Outlook on the EU road fuel consumption through 2035

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Abstract

Saudi Aramco (SAO) is enhancing its refinery capacity mainly for export. The company's export share to Europe increases rapidly and has reached 20% since 2016. In light of this, it is of value for SAO to understand the future trend of road gasoline and diesel demand in Europe. This research, which was conducted in the Market Insights & Technology Intelligence (MITI) group of Aramco Overseas Company (AOC), assessed the relevant policy in the European Union (EU), automaker's future strategy and the effect of electric vehicle (EV) uptake. A forecast was derived from an existing outlook with respect to these factors on road energy demand through 2035, including diesel, gasoline and electricity. Current growth in road oil fuel demand and the rising diesel share will continue until the cost of EV breaks through the market threshold for mass commercialisation. The penetration is anticipated to happen in 2023. After that, both oil-based fuels for road transportation and the share of diesel in the fossil fuels will decline due to the substitution effect of EVs. By the end of the forecast period (2035), fossil fuel will continue to govern the road fuel demand and will be dominated by diesel. Backed by policy and automakers, EV penetration will accelerate after the breakthrough, which suggests a disruptive transition of road energy structure will happen soon after the forecast period.

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Introduction

Fossil fuels have dominated the transport energy for nearly a century. However, its role in transport sector is expected to fade concerning the challenge of Greenhouse Gas (GHG) emission, environmental pollution as well as energy security. The EU have established the objective to reduce the dependency on oil-based fuel in its recent policy strategy for transport sector. The emerging alternative technologies for mobility, particularly the electric vehicles (EVs), and the new business models such as shared mobility are suggested to bring about disruptive revolution to EU's transport sector in which the consumption of both gasoline and diesel will significantly decline. Most European vehicle manufacturers have announced EVs as one of their core business and will roll out more EV models in the next decade. **In this context, what trend of road diesel and gasoline demand through 2035 would be concluded?** This report is designated to answer the question by reviewing relevant policies and the strategy of automakers and by assessing the effects of the technological progress and market penetration of EVs. A new outlook will be derived from an existing one on road energy demand with respect to regulatory pressure from policy and the introduction of EVs.

Saudi Aramco (SAO) aims to enhance its current refining capacity from 5 million bpd to 8-10 million bpd by 2030. As the domestic demand of refining product in Saudi Arabia has been saturated (*Figure 1*) according to SAO's annual report, the further growth in refining capacity will mainly serve the export. SATORP is a refinery joint venture with Total and it produces ultra-low sulphur diesel that is suitable for EU fuel market, so its refining capacity is aimed for export to EU. As displayed in *Figure 1*, diesel accounted for the central growth in its refining capacity of road fuels, i.e. gasoline and diesel. *Figure 1* also presents that the refined product export to Greater Europe[1] region has expanded to 20% of SAO's total refined product export. Europe is becoming more and more important as a destination for refined product export. In this context, whether the refining capacity portfolio of SAO matches the future demand in EU market would influence the further growth of SAO's refining product export. In light of this, it is of value for SAO to understand the trend of diesel and gasoline demand for EU road transportation.

[1] Including some North Africa countries that take up marginal share in the exportation

