity) is another determinant of growth in EV registrations. Yet other factors to consider are vehicle price (which varies between countries) and the price differential between conventional fuels and electricity. Finally, the dominant type of local dwellings is also important: people living in detached or semi-detached housing are likely to be more inclined to buy an EV because it is easier for them to have their own charging point at home. We have also ana-

**Table 2. Estimated Effect of Direct Incentives in 2016**

		France	Germany	Netherlands	Norway	Sweden
Share of EV registrations over total registrations	%	1.46	0.73	6.39	28.76	3.41
	Position	4	5	2	1	3
Percentage of the direct incentive on the final price of vehicle	%	25.6	10	16.8	39.5	10.6
	Position	2	5	3	1	4

Source: Álvarez et al., 2017, based on EAF0, 2017; Tietge et al., 2016; IEA, 2017 and 2016.

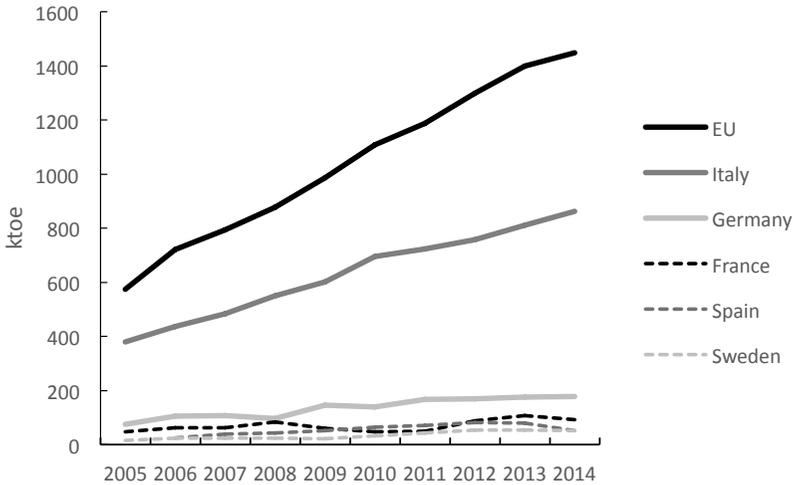
lyzed other factors affecting the penetration rate of EVs (e.g., the relationship between area and population density with the density of charging infrastructure); however, they do not show clear results.<sup>28</sup>

One relationship that does stand out is that between EV registrations and the level of electricity-generated CO<sub>2</sub> emissions in each country. Often, countries with higher emissions present lower EV registrations. However, this does not appear to be a clear causal relationship. Consider that from the consumer point of view—which has a tendency to take into account only the tank to wheels (TTW) chain of emissions—an EV emits zero emissions; but for technicians and governments, the policy point of view should incorporate the system to wheels (STW) chain of emissions (at least for GHGs)—a more inclusive accounting cycle of emissions that also captures the carbon footprint of the power sector that supplies electricity to EVs.<sup>29</sup> This means that consumers generally do not consider the nature of the electricity mix in their decisions. But although the generation mix is not a determining driver of EV penetration, it does directly affect the level of emissions reduction at each level of EV penetration. Decarbonization of the power mix remains the central fulcrum which allows EV penetration to further reduce emissions.

28. For more, see Álvarez et al., 2017.

29. For more, see section on environmental aspects later in this chapter.

**Figure 3. Consumption of Natural Gas in Transportation in Selected EU countries, 2005–2014**



Source: Álvarez et al., 2017, based on Eurostat, 2017. Note: the Netherlands is not represented in this figure. Although it is considered an important case for natural gas vehicles, the Dutch consumption volume is too negligible, compared with the others shown here, to be captured by the graph.

## Gas-Fueled Vehicles

Natural gas is another alternative transportation fuel that could contribute to a reduction of the transport sector’s GHG emissions. In this chapter, we refer mainly to the use of compressed natural gas (CNG) by private cars engaged in passenger transportation. Heavy transport vehicles should also be mentioned, given that in case of road or maritime freight transport, there is a trend toward the use of liquefied natural gas (LNG), although freight transport is not dealt with directly in this analysis.<sup>30</sup>

The number of vehicles worldwide running on natural gas has grown at an average annual rate of 20 percent over the last 10 years. Despite this global growth, EU sales have registered a slowdown in recent years: in 2016 sales of gas-fueled passenger cars were only 40 percent of their 2008 levels.<sup>31</sup>

30. For a discussion of LNG as a fuel for road freight and maritime cargo, see Chapter Seven of this volume “The Greening of Maritime Transportation, Energy and Climate Infrastructures in the Atlantic Basin: The Role of Atlantic Port-Cities,” by Joao Fonseca Ribeiro.

31. (EAFO, 2017).

**Table 3. CNG Refueling Infrastructure, Leading EU Countries, 2016**

Country	Public CNG Refueling Stations	Passengers Vehicles per CNG Refueling Station
Italy	1,104	808
Germany	883	104
Sweden	169	307
Netherlands	162	61
France	43	178
Spain	45	42

Source: EAFO, 2017 and NGVA 2017.<sup>32</sup>

Today Italy stands out as the largest European consumer of natural gas used in transport. Gas is also used as a transportation fuel in the Netherlands, Germany and Sweden.

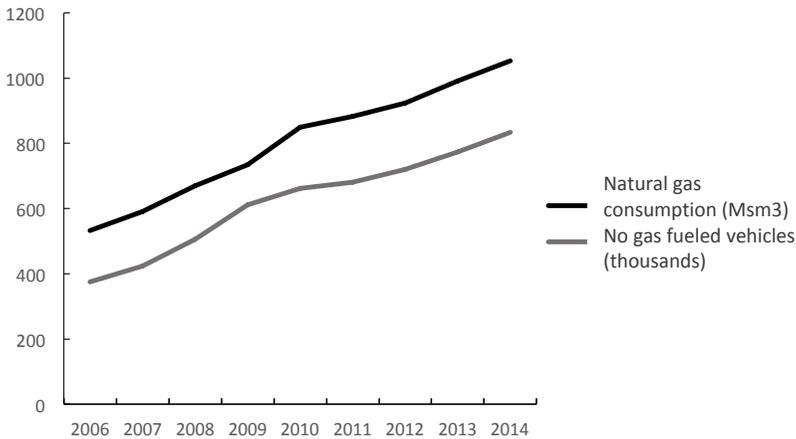
With respect to gas vehicle infrastructure, 70 percent of the gas refueling stations in the EU are found in just two countries: Italy and Germany (see Table 3). The number of vehicles per refueling station varies from 808 to 79 vehicles/station in Italy and the Netherlands, respectively.