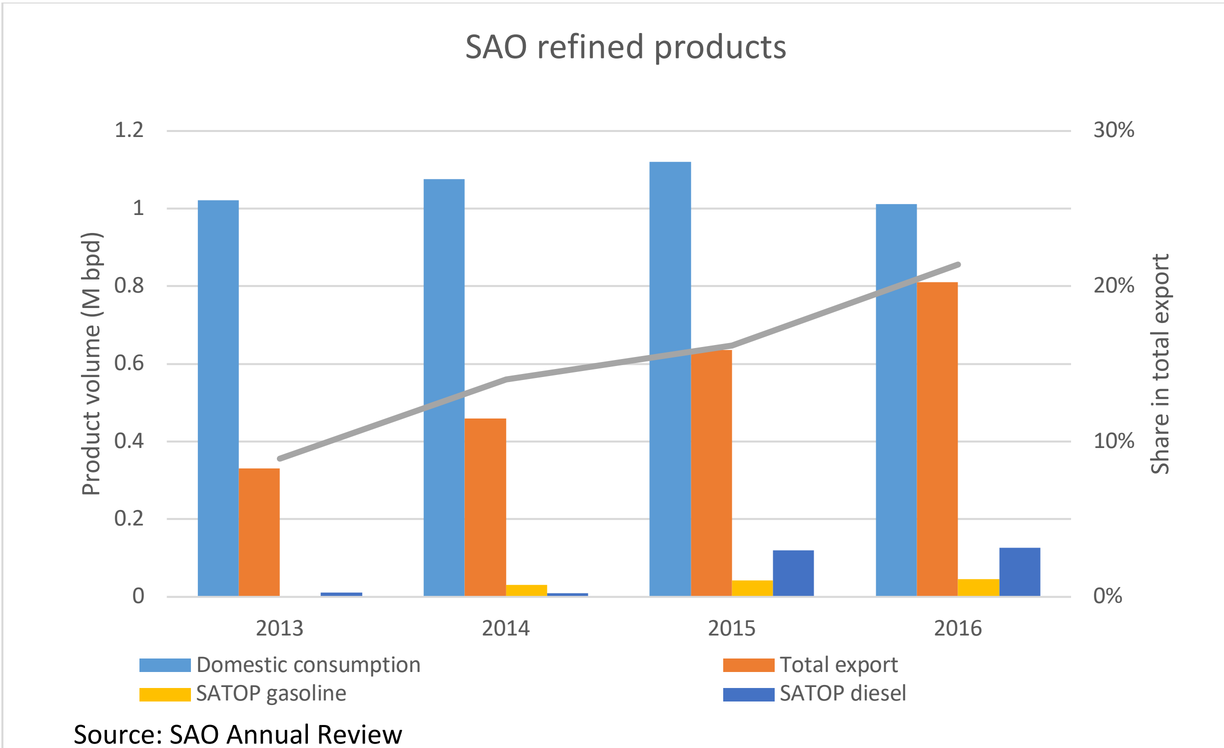


Figure 1 SAO refined products

Diesel and gasoline are mainly used for road transportation on which this study will focus. The MITI group of AOC identified three key driving factors that may shape the oil fuel consumption, both its volume and structure, of EU road transport sector: regulatory pressure (incentive), action plans of automakers, and innovation of either technology or business model. Policy represents the awareness of the society on the issue to be addressed. It sets the objective that the society is obliged to accomplish. In the meantime, the policy also implies potential pathways by which the goal will be realised in the way the target is set. Automakers provide vehicle options to consumers, which suggests the energy choice for transportation activity. The action plan, or strategy, established by automakers is the response to both market trend and regulatory pressure with available technologies. It indicates the attitude of vehicle manufacturers on the promising pathways among policy implications. Innovation is an underlining supplier of solutions for policy and automakers to address challenges. Vice versa, policy and automakers are partly in charge of the development and adoption of innovations. It can therefore be inferred that policy, automaker, and innovation would generate a complex effect on the road energy consumption. The following chapters will discuss the three factors in turn. The implication and effect of them will be applied in chapter 4 for assessing the forecasts through 2035 on oil fuel demand in EU road transport sector.

1. Policy review

1.1 EU policy overview

In this section, the relevant policies for realising road transportation objectives in EU will be discussed. A unified EU transport policy originated in 1986. Since 1992, environmental protection has been incorporated as one of the main targets into the EU transport policy in the Maastricht Treaty. The most recent EU policy strategy in transportation sector is the ‘Roadmap to a single

European transport area - Towards a competitive and resource efficient transport system' issued in 2011 (White paper 2011). It sets the goal of a less polluting and more energy efficient EU transport system. As in 2010 oil fuel supplied 96% energy consumption of the EU transportation, accounted for 210 billion € EU import bill, dependency on oil as a fuel source was then perceived as a principal challenge for the EU transport sector (European Commission 2011) to secure EU's energy supply.

Another strategy that guides the policy design for transport sector is the "2050 low-carbon economy" roadmap also proposed in 2011 which sets the target of CO_2 emission reduction through 2050 for EU transportation. GHG emissions from transportation takes up 20% of total GHG emission of the EU (EEA 2018) in 2011, the second largest emission source among all economy sectors. In order to realise the general GHG emission reduction target, it was suggested that the transport sector needs to cut at least 60% GHG emission with respect to its 1990 level by 2050, which corresponds to 8% above the 1990 level by 2030 (European Commission 2011). The roadmap also suggested a two-stage route for GHG emission reduction, which are 1) to improve fuel efficiency of petrol and diesel engines in the short-term, and 2) to further reduce CO_2 emissions through mass adoption of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) in the mid- to long-term (European Commission 2011). A similar strategy is recommended as well in the White paper 2011 that encompasses both increasing fuel efficiency and finding alternative energy sources so that the industry can be prepared to decarbonise without reducing the mobility the EU economy.

Currently, fossil oil still accounts for 94% (was 96% in 2011) of the EU transport energy demand (European Commission 2017). Additionally, the share of transportation GHG emission even increases to 21.7% of the total (EEA 2018), higher than the 20% in 2011, which means the decarbonisation process in transport sector is slower than in other economy sectors. This evidence marks the difficulty in EU transport sector to mitigate CO_2 emissions. Therefore, more regulations are foreseen to be implemented in order to realise the objective set by the EU strategy. In terms of road transportation specifically, it has generally been accepted over the EU to promote sustainable mobility that is: 1) decarbonised, 2) less dependent on oil fuel, and 3) environmentally friendly. The mission is suggested to complete by improving fuel efficiency of conventional internal combustion engine (ICE) vehicles and seeking for alternative fuel vehicles (AFVs) for road transportation.

Following the roadmap for the entire EU transport sector, a series of policy have been issued. *Table 1* illustrates the latest EU policies that are directly linked to the energy consumption for road transportation. Each policy has its exclusive regulatory realm. The policies are divided into four groups in terms of their effect on realising the strategy targets. In each category, policies are ranked ascendingly in terms of the influence on road fuel demand. Policies that are marked by bold font are considered as the direct restrictions when deriving the new forecast. One thing should be noted is that energy efficiency improvement is implied more or less in all groups. The following sections will provide insight on the potential impact of these policies on road fuel demand.

Table 1 EU policies relevant to road transport fuel demand

Functional category	Policy	Policy code
1. Activity mode management	1. Eurovignette Directive on road infrastructure charging	Directive 2011/76/EU
	2. Regulation on common rules for access to the international road haulage market	Regulation (EC) No 1072/2009
	3. Third railway package	Directive 2007/58/EC
	4. Directive establishing a single European railway area (Recast)	Directive 2012/34/EU
	5. TEN-T guidelines	Regulation (EU) No 1315/2013 supported by the Connecting Europe Facility (Regulation (EU) No 1316/2013)
	6. Energy Taxation Directive	Directive 2003/96/EC
2. Decarbonisation	7. GHG Effort Sharing Decision & EU ETS directive	Decision 406/2009/EC, Regulation 2018/842 & Directive 2009/29/EC
	8. Regulation on CO_2 from cars	Regulation (EC) No 443/2009, amended by Regulation EU No. 333/2014
	9. Regulation on CO_2 from vans	Regulation (EU) No 510/2011, amended by Regulation EU 253/2014
3. Alternative fuel vehicles	10. Directive on the promotion of the use of energy from renewable sources	Directive 2009/28
	11. Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles	Directive 2009/33/EC
	12. Directive on the deployment of alternative fuels infrastructure	Directive 2014/94/EU
4. Environmental pollution control on fuels	13. Fuel Quality Directive	Directive 98/70/EC, as amended by Directive (EU) 2015/1513
	14. Regulation EURO 5 and 6	Regulation (EC) No 715/2007
	15. Regulation Euro VI for heavy duty vehicles	Regulation (EC) No 595/2009

1.1.1 Activity mode management

The policies of group 1 are designed to adjust the ground transportation activity modes with preference to energy efficient ones. Policy 1 and 2 attempt to facilitate the utility of road freight transportation by unifying the road charge systems of EU member states and by removing administrative restrictions on international haulage market, respectively. In addition, the Eurovignette Directive on road infrastructure charging internalises the external cost of heavy-duty vehicles (HDVs). With both directives implemented, national tolls and vignettes must be non-discriminatory and better associated with the road use and the corresponding air pollution. This measure is expected to reduce the inefficient utilization on road haulage, especially the empty haulage, and hence the HDV fleet energy efficiency is improved. Yet the EU now deem the force of Eurovignette are still insufficient to promote its objective, so a new proposal[2] to amend the directive has been raised reinforce this policy. Road transportation, of both passenger and freight, is apparently more energy intense than transport by railway and waterborne (EEA 2016). It is thus suggested in the White paper 2011 that 30% of road freight over 300 km should shift to rail or waterborne transport by 2030, and more than 50% by 2050, and similarly, that the majority of medium-distance passenger transport should go by rail (European Commission 2011).

[2]Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures, COM(2017) 275 final - 2017/0114 (COD)

Policy 3 and 4 aim at the goal via reducing the costs and administrative barriers of railway transportation within the EU. The Trans-European Transport Network (TEN-T) is a European Commission policy to develop a Europe-wide transport network that includes roads, railway lines, inland waterways, maritime shipping routes, ports, airports and railroad terminals. In the current period, 2014 to 2020, an estimated 500 billion € financial investment is required for projects necessary for the implementation of the TEN-T, and by 2030, approximately 750 billion € investments will be required (European Commission 2016). There are 18 railway projects in the 30 priority projects to be completed by 2020 (European Commission 2018). Railroad construction projects also dominates the Core Network Corridors plan of which the completion will be in 2030. Up to 2015 as the latest report shows, around 100 billion € had been set up on EU level (European Commission 2017). In addition, for the railway infrastructure network, half of the key indicators (3 out of 6) had reached 75% compliance, whereas the compliance for all road infrastructure indicators were still below 75%. The TEN-T on the one hand, reinforces the connection over the Europe and thus can promote road transportation activity. On the other hand, it encourages the modal shift from road to railway. Study shows that the share of freight transport on road would have dropped to 52% in 2030 from the current 75% if the modal shift goal for freight transport is reached (Tavasszy and van Meijeren 2011, 7). This change, as estimated in this research, can reduce the road oil fuel demand of EU by 10% from the 2015 level.

Energy tax affects the activity volume of transportation by adding on fuel costs. As fuel taxes take up more than 50% in consumer prices of oil fuels over the EU (*Figure 7*), the tax rate of oil fuels could be determinant to the consumption balance between diesel and gasoline and to their competency against alternative energy. The Energy Taxation Directive (ETD, Council Directive 2003/96/EC) defines taxation levels on energy products and electricity. The ETD sets minima levels of taxation on products used as motor fuel, with EU member states free to set national rates beyond these minima. Minimum levels of taxation as defined in the Directive are respectively 0.3359 €/litre for gasoline and 0.3330 €/litre for diesel (European Council 2003). With these minimum levels of taxation, EU Member States then have the flexibility to define and implement national policies and adjust the taxation levels accordingly. It is on a Member State basis, and not on an EU basis, that the taxation levels for diesel and gasoline have differed wildly to create a demand imbalance between gasoline and diesel. This is illustrated in *Table 2* below.

Table 2 Excise Duties in different EU countries, July 2018

Unit: € per 1000 litres	Austria	France	Germany	Netherlands	Spain	Italy	United Kingdom
Diesel	410	610	470	498	367	617	656
Gasoline	493	691	655	786	461	728	656

In light of the Volkswagen scandal, and to support their fledging refining industry, a number of EU countries have announced changes in excise duty levels to rebalance gasoline demand against that of diesel. This trend happens over the entire EU as displayed in *Figure 2* below. The taxation level of both diesel and gasoline has increased gradually since 2016 and the excise duty on diesel has been rising fast approaching the level of gasoline since late 2015 after the Volkswagen scandal.