An important factor affecting the use of such vehicles is the price of natural gas, which remains volatile, given that it is still relatively tightly linked to oil prices (themselves volatile). Still, the final price of natural gas—the sum of the international price plus the supply and distribution costs, and taxes—has fallen. Not only did the natural gas price differential widen with respect to diesel across Europe during 2016; gas prices are also currently below those for low-sulfur fuel oil.

### *Italy*

Italy has developed the use of natural gas in transportation more than any other country in the EU (see Figure 4), and now has the most natural gas vehicles (967,090 in June 2017) and refueling stations (1,104 in 2016). The use of gas for transport began more than 30 years ago, and has sustained a

32. NGVA, Statistical Report 2017. [https://www.ngva.eu/downloads/NGVA\\_Europe\\_Statistical\\_Report-2017.pdf](https://www.ngva.eu/downloads/NGVA_Europe_Statistical_Report-2017.pdf).

**Figure 4. Evolution of natural gas consumption and gas-fueled vehicles in Italy**

Source: Álvarez et al., 2017 based on Eurostat, 2017<sup>33</sup> and ANFIA, 2015.<sup>34</sup>

growth rate of 9 percent per year. This increased demand has stimulated the development not just of an industry for the conversion of vehicles and the production of related equipment, but also of new standards and legislation. Nevertheless, natural gas still accounts only for 3 percent of total energy consumption in Italian road transport.

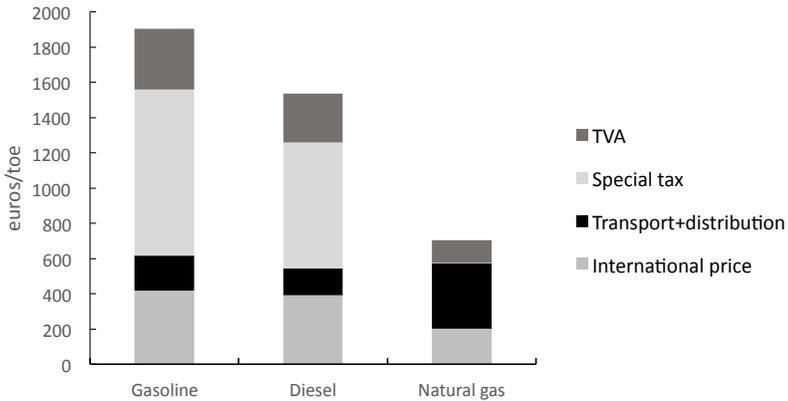
The natural gas used in transport is consumed mainly in the form of compressed natural gas (CNG) in low-consumption vehicles: small and medium-sized low-capacity vehicles with high levels of utilization (more than 20,000km/year). As a result, their acquisition—without incentives or subsidies—would be amortized over five to seven years (which is the average fleet renewal period).

The market was initially developed through: (1) a strategy to promote the consumption of own energy sources; and (2) the promotion of the vehicle conversion industry. Vehicle conversions were encouraged through a subsidy of € 600 € to € 2,400 per vehicle. A significant number of stakeholders, however, also have an interest in this market (R&D centers, international

33. Eurostat, 2017.

34. ANFIA, Associazione Nazionale Filiera Industria Automobilistica, 2015. [www.anfia.it](http://www.anfia.it).

**Figure 5. Gasoline, Diesel and Natural Gas Prices, Italy, November 2016**



Source: Álvarez et al., 2017.

organizations such as UNECE [United Nations Economic Commission for Europe], etc.).

Italy is also the European leader in the development of regulation for gas-fueled vehicles. In Italy, natural gas enjoys an exemption/reduction of the minimum excise duty of 2.6 €/GJ (set by Directive 2003/96/EC). The Blue Corridors project,<sup>35</sup> with its build-up of LNG and CNG refueling stations, will also facilitate the development of the gas infrastructures in Europe, and not only for freight transport.<sup>36</sup>

35. European Commission, Good Practice Examples Appendix D - LNG Blue Corridors Project Fact Sheet, 2016. <https://ec.europa.eu/transport/sites/transport/files/themes/urban/studies/doc/2016-01-alternative-fuels-implementation-good-practices-appendix-d.pdf>

36. LNG Blue Corridors is a European project financed by the Seventh Framework Programme (FP7). The project is co-funded by the European Commission to the amount of €7.96 million (of €14.33 million in total investments), involving 27 partners from 11 countries, all members of Natural Gas Vehicle Association (NGVA) Europe. The aim is to establish LNG as a real alternative for medium- and long-distance transport—first as a complementary fuel and later as an adequate substitute for diesel. The project has defined a roadmap of LNG refuelling points along four corridors covering: (1) the Atlantic area; (2) the Mediterranean region and (3) connecting Europe's South with the North and its (4) West and East. To help catalyze a sustainable transport network for Europe, the project's goal is: (a) to construct approximately 14 new LNG or L-CNG refueling stations (both permanent and mobile) at critical locations along the Blue Corridors; and (b) to rollout a fleet of some 100 heavy duty vehicles (HDV) powered by LNG.

Somewhat in contrast to the case of EVs, the price of natural gas is key to the penetration of gas-fueled vehicles. This gas price driver is further reinforced by the relatively small difference between the price of conventional vehicles (running on gasoline and diesel) and that of gas-fueled vehicles. In this respect, the prices of gas for transport have an advantage over conventional fuels (gasoline and diesel), given that they are exempted from taxes (see Figure 5).

### *The Netherlands*

The Netherlands is the largest natural gas *producer* in the EU. However the use of natural gas as a transportation fuel in the country is a relatively recent development and began only in 2005 with the construction of the first CNG refueling facilities.

The country sees the use of natural gas as fuel in light vehicles as a transitional solution to promote the use of biogas. Therefore, there is no forecasted expansion of the natural gas distribution network and the current network of 145 supply stations (in 2016) seems to be sufficient given current Dutch plans.

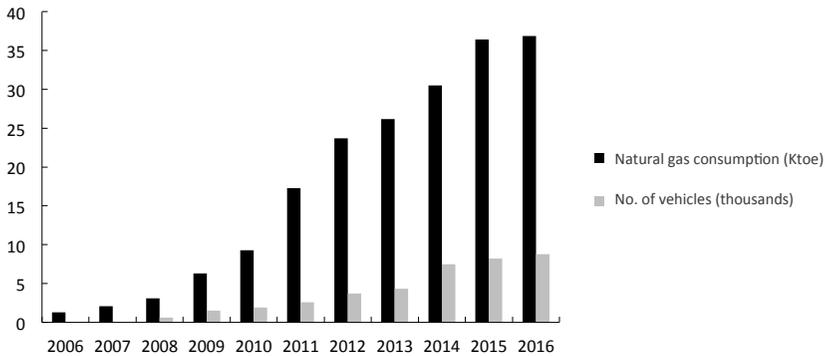
Following a government stimulus program for natural gas-fueled company cars in 2011, natural gas consumption in transportation grew at an average annual rate of 30 percent while the number of gas-powered vehicles increased from 4,000 to 11,000. However, this amount of gas-powered vehicles represents only 0.15 percent of the total fleet, and the total consumption of natural gas in transport does not yet exceed 0.2 percent of total energy consumption.