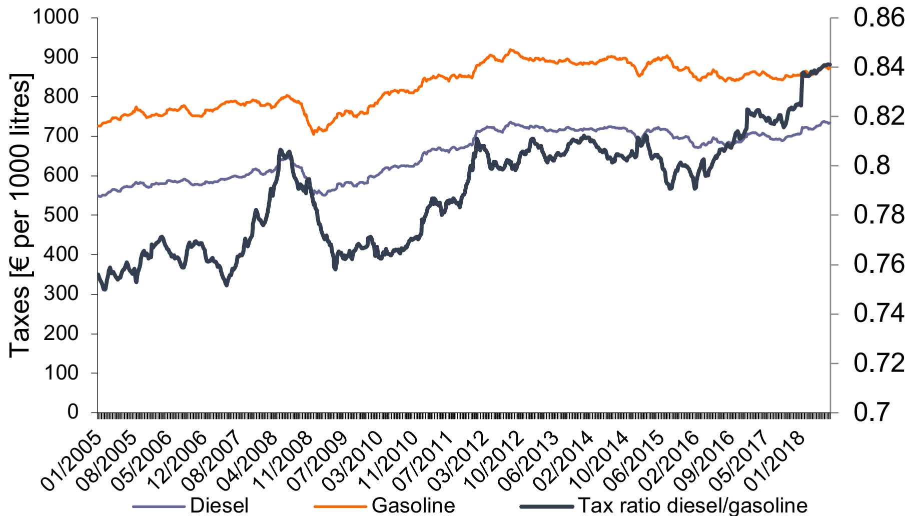


Figure 2 All taxes included in consumer prices of oil fuels - EU weighted average (source: Weekly Oil Bulletin, European Commission)

1.1.2 Decarbonisation

In group 2, policies aim at controlling the EU-wide CO_2 emission as well the CO_2 emission intensity of vehicles. The Effort Sharing Decision (Decision 406/2009/EC, and its sister Regulation 2018/842) establishes binding annual GHG emissions reduction targets, respectively for the periods 2011 to 2020, and 2021 to 2030, which covers the emissions from road transport sector. Although there is another directive that builds up the EU Emissions Trading System (EU ETS) to mitigate CO_2 emissions from the whole EU economy, road transport sector is not involved into the system. In the Effort Sharing Decision, targets are set for each EU Member State in accordance with their wealth and economic growth potential. Less wealthy countries have less ambitious targets, in light of their lower capacity for investment in emission abatement. Resulting 2030 targets range from 0% to 40% compared to 2005 levels. The EU has maintained flexibility between the Effort Sharing Decision and the EU ETS, with Member States able to cover a portion of their emission reduction targets under the Effort Sharing Decision with EU ETS allowances, to the limit of 100 million tonnes EU wide. The external allowance used to compensate the emission reduction target in the Effort Sharing Decision would alleviate the burden on road transportation to reduce oil fuel consumption to some extent. However, when looking into the flexibility of each eligible country (*Table 3*), it is observed that the overall influence of this flexibility on the CO_2 emission over the EU is limited within 4%. As road transport is only part of one sector (the entire EU transport sector) out of the all five Effort Sharing Decision sectors, estimated annual influence on oil demand EU-wide will not exceed 2% of 2005 consumption level.

Table 3 Emission reduction targets and flexibility for 2030

EU member states	2030 target compared to 2005	Maximum annual flexibility (as a % of 2005 effort sharing sectors emissions) from ETS to Effort Sharing Regulation
LU	-40%	4%
SE	-40%	2%
DK	-39%	2%
FI	-39%	2%

DE	-38%	
FR	-37%	
UK	-37%	
NL	-36%	2%
AT	-36%	2%
BE	-35%	2%
IT	-33%	
IE	-30%	4%
ES	-26%	
CY	-24%	
MT	-19%	2%

Regulations on CO_2 from cars and from vans set binding emission targets for new car and van fleets so that average emissions are falling each year as the automotive industry works towards meeting these targets. These regulations cover the emissions from light duty vehicles (cars and vans, vehicle category N1 and M1 with reference mass less than 2610 kg), which accounts for 15% total EU CO_2 emission, in which 12% is from cars and 3% is from vans (European Commission 2017). *Table 4* Presents the latest emission restriction for new registration cars and vans. As reported by the European Environment Agency (EEA), average CO_2 emission of new car sold in 2017 was 118.5 gCO_2/km and the average emission of new registration van in 2016 was 163.7 gCO_2/km. In November 2017, the Commission presented a legislative proposal setting new CO_2 emission standards for cars and vans for post-2020 period. Once the European Parliament approves the proposal, the emission from new registration cars and vans in 2025 will be 15% lower than their respective 2021 level and that in 2030 will be 30% lower.

Vehicle GHG emission represent not only the climate impact but also the fuel efficiency. It is the key indicator to forecast road gasoline and diesel demand. The emission targets for 2020 that are enforced now means a fuel consumption for cars of around 4.1 L/100 km of petrol or 3.6 L/100 km of diesel, and for vans of around 5.5 L/100 km of diesel. According to the proportional relation between carbon emission and fuel efficiency, the corresponding fuel efficiency to current emission level is estimated to be 5.1 L/100 km for petrol cars, 4.5 L/100 km for diesel cars, and 6.1 L/100 km for diesel vans.

For heavy-duty vehicles (HDVs, including buses and trucks) whose emission corresponds to 6% of total EU CO_2 emission, there has not been a regulation on the emission yet. On 17 May 2018, the European Commission presented a legislative proposal setting the first ever CO_2 emission standards for HDVs in the EU. Similar targets as for cars and vans are set in the proposal for HDVs. The CO_2 emission of new registration HDVs in 2025 will have to be 15% lower than the 2019 level and 30% lower in 2030 (European Commission 2018). Zero- and low-emission vehicles is recommended to achieve this mandatory target in the proposal where a reward system is employed to encourage HDV manufactures to replace the power source of HDVs, of which 98% are propelled by diesel engine, with batteries.

Table 4 CO_2 emission limits for new cars and vans

Unit: gCO_2/km	2012	2015	2016	2020	Sources
Cars		130		95	(European Council 2009)
Vans	181		175	147	(European Council 2011)

1.1.3 Alternative fuel vehicles (AFVs)

Policies in the 3rd group emphasise on finding the solution for EU transportation from alternative energy sources. The Directive on the Promotion of the Use of Energy from Renewable Sources ("RES" Directive) establishes an overall policy for the production and promotion of energy from renewable sources in the EU. As regulated by the present policy, all EU countries must ensure that at least 10% of their transport fuels come from renewable sources by 2020 (European Council 2009), where electricity generated from the renewables (not from fossil sources) can also count. On 30 November 2016, the Commission published a proposal for a revised Renewable Energy Directive. The 10% renewable source target will be substituted with the target for bioenergy that the minimum share shall be at least equal to 1.5% in 2021, increasing up to at least 6.8% in 2030 (European Commission 2016). This adjustment presents the new EU viewpoint to refrain the consumption of food-based biofuels and to improve the sustainability requirement of biofuels. On the other hand, to encourage the adoption of renewable electricity for road transportation will be excluded and left to be regulated by other policies once the new directive is approved.

The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (Directive 2009/33/EC) aims at a broad market introduction of environmentally friendly vehicles. It requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in all purchases of road transport vehicles. It also provides factors to monetise the impacts in calculating the lifetime costs linked to the operation of vehicles for purchasing decision. In 2017, the Commission published a proposal for amending the Directive 2009/33/EU on the promotion of clean and energy-efficient road transport vehicles (COM/2017/0653 final - 2017/0291 (COD)). The proposal redefines "clean vehicle" with a full-range environmental emission standard (*Table 5*). The standard is significantly stricter than the current regulations for the future decade. In 2030, as regulated by the proposal, a clean vehicle must be zero-emission vehicle. The proposal also sets the minimum target for the share of clean vehicle in the total public procurement at Member State level, which covers both LDVs and HDVs. If the Parliament adopts this proposal, the consequence can be profound by which the public procurement target will act as the benchmark to incentivise the penetration of clean vehicles.

Table 5 Definition for clean vehicles

Vehicle categories	2025		2030	
LDVs	CO_2 g/km	RDE air pollutant emissions* as percentage of emission limits**	CO_2 g/km	RDE air pollutant emissions* as percentage of emission limits
	25-40	80%	0	N.A.
HDVs	Electricity***, hydrogen, natural gas including bio-methane, in gaseous form (compressed natural gas (CNG)) and liquefied form (liquefied natural gas (LNG)			
* Real driving emissions of ultrafine particles in #/km (PN) nitrogen oxides in mg/km (NOx) measured according to the applicable version of Annex IIIA, Regulation 2017/1151.				
** The applicable emission limit found in Annex I of Regulation (EC) 715/2007, or its successors.				
***For use in a vehicle as defined in Art. 2 (2) of Directive 2014/94/EU, provided that electricity is used for a relevant part of the operational use of the vehicle.				

The Directive on the Deployment of Alternative Fuels Infrastructure (Directive 2014/94/EU) aims to alleviate oil dependency of the EU transport sector by facilitating the accessibility to refuelling points in public areas of alternative fuels. Construction targets are set up to 2025. It concerns a thorough spectrum of alternative fuels encompassing electricity, hydrogen, biofuels, CNG, LNG and LPG. The Directive and its accompanying action plan (European Commission 2017) have recommended electricity/battery as the principal alternative power source for urban transportation in the future; liquefied gas/petroleum as well biofuel serve as the main alternative fuel for freight transport on core networks, such as the TEN-T projects; and hydrogen is still in its demonstration stage, corresponding to 0.3-0.4% of the total vehicle stock in 2025. The EU Member States have obliged to ensure the minimum coverage requirement for charging points, i.e. ten EVs per charging point, as suggested by the directive (European Commission 2014). At present, there are about 157,547[3] public accessible charging points and it is estimated that 440,000 would be needed by 2020 to serve 4 million EVs on road (European Commission 2017). The accomplishment of this directive will probably remove physical barriers to the market penetration of alternative fuel vehicles, especially that of EVs. In compliance with this directive, the EU member states have submitted their development targets for AFVs, of which 21 countries confirm to develop EVs and 10 of them, including the UK, Germany and France, prioritise the electromobility in their alternative transportation plans (T&E 2018). Electric vehicle has become the most popular among all AFV options from the EU policy perspective.