Natural gas vehicles in the Netherlands enjoy the benefit of reduced taxes, but such benefits are limited. The natural gas energy tax, although considerably lower than that for conventional fuels, remains above the minimum stipulated by the EU. Furthermore, the Netherlands does not take advantage of the kind of tax reductions or exemptions that natural gas fuels enjoy in other countries such as Italy or Spain. In the Netherlands, taxation on vehicle ownership (registration, circulation, and income from the private use of company vehicles) is based on the vehicle's CO<sub>2</sub> emissions per kilometer.

### *Germany*

Germany has 100,000 gas-fueled vehicles and 913 refueling stations. As a part of the national strategy to reduce dependence on oil in the transport

**Figure 6. Gas Consumption in Transportation and Gas-fueled Vehicles, the Netherlands, 2006–2016**



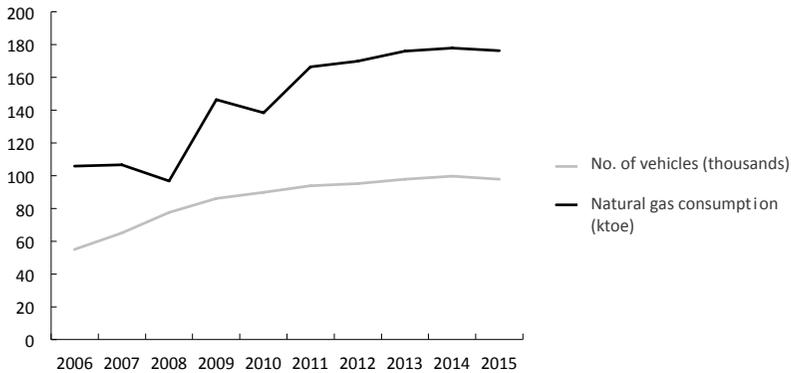
Source: Álvarez et. al. 2017. Note: Ktoe = thousand tons of oil equivalent.

sector, in 2010 Germany launched the *Initiativ Erdgasmobilität* (Initiative for Mobility Based on Natural Gas).

The German government *does not* envisage providing any incentives for the purchase of gas vehicles at present. However, under the Action Program for Climate Protection 2020 (*Aktionsprogramms Klimaschutz 2020*) of 2014, the government took additional measures aimed at expanding the use of LNG as a transportation fuel for both maritime (and inland) shipping and for heavy road transport. The program also proposes a reduction of the energy tax on natural gas as of 2018.

The German government is working with the LNG Platform in road transport, with the collaboration of the automotive industry and other stakeholders, to develop measures to achieve the established target of a 4 percent contribution from natural gas to the energy mix of road transport in 2020. The specific measures under consideration include: a) promoting the installation of LNG service and refueling stations based on the production of biogas and synthetic natural gas; b) encouraging the conversion of CNG service and refueling stations for use by local passenger and commercial vehicles; c) establishing prices for tolls in the natural gas network; d) improving semi-public service and refueling stations for fleet operators; and e) special rights for commercial vehicles operating with CNG/LNG. Biomethane is also important in the Germany strategy to boost natural gas in transport.

**Figure 7. Gas Consumption in Transportation and Gas-fueled Vehicles, Germany, 2006–2015**



Source: Álvarez et. al. 2017. Note: ktoe = thousand tons of oil equivalent.

### *Sweden*

Gas represents 1.8 percent of total energy consumed in road transportation in Sweden, where there are currently some 52,000 gas-powered vehicles, 2,300 buses (15 percent of the entire fleet and 40 percent of total gas consumption in transport) and 205 public service and refueling stations.<sup>37</sup>

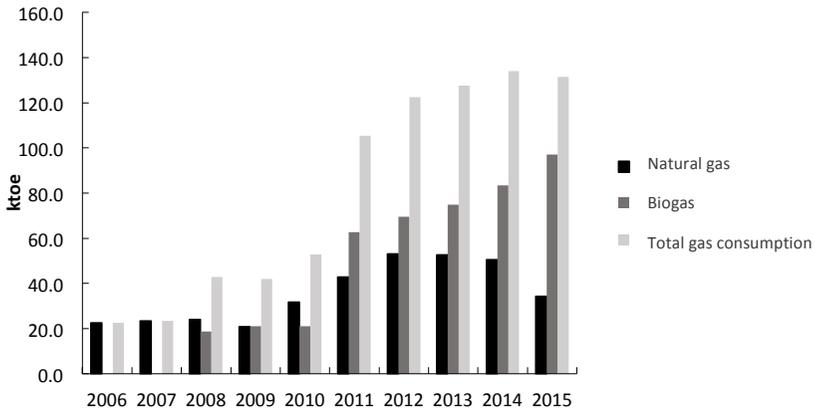
The Swedish parliament has accepted the government’s ambitious goal to achieve a vehicle fleet that does not depend on fossil fuels by 2030.<sup>38</sup> This objective is a first step towards the broader objective of achieving zero net CO<sub>2</sub> emissions by 2050. To generate even less CO<sub>2</sub> emissions from gas-fueled vehicles, Sweden is also promoting the use of biogas mixed with natural gas.

In March 2017, the government proposed a new climate action framework, and a new law was expected to be approved in June. The new targets establish zero net GHG emissions in 2045 and a 70 percent reduction in emissions in 2030 (compared with 2010). Therefore, the government must develop political measures to achieve these objectives. Among these measures, the most important are taxes on energy and CO<sub>2</sub>, and a VAT of 25 percent added to each conventional fuel, such that taxes will represent a greater weight in the final price.

37. NGVA Europe, 2016. <https://www.ngva.eu/>.

38. Government of Sweden, *Proposition 2008/09.162*, 2009.

**Figure 8. Gas Consumption in Transportation and Gas-fueled Vehicles, Sweden, 2006–2015**



Source: Álvarez et. al. 2017. Note: ktOE = thousand tons of oil equivalent.

Further relevant data from the European countries examined above are summarized in Table 4.

**Table 4. Natural Gas Use in Transportation in Europe, Summary Data from Selected European Countries**

Netherlands	Germany	Sweden
Focus on a long-term goal for electricity rather than on natural gas in light duty transport.	Germany is the second leading country in the EU in natural gas refueling infrastructures	Clear goals for transport emissions reduction.
Clear orientation to biogas.	Number of vehicles per refueling station is below other European countries with less infrastructure.	Encourages the use of biogas, which has significantly increased its weight (75%) within the fuels of natural gas vehicles (NGVs).
11,000 CNG vehicles	100,000 CNG vehicles	52,000 CNG vehicles
35,000 toe natural gas consumed in transport	180,000 toe natural gas (of which 36,000 toe is biogas)	30,000 toe natural gas (of which 90,000 toe is biogas)

Source: own elaboration. Note: toe = tons of oil equivalent.

## Alternative Fuels for Passenger Transportation: Environmental Benefits and Costs

To assess the costs and benefits of deeper penetration of alternative fuels in European transportation, our recent study, *Energías alternativas para el transporte de pasajeros. El caso de la CAPV: análisis y recomendaciones* (Alternative Energies for Passenger Transportation), analyzed a range of available alternative vehicle and energy/fuel types, incorporating assumptions and data on the technologies and fuels currently used in the vehicle fleet, vehicle and energy prices, and necessary supply infrastructures and investment.<sup>39</sup> The sections that follow present and analyse the main economic and environmental characteristics of each type of alternative fuel vehicles (AFVs), along with the main findings of the study.

### *Economic Aspects*

One important issue for the penetration of alternative transportation fuels is the cost of electric vehicle (EV) charging infrastructures and compressed natural gas (CNG) refueling points. For biofuels, because there is already a supply infrastructure in place, there is no need for additional investment in infrastructures. In the case of liquefied petroleum gases (LPG), some new infrastructure investments would need to be considered.

For conventional vehicles, current prices are around €14,000–16,000 per vehicle. EVs are priced at €34,000 in our study and CNG vehicles at €25,000.<sup>40</sup> These figures are based on current market prices. A price of €26,000 has been assumed for conventional hybrids.

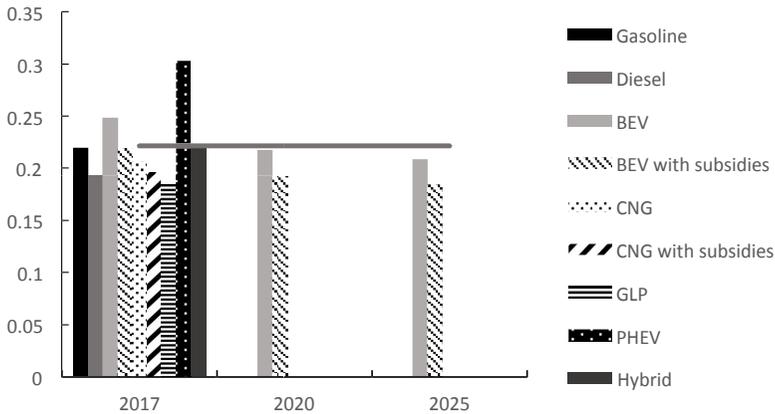
The cost of electrical charging points on public roads has been assumed to be in the range of €7,500 to €10,000 for conventional charging and €35,000 to €50,000 for fast charging. For home charging points, with power levels of 3.7–22 kW, a cost of between €2,200 and €2,400 per point is considered. In the case of CNG refueling stations, costs vary depending on the

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39. Eloy Álvarez y Jaime Menéndez, *Energías alternativas para el transporte de pasajeros. El caso de la CAPV: análisis y recomendaciones*. Energy Chair of Orkestra—Basque Institute of Competitiveness, 2017, <http://www.orkestra.deusto.es/es/investigacion/publicaciones/cuadernos-orkestra/1150-energias-alternativas-transporte-pasajeros>.

40. According to industry sources, a vehicle with a maximum authorized weight (MAW) of 3,500 kg, might have a purchase cost of €28,000 + VAT, whereas under a 5-year renting arrangement, the cost would be €1,254.87, not including VAT. For a vehicle with an MAW of 5,000 kg, the price would be around €29,000 plus VAT.

**Figure 9. Comparative Evolution of Estimated TCO (€/km), Conventional and Alternative Fuel Vehicles**



Source: Álvarez and Menéndez, 2017.

capacity and filling type (slow or fast): from a minimum of US\$5,000 to a maximum of US\$700,000.

From an economic point of view, it is also important to consider vehicle and fuel prices. The price of the vehicle and the cost of the fuel over its lifetime, together with other costs of use (maintenance and others) make up the total cost of ownership for the owner (TCO). Based on the assumptions we have made, our estimates suggest that TCO of AFVs will equalize with that of conventional vehicles by 2025 (see Figure 9).

The TCO may have an impact on the preferences of citizens for one or another technology. It should be kept in mind that, in the end, the decision of which type of car to buy will be taken by the consumer. Along with conventional vehicles, both natural gas or LPG vehicles are sufficiently proven technologies with high production volumes. However, EV technology (and batteries in particular) remain on the learning curve. Therefore, future reductions in their price may affect the TCO.

According to forecasts in 2014 by McKinsey & Company, the price of batteries is projected to fall from 383 US\$/kWh in 2015 to US\$197/kWh in 2020 and US\$163/kWh in 2025—a cost reduction of more than 50 percent over the coming decade.<sup>41</sup> Because battery costs currently represent around

41. McKinsey & Company, *Evolution. Electric vehicles in Europe: gearing up for a new phase?* 2014. [http://www.mckinsey.com/~/media/McKinsey%20Offices/Netherlands/Latest%20thinking/PDFs/Electric-Vehicle-Report-EN\\_AS%20FINAL.ashx](http://www.mckinsey.com/~/media/McKinsey%20Offices/Netherlands/Latest%20thinking/PDFs/Electric-Vehicle-Report-EN_AS%20FINAL.ashx).

**Table 5. Future Batteries Prices, Forecasts from Various Sources (US\$/kWh unless indicated)**

Source	2020	2022	2025	2030
Nykvist and Nilson	200-450	-	150-250	150-250
Lux Research			175	
Stockholm Environment Institute			150	
DOE	125	-	-	-
OEM	-	100	-	-
McKinsey	200	-	163	-
Element Energy	-	-	-	215
Fraunhofer (€/kWh)	100-300	-	-	-
General Motors	-	100	-	-
SET-Plan (€/kWh)	200			
Highest and lowest	High: 100 Low: 450	High: 100 Low: 200	High: 150 Low: 250	High: 150 Low: 250

Source: Álvarez and Menéndez, 2017. Note 1: Figures of this table are represented in the currency in which study was conducted. Most of them in US\$, unless the Fraunhofer study and the SET-Plan, where the currency employed is €. Note 2: Where more than one type of battery prices were offered, the lithium-ion battery was chosen.

35 percent of the price of EVs, these and other cost reductions could easily bring the TCO of EVs to approximately that of gasoline and natural gas vehicles (as seen in Figure 9).