1.1.4 Environmental pollution control on fuels

Policies in group 4 regulate the quality of fossil fuels in terms of environmental pollutants. The Fuel Quality Directive (Directive 98/70/EC, as amended by Directive (EU) 2015/1513) is initially designed for a unified standard over the EU of the content and the physical-chemical performance of transport fuels, such as gasoline, diesel and biofuel. Its environment relevant contribution encompasses a target for life-cycle GHG intensity of fuels through 2020, a sustainability requirement on biofuels, and the limit of sulphur content for diesel and gasoline. The life-cycle GHG intensity of fuels needs to be reduced by 6% compared with the 2010 level as minimum; the GHG emissions from biofuels must be at least 50% lower than from the fossil fuel they replace; and the sulphur content of gasoline and diesel shall not exceed 10 mg/kg (European Council 2009). The reduction in sulphur content is effective as the average sulphur content of petrol and diesel fallen below 10 ppm since 2009 (European Commission 2017).

The Regulation EURO 5 and 6 (Regulation (EC) No 715/2007) governs the pollutant content of the exhaust emissions from gasoline and diesel, and the similar Regulation EURO VI (Regulation (EC) No 595/2009) is for HDVs. The EU standard values are presented in *Table 6.* All emission levels are tested under the New European Drive Cycle (NEDC). Emissions levels in real-world driving may differ from the test cycle values. Since 2016, the compliance with Euro 6 standard of new registration cars has reached 90%, as measured over the NEDC. However, the conformity of real-world nitrogen oxide (NOx) emissions could be problematic. As *Figure 3* illustrates, on-road measured NOx emissions from gasoline cars are generally in line with the emission limits, whereas the value of diesel cars deviates much (approximately 5 times higher) from the EURO standards. Over the ensuing two years, a number of government agencies across Europe began to

[3] Source: The European Alternative Fuels Observatory: http://www.eafo.eu/electric-vehicle-charging-infrastructure.

systematically test diesel cars for their emission levels. On average, for 541 diesel cars tested by, among others, the German, French and UK governments, the average conformity factor for Euro 5 vehicles was 4.1 and for Euro 6 vehicles 4.5, meaning that the actual emissions are more than 4 times the legal limit of 180 mg/km. The difference between individual vehicle models is particularly remarkable, with some Euro 6 diesel cars emitting less NOx than the limit while others exceed the regulatory limit by a factor of 12. Only 10% of tested Euro 6 vehicles would meet the Euro 6 limits on the road (Baldino, et al. 2017). Together with the Volkswagen scandal, the situation highlights that laboratory emission measurements have shown their limits in enforcing strict pollution limit standards on vehicles.

Current efforts from the EU have led to the adoption of Real-Drive emissions testing by means of portable emissions measurement systems (PEMS) and under the Worldwide harmonized Light vehicles Test Procedure (WLTP), by which the discrepancy between laboratory and on-road emission performance can be minimised. Furthermore, a ceiling seems appear against improving environmental performance, especially in NOx emission, of diesel engine, as indicated in these events. Pollution emission regulations may become a massive pressure on sustaining the demand of diesel in the future.

Table 6 EU exhaust emission limits for fossil fuels

Unit: g/km	Effective date	CO	HC	NMHC	NOx	HC+NOx	PM	PN
EURO 5 gasoline	Sep 2009	1.00	0.10	0.068	0.06	–	0.005	–
EURO 5 diesel		0.50	–	–	0.18	0.23	0.005	–
EURO 6 gasoline	Sep 2014	1.00	0.10	0.068	0.06	–	0.0045	$6.0*10^{11}$
EURO 6 diesel		0.50	–	–	0.08	0.17	0.0045	$6.0*10^{11}$
EURO VI (in g/kWh)	Jun 2009	4.00	0.50	0.160	0.40	–	0.01	–
CO: Carbon monoxide; HC: Hydrocarbon; NMHC: Nonmethane hydrocarbon; NOx: Nitrogen oxides; HC+NOx: Hydrocarbon and nitrogen oxides; PM: Particulate matter; PN: Particulate number								

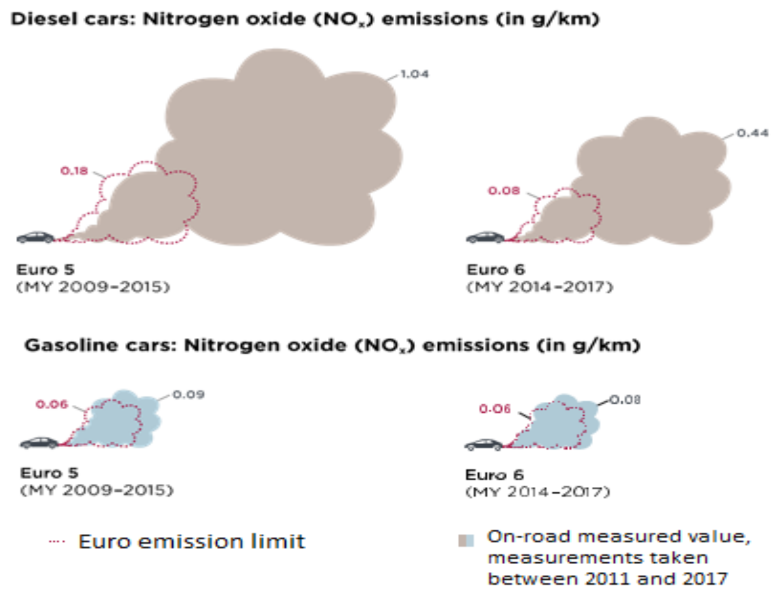


Figure 3 Conformity of on-road NOx emission with the EURO standards (source: ICCT)