In line with this cost reduction trend, the European Commission, through the European Strategic Energy Technology Plan (SET-Plan) has set the target for the costs of lithium-ion batteries of €200/kWh between 2020 and 2030.<sup>42</sup> Some uncertainty remains around the future price of batteries given that projections vary widely among the various institutions producing them. A comparison of several battery cost projections is presented in Table 5.

42. European Commission, *Materials Roadmap Enabling Low Carbon Energy Technologies*. Commission staff working paper, SEC(2011) 1609 final, 2011. [https://setis.ec.europa.eu/activities/materials-roadmap/Materials\\_Roadmap\\_EN.pdf/view](https://setis.ec.europa.eu/activities/materials-roadmap/Materials_Roadmap_EN.pdf/view).

### *Environmental Aspects*

In a comparative environmental analysis of alternative fuels and vehicle technologies, the first distinction that must be made is between air pollutants and greenhouse gas emissions (GHGs). This is because each distinct yet related set of emissions operates on a different scale of impact and potential damage. Air pollutant emissions have a greater direct impact when people are exposed to them at the local level, and their main risk is related to health when they are inhaled. On the other hand, the GHG emissions present the global risk of climate change. But although GHGs do not represent a direct or immediate problem for citizens, at the global scale, however, their generalized effects build up in the pipeline and eventually have concrete, if indirect, impacts everywhere.

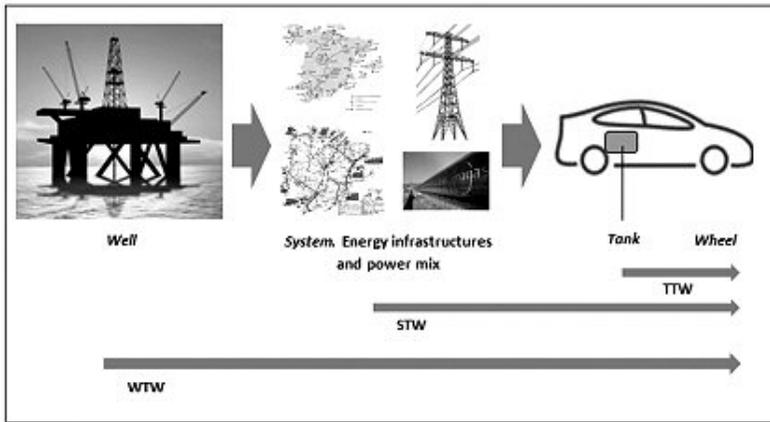
Following from this, the place where air pollutant emissions take place does matter. This happens where vehicles are driven, which generally means greater and more direct exposure to air pollutants among urban populations. On the other hand, the place where GHG emissions take place does not specifically matter: their direct destination is the general atmosphere (and the oceans) that all of us share.

This is why each category of transportation emissions (air pollutants and GHGs) should be analyzed within the frame of different scales (or emissions cycles), depending on their origin and the geographical reach of their potential damage. A smaller scale (or shorter cycle)—used in the case of air pollutants—is known as *from tank to wheels* (TTW) and represents only those emissions that are generated on vehicle roads.<sup>43</sup> A more global scale—used in the case of GHGs—covers the entire chain of emissions. Known as *from well to wheels* (WTW), this scale includes not only the emissions directly from the vehicle, but also from the production, treatment and transportation of the fuel before it reaches the vehicle.

The analysis in this chapter (and based upon our previous study) therefore considers both TTW and WTW emissions scales, because both are critical to an understanding of the broader environmental implications of each fuel. Furthermore, the emissions that each country produces within its own national energy system are typically generated in a cycle somewhere between the WTW and TTW scales. This is especially relevant for the analysis of the electric vehicle, given that its environmental impact (i.e., emissions reductions)

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43. Not only the emissions produced from the combustion of fuel inside the engine should be considered, but also those produced by the erosion of the wheels and the road when the vehicle is moving (which throws particulate pollution into the atmosphere).

**Figure 10. Comparison of TTW, STW and WTW**

Source: Álvarez and Menéndez, 2017.

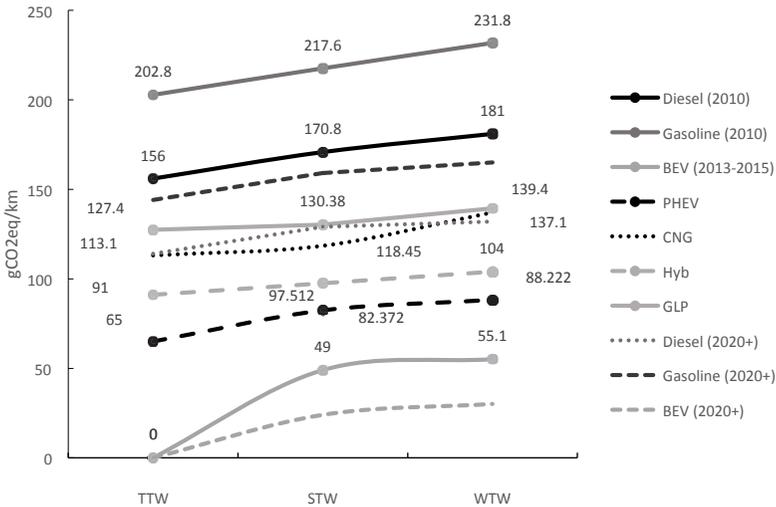
is directly related to the structure of the national power mix and the level of emissions resulting from electricity generation. Therefore, this scale—called from *system to wheels* (STW)—has been also calculated and estimated. An illustration of these three different scales appears in Figure 10.

Both CO<sub>2</sub> and air pollutant emissions in the TTW, STW and WTW calculations vary by type of energy, and it is important to remain aware of the differences between them (as illustrated in Figure 11). Both the STW and WTW measures for BEV (and also partly for PHEV, when it is charged) depend on the emissions of the particular national electricity generation mix. Such estimates of emissions levels, then, are more than likely to change in the coming years, given the overall trend toward decarbonization of the power sector. Therefore, to make a homogenous comparison between technologies with 2020+<sup>44</sup> projection values and BEVs, we have estimated and projected lower GHG emissions in future, primarily given the expected increasing penetration of renewable energies (RE). This future RE penetration trend will partly affect the scale of emissions projections for PHEV (in periods of charging), but the main difference is a marked positive effect on the emissions projections for BEV.

Figure 12 presents TTW and STW emissions estimates for air pollutants (NO<sub>x</sub> and PM). The WTW scale of the emissions chain is not shown because

44. 2020+ refers to any vehicle model that is produced from that year.

**Figure 11. CO<sub>2</sub>e Emissions (TTW, STW and WTW) for Each Vehicle Type**



Source: Álvarez and Menéndez, 2017. Note: For the sake of clarity, diesel, gasoline and AFV 2020+ emissions are stated again here: Diesel (gCO<sub>2</sub>e/km): TTW 114, STW 129, WTW 132. Gasoline (gCO<sub>2</sub>e/km): TTW 144, STW 159, WTW 165. BEV (gCO<sub>2</sub>e/km): STW 24, WTW 30.

it is much less relevant for local emissions. Our 2020+ projections for air pollutant emissions foresee reductions for BEV, but PHEV would also generate net pollutant emissions reductions (to the extent that they rely on charging).

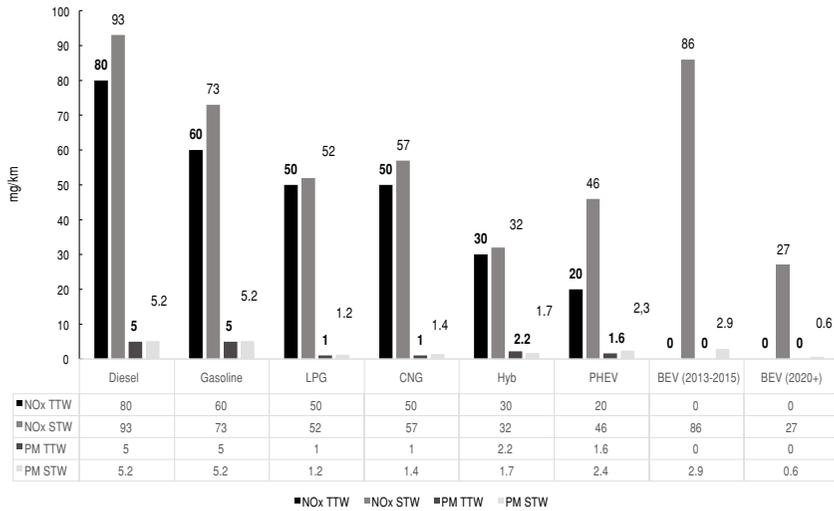
Incorporating the above data, Table 6 presents the main assumptions underlying the different emissions estimates (GHG, NO<sub>x</sub> and particulate matter) for TTW, STW and WTW and for each vehicle type. This lays the foundation for an analysis of possible future scenarios for alternative fuels penetration into the passenger transportation sector.

## Scenarios for Alternative Energies in European Transportation: Approaches and Main Findings

Because of their relatively low emissions, alternative fuels,<sup>45</sup> such as electricity or natural gas, are critical for future transportation sustainability.

45. In this section, four alternative technologies are analyzed: BEVs, PHEVs, CNG and LPG. Additionally, conventional hybrid cars are included (Hyb), as well as conventional cars (CONV).

**Figure 12. Pollutant Emissions, TTW and STW, by Vehicle Type**



Source: Álvarez and Menéndez, 2017. Note 1: The particulate emissions which derive from electricity consumption are known as PM10. Note 2: Substantial reductions of NO<sub>x</sub> are foreseen in the electric system for the years to come.

The penetration of these energies into the transportation fuel mix will have both environmental and economic implications. To analyze and compare these impacts, we have framed our estimates and projections around two different approaches for the penetration pace of alternative energy fuels in the mix and alternative energy vehicles in the fleet: (1) the immediate, overnight replacement of the existing conventional car fleet by one other single type of fuel/technology; and (2) a gradual, progressive replacement of the current fleet (conventional) with a combination of alternative energy vehicles (see Figure 13).

The first approach assumes complete (100 percent) replacement (overnight) of the current conventional car fleet by one single type/technology of alternative fuels/vehicles, while the second approach assumes ultimate incorporation of different combinations of technologies in the mix. The second approach assumes progressive penetrations with different rates of replacement of conventional vehicles by alternative electric vehicles.

Because of the availability close at hand of a high-quality and relatively complete data set on passenger mobility, we have conducted this exercise

**Table 6. Summary of the Main Assumptions of the Study's Emissions Estimates and Projections**

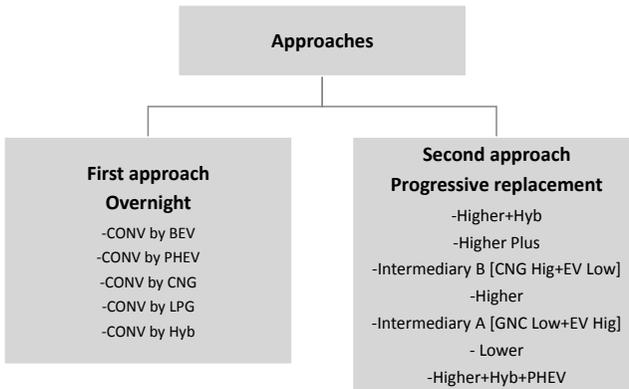
Type of vehicle	TTW emissions			STW emissions			WTW emissions
	GHG (gCO <sub>2</sub> e/ km)	NO <sub>x</sub> (mg/km)	PM (mg/km)	GHG (gCO <sub>2</sub> e/ km)	NO <sub>x</sub> (mg/km)	PM (mg/km)	GHG (gCO <sub>2</sub> e/ km)
Petrol (2010)	203	60	5	218	73	5.2	232
Diesel (2010)	156	80	5	171	93	5.2	181
BEV (battery electric vehicle) (2013–2015)	0	0	0	48.5	86	2.9	55
PHEV (plug-in hybrid) (2020+)	65	20	1.6	86	46	2.4	88
CNG (compressed natural gas) (2020+)	113	50	1	118	57	1.4	137
LPG (liquefied petroleum gas) (2020+)	127	50	1	130	52	1.2	139
Hyb (hybrid) (2020+)	91	30	2.2	98	32	2.3	104

Relevant at local/zone scale: TTW emissions (NO<sub>x</sub>, PM). Relevant at the scale of the mainland energy system: STW emissions (NO<sub>x</sub>, PM)

Source: Álvarez and Menéndez, 2017. Note: Substantial reductions of NO<sub>x</sub> are foreseen in the electric system for the years to come.

for the Basque Country, a European region (both industrial and rural) located in the north of Spain, and bordering on Pyrenees and France. This region has developed a transportation survey which tabulates the daily number of trips made by passenger cars among and between different areas and zones.<sup>46</sup> Based on such survey data, Álvarez and Menéndez (2017) generated a range of simulated projections for the Basque Country, with a study set covering 72 percent of the total automobile journeys in the region.

46. Government of Basque Country, *Estudio de la Movilidad de la Comunidad Autónoma Vasca 2011*, 2012. [http://www.CAPV.eus/contenidos/documentacion/em2011/es\\_def/adjuntos/Movilidad%20Encuesta%202011.pdf](http://www.CAPV.eus/contenidos/documentacion/em2011/es_def/adjuntos/Movilidad%20Encuesta%202011.pdf)

**Figure 13. Approaches and Scenarios**

Source: own elaboration.