Taxes on vehicle purchase/registration/ownership can steer the demand of vehicles and hence influence the fuel consumption. There is little EU-wide legislation at present in the area of passenger car taxation. Therefore, it is on Member State side to lay down national provisions for the taxation of these cars. On the other hand, 20 out of 28 EU Member States (including France, Germany, the Netherlands, Spain, and the United Kingdom) have set up taxes to the registration and/or ownership of passenger cars partially or totally based on the cars' CO_2 emissions and/or fuel consumption (ACEA 2018). Most EU countries (except for Croatia, Estonia and Lithuania) have established incentive schemes for electric cars. The incentives mainly consist of tax reductions and exemptions, as in countries such as Austria or Germany, and bonus payments and premiums for the buyers of electric vehicles in France and the UK (ACEA 2018).

1.2 Policy in China

China is one of the largest markets for vehicles and oil consumption in the world. Asia ranks on top of the export destinations of Saudi Aramco in terms of crude oil and refined products (Saudi Aramco 2017). With the huge consumption volume, China's policy may be influential on the trend of oil product demand in Asia. Following in this section, we will briefly summary policies that are relevant to fuel demand of road transport in China.

The objective of energy policy in China concerns improving energy efficiency, safeguarding energy security and protecting the environment. The Chinese government has committed to increase the share of non-fossil energy in its total primary energy consumption to 15 percent by 2020, and to reduce CO_2 emission per unit of GDP by 40-45 percent per 2005 level (China's State Council 2012). In road transportation, energy conservation and emission reduction are the main policy goals. The taxes of diesel and gasoline are 1100CNY (140€)/1000 litres and 1400CNY (180€)/1000 litres respectively. The burden of fuel taxation is much lower than the EU level and the ratio of these two taxes is 0.78, similar to the EU. However, China's road transportation is heavily gasoline based (IEA 2017). It is thus inferred that the low tax ratio in China makes it ineffective to the fuel demand. The low tax burden on fuel in China has Excise duty on passenger cars is levied with progressive rates based on exhaust volume (*Table 7*). Since 2018, China has implemented China 5/V (GB 18352.5—2013 and GB 17691—2005) standards for fuel quality exhaust emission limits nationwide. The new China standard is identical with Euro 5/V in sulphur content and the emission of CO and NOx but is more stringent with respect to PM emission and test method for HDVs (Shao 2015). Although there is also the problem of conformity of on-road emission against the China 5/V standard (Yang, et al. 2018) as in EU, the China 6/VI (GB 18352.6-2016) standard, which is stricter than Euro 6/VI, has been announced to implement from 2020 onwards. Energy efficiency is one of the main concerns on road transportation. As announced in the "Mid- and Long-term Plan on Automobile Industry", the fuel efficiency of new cars should fall below 5 l/100km by 2020 and 4 l/100km by 2025 (MIIT 2017).

Table 7 Excise duty on passenger cars

Source: (Minishtry of Finance 2008)	
Exhaust volume (V) of passenger car	Tax rate
V ≤ 1 L	1%
1 L < V ≤ 1.5 L	3%
1.5 L < V ≤ 2 L	5%
2 L < V ≤ 2.5 L	9%
2.5 L < V ≤ 3 L	12%
3 L < V ≤ 4 L	25%
4 L < V	40%

In addition to the stringent regulations set on fuel and emission, China has adopted new energy vehicles (NEV), especially EV, as the priority in the development of its automobile industry. On central government level, the development of NEVs has been included into the national strategy for industry. The "Made in China 2025" policy claims that the EV and FCV manufacture is one of the ten industrial sectors focus. Targets are set for the NEVs that by 2020, the annual production and sales should reach 2 million with the battery cost drop down to 140€/kWh; and by 2025, the market share of NEVs should take up 20% of the total production and sales in the country (MIIT 2017). On January 1, 2017, China implemented an updated subsidy program for NEVs. The 2017–2020 Policy Adjustment details subsidies for manufacturers rather than end users and features the phase down of a national subsidy, tightened vehicle qualification requirements, improved incentive design, and robust anti-fraud and enforcement measures (Cui, Yang and He, Adjustment to subsidies for new energy vehicles in China 2017). In September 2017, China finalized its New Energy Vehicle (NEV) mandate. The NEV mandate is a modified version of California's Zero Emission Vehicle (ZEV) mandate, with goals of promoting new energy vehicles and providing additional compliance flexibility to the existing fuel consumption regulation. It applies only to passenger cars and has taken effect April 1, 2018. The rule establishes NEV credit targets of 10% of the conventional passenger vehicle market in 2019 and 12% in 2020 (Cui 2018). Each NEV sold generates some number of credits, depending on characteristics such as electric range, energy efficiency, and rated power of fuel cell systems. The final NEV market share achieved under the influence of the credit targets will therefore depend on the final fleet mix.

Cities, such as Beijing, Shanghai, Shenzhen and Guangzhou, the 4 largest cities and other 7 provincial capital cities, have implemented incentive policies to promote NEV penetration. The policy consists of free registration license, exemption from the vehicle restriction rule and discount in car parking (Tesla 2018). In Beijing, car registration is allocated by a license-plate lottery system; in Shanghai, auction is adopted for registration allocation; and Guangzhou combines the two measures. It is reported that the success rate of lottery in Beijing is less than 1% and the average auction price for a license in Shanghai has exceeded €10,000. In this context, the incentive measures for NEVs could be tempting to consumers.