In the first approach, called Overnight<sup>47</sup>—the assumed immediate and complete replacement of the existing conventional car fleet by a single alternative vehicle type—the complete substitution of the current fleet, for instance, with electric vehicles—results in an extra accumulated net cost of around €4.8 billion (over and above the those for the existing conventional fleet). CO<sub>2</sub> emissions would decline by between 1.5 and 1.8 MtCO<sub>2</sub>e/year (WTW and TTW, respectively) in perpetuity. NO<sub>x</sub> and particulates fall by 741 tons/year and 76 tons/year (TTW), respectively.

Given the diverging economic and environmental impacts of such a fleet replacement (i.e., higher economic costs and lower emissions), no single fuel/technology can claim the best results according to all of the criteria. Only by focusing on a single impact does one or another alternative fuel/technology emerge as clearly the most suitable. Table 7 lays out the different criteria for assessment: (1) fuel savings; (2) CO<sub>2</sub> specific cost (the ratio of the cost of vehicle and infrastructure to the amount of CO<sub>2</sub> reductions); (3) reduction of environmental cost (in which a price for NO<sub>x</sub> and PM are considered); and (4) specific contribution to the CO<sub>2</sub> reduction targets of the Basque Country. Broadly speaking, electric and hybrid vehicles present good relative positions/results for most of the criteria.

47. This substitution exercise, however, is a hypothetical, not a real, analysis. It provides ordered figures for comparing the results of the alternatives. It also forms a basis for the progressive replacements analysed later.

**Table 7. Order of Alternatives, Overnight replacement approach results against different criteria**

	Fuel saving	Specific cost CO <sub>2</sub>	Reduction in environmental costs	Contribution to meeting GHG reduction targets
CONV by BEV	1	4	3	1
CONV by PHEV	3	5	1	2
CONV by CNG	2	3	4	4
CONV by LPG	4	1	5	5
CONV by Hyb	5	2	1	3

Source: Álvarez and Menéndez, 2017. Note: Basic sensitivity analyses carried out demonstrates no significant changes with the reference scenarios, therefore results can be judged as robust.

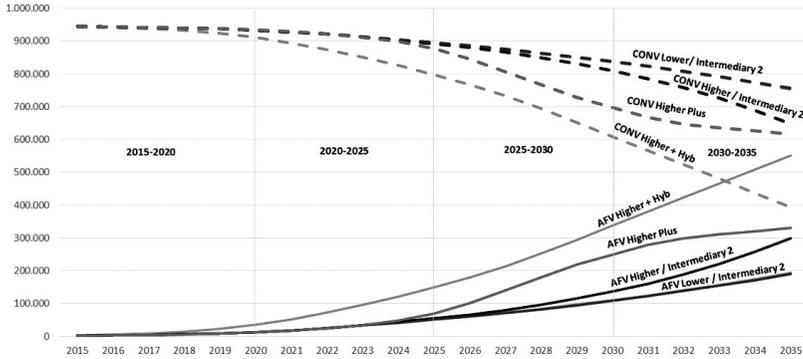
In the second approach, the progressive replacement of the conventional fleet with alternative energies/technologies, different ultimate shares of each energy/technology (BEV, PHEV, CNG, LPG and Hyb) are projected for the future.

Based on different rates of penetration, several basic cases or assumptions are established, assuming higher or lower EV penetration (EV Superior and EV Inferior). The same is assumed and projected for gas (CNG Superior or CNG Inferior). Furthermore, basic hypothesis about the penetration of conventional Hybrids and LPG are considered. The combination of these hypotheses results in different rates of penetration leading to different potential scenarios, as can be observed in Figure 14. It can be observed that alternative fuels vehicles (AFV) penetration corresponds with a decline of the conventional vehicle penetration rates.

Therefore, conventional vehicles will gradually be replaced by alternative energies. As a result, alternative fuel vehicles will coexist with conventional vehicles for some time. By 2030, however, alternative fuel vehicles (including conventional hybrids) could represent more than a half of the total passenger vehicle fleet in the territory. Table 8 presents the range of the simulated projections.

An example of the economic and environmental impact of the scenarios in terms of: (1) greater cost of vehicles; (2) investment in new infrastructure; and (3) the reduction of GHG and air pollutant emissions can be found in Annex 1.

**Figure 14. Progressive Introduction of AFVs to 2035 in the Basque Country, No. of Vehicles**



Source: Álvarez and Menéndez, 2017.

**Table 8. Cumulative Impacts of AFV Penetration by 2035 under Progressive Replacement**

Criterion	Minimum	Maximum
Extra net cost in vehicles	€500 mn	€2,300 mn
Infrastructure investment requirements	€80 mn	€180 mn
Fuel savings	€770 mn	€1,900 mn
CO <sub>2</sub> emissions reductions	2 MtCO <sub>2</sub> e	5 MtCO <sub>2</sub> e
NO <sub>x</sub> emissions reductions	860 tons	2,300 tons
Particulate emissions reductions	100 tons	200 tons

Source: own elaboration.

As with the Overnight fleet replacement scenarios in Table 7, the analysis of the progressive replacement scenarios according to the same criteria is presented in Table 9.

There is *no single best option in terms of both economic and environmental impacts*. Each alternative stands out with respect to one or more scenarios and criteria. In any case, *a higher penetration of battery electric cars and hybrids provides the best overall results*.<sup>48</sup>

48. For scenarios information and results, see Annex 1.

**Table 9. Order of Alternatives, Progressive Replacement by AFV**

	Fuel saving	Specific cost of CO <sub>2</sub>	Savings in environmental costs	Climate contribution
Higher + Hyb	1	4	1	1
Higher Plus	3	3	3	3
Intermediary B	6	5	6	6
Higher	4	7	4	4
Intermediary A	5	2	5	5
Lower	7	1	7	7
Higher + Hyb + PHEV	2	6	1	2

Source: Álvarez and Menéndez, 2017.

## Conclusions and Recommendations

For at least two decades, the EU has been highly concerned with the issue of transportation, both in terms of mobility and trade infrastructure (i.e., TEN-T) and with respect to alternative fuels and emissions. Given the still positive relationship between GDP and both passenger and freight mobility, the transportation sector is expected to continue to grow, contributing still more emissions to those also released by the power, building and land sectors.

As a result, the EU and its member states have developed and passed a range of legislation to reduce greenhouse gas and air pollutant emissions (NOx and particles) across most emitting sectors, including transportation.

Although GHGs are principally an issue at the global scale, air pollutant emissions have more local and regional implications. However, both groups of emissions, and the nature and effects of policies to reduce them, are relevant for the transportation sector—GHGs from the top-down and air pollutants from the bottom up.