2. Future vision from automakers

This section will present the future strategy of automakers. These strategies represent the prospect of vehicle suppliers on the market trend and their response to policies in the transport sector. Road transport fuel consumption inevitably relies on vehicle fleet. Option for buyers on automobiles is to some extent determined by the supply of car models. Therefore, vehicle manufacturers' decision in production is indispensable in forging the future car market as well as the fuel consumption of road transportation.

Volkswagen Group, the world's largest vehicle manufacturer, highlights their objective in EVs in the "Strategy 2025". Visioning the expansion of EVs, Volkswagen determines to become a driving force of the trend. The group plans to develop more than 30 new pure-electric vehicles and to sale 2 to 3 million EVs per year by 2025, which is equivalent to 20-25% of total sales (Volkswagen 2018). Battery technology will be developed as a new core competency. As anticipated for its own EV fleet use in 2025, Volkswagen will build up 150GWh annual production capacity of battery (Volkswagen 2018). Other European automakers, such as Daimler, BMW, the PSA group, Volvo and Fiat, are also convinced that the future of mobility belongs to EVs. They have launched strategies to develop EV technology with their own emphasis. Daimler has rolled out a spectrum of EV models spanning from passenger cars to vans, buses and trucks. BMW has committed to expand the share of EVs and PHEVs in its car fleet. Besides, BMW has unique interest in charging facilities and leads in wireless charging. Both Daimler and BMW have invested in battery production. In addition, the PSA group, Volvo and Fiat concentrate on EV model development.

In the US, the two main automakers, Ford Motors and General Motors do not publicly release a specific strategy to promote alternative energy vehicles. Ford has a few models of EV and hybrid vehicles and it has committed to develop its battery technology. On the other hand, there are emerging new manufacturers to produce EVs in the US. The well-known EV manufacturer, Tesla, for example, grows rapidly in recent decades. Tesla leads in battery charging technology and it has the plan to develop electric trucks.

In China, most of the domestic manufacturers have launched the production of NEVs where the EV accounts for 80% of NEV sales (e-Institute 2018). China's manufacturers are not only developing the technology of NEV and battery, but also innovating the business model for EV sales. To address the problems of long recharging times and high price that deter consumers from purchasing EVs, several players in China are trying radically different solutions than the rest of the global auto industry. Beijing Automotive (BAIC) and EV newbie NIO are advancing a "battery-car unbundling" scheme in which consumers purchase the EV without battery and rent the service of battery usage. In this business model, EV owners offload a depleted EV battery and replace it with a fully-charged one within just three minutes in an automated swapping station, rivalling the time needed to pump petroleum fuels. Besides, the upfront cost to buy a car would be slashed by nearly 40% based on the scheme's principle of decoupling car and battery ownership.

Battery-swapping business model is also advantageous in battery maintenance and recycling since the battery are expertly managed through optimal measurements. If these solutions to cost and charging convenience succeed, in either operation management or consumer acceptance, it may prove a significant factor in phasing out conventional cars.

Unlike the counterparts in Europe, China and the US, which are fully embracing the EVs, Toyota resorts to a hybrid technology roadmap. Aiming to reduce 90% CO_2 emission of its new vehicle fleet in 2050 (Toyota 2018), Toyota adopts a comprehensive strategy that covers energy-saving adaptation and fuel diversification. In the short-term, Toyota will keep on improving the fuel efficiency of the gasoline and diesel vehicles that is believed to dominate the market in the near future. In the long-term, Toyota sees hybrid technology as a core technology and is engaged in wide-ranging development including electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles. *Figure 4* shows the sales provision through 2050 from Toyota. Hybrid vehicle, whether plug-in or not, will be the emphasis of Toyota after 2030. Toyota believes that current alternative fuel vehicles have their own strengths and weaknesses and that each technology is suitable for particular mobility purpose (*Figure 5*). Additionally, energy policies vary by country and region. Therefore, the company does not settle for any particular technology but engage in all-round development activities to explore the potential of a diverse range of fuels.

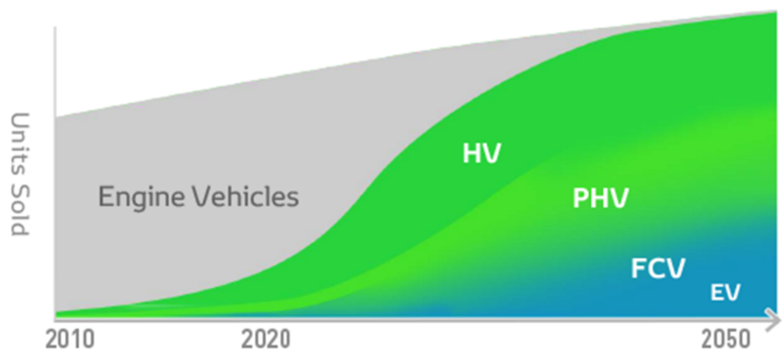


Figure 4 Toyota's provision of vehicle sales towards 2050

	Electricity EV	Hydrogen FCV	Biofuel Internal Combustion Systems	Natural Gas Internal Combustion Systems
Well to Wheel CO₂*	★~★★★	★~★★★	★~★★★	★★
Supply Volume	★★★	★★★	★	★★
Cruising Distance	★	★★★	★★★	★★
Refueling Time