But European transportation has no future without a sustainability framework. Sustainable mobility rests on three foundational pillars of social, economic and environmental sustainability. Policy to develop and deploy different alternative transportation fuels, vehicles and infrastructures can

also contribute to sustainable mobility in all these ways, although with different relative economic and environmental impacts.

The current European leaders in the promotion of alternative fuels and vehicles are: (1) France (EU) and (2) Norway (non-EU) in electric vehicles, and (3) Italy in natural gas vehicles.

An analysis of these (and a range of other relevant EU) countries reveals that two factors stand out as important for the pace of EV roll-out and penetration: (1) facilitative policies and (2) appropriate incentives. A number of other economic and market parameters are also highly relevant: (3) GDP per capita, (4) vehicle prices, the (5) relative price of fuel, along with (6) the dominant type of housing, are among the most important, although none is dominant in their influence. On the other hand, the energy mix *does not appear* to be a noticeable factor affecting the rate of penetration of EVs or the pace of EV infrastructure roll-out.

Italy is the most important EU country in terms of compressed natural gas vehicles. This is largely the result of a long-running continuity in Italian gas policies. Germany and Sweden—also European leaders in gas fuels—are both actively developing a biogas policy to help supply gas-fueled vehicles.

In one of our study's progressive replacement scenarios for the relatively small but emblematic Spanish-European region of the Basque Country, alternative fuel vehicles (mainly BEV but also conventional hybrids-AFV Superior+Hyb) are seen to gradually displace conventional vehicles from the fleet and would constitute more than half of passenger light-vehicles by 2035. Although the initial policy effort and economic investment implied would not be irrelevant, both would dwindle over time.

In our multicriteria evaluation, no single best solution emerges from among the range of alternative fuel vehicle options widely available in Europe (BEVs, PHEVs, CNG, LPGs and also conventional hybrids). However, the best policy option would promote a combination of alternative fuel vehicles—mainly EVs but also conventional hybrids (and in some parts of Europe, CNG vehicles)—to progressively displace conventional fossil-fuel vehicles from the vehicle fleet.

Thus, the EU and its member states are attempting to promote and develop sustainable mobility across Europe to help achieve its energy efficiency, renewable fuels and emissions reduction commitments.

Many stakeholders must be considered, including consumers, operators, OEMs, component manufacturers, and others, but vehicle owners and pur-

chasers are the key, indispensable agents. New regulation and other local measures aimed at vehicle owners (such as free parking places for alternative fuel vehicles) can therefore provide powerful levers to support the penetration of alternative fuel vehicles.

But to meet the challenge of facilitating alternative fuels and vehicles as an emissions reduction strategy, requires genuine commitment from governments in the form of incentives for the purchase of alternative fuel vehicles and the deployment of charging and refueling infrastructures.

Therefore, it would be wise to allocate sufficient public budget lines to provide for infrastructures and incentives to offset at least some of the extra costs of alternative fuel vehicles in order to achieve the significant environmental benefits of GHG and air pollutant emissions reductions.

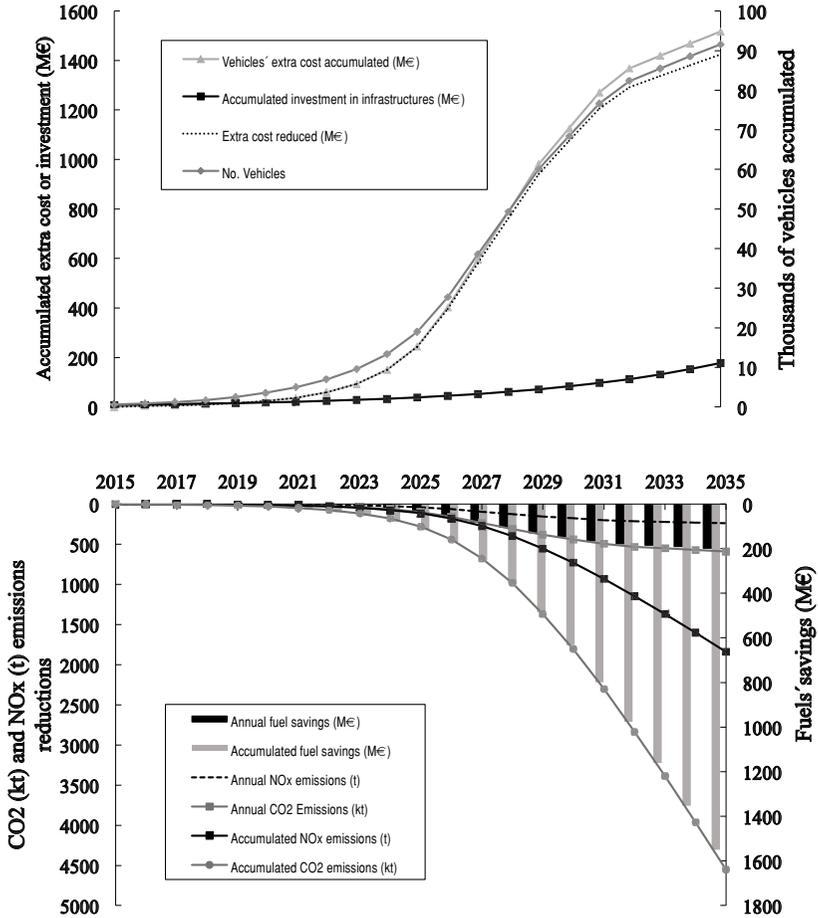
## **Annex 1: Alternative Fuel Vehicles Penetration Scenarios**

The study develops several scenarios, each assuming different penetration rates for each AFV. Here, only one of them, progressive replacement with only BEVs, is described as a representative example. In this case, the main assumption is that EV sales are strictly BEV (based on the probability that this technology could become the main segment of EU market). This assumed immediate market displacement of PHEV and conventional hybrids by pure battery EVs gives rise to rapid BEV deployment and an acceleration of battery development within the automotive and fuels industries that produces a faster drop in battery prices over time, and that facilitates the achievement of the objectives of OEMs.

For CNG vehicles this scenario assumes optimistic growth. For LPGs the assumptions are the same in all the scenarios as it is the most developed alternative fuel. Conventional hybrid vehicles would be displaced by the growing BEV market.

The results show an increase in extra infrastructure investment. This may be due, to a certain extent, to the way penetration is achieved. Unlike other cases considered, BEV penetration implies higher costs in the first stages, but a subsequent stabilization of replacement costs in later stages.

**Figure 15. Progressive Replacement, only BEVs, Investment Costs, Number of Vehicles, Emissions Reduction and Fuel Savings**



Source: Álvarez and Menéndez, 2017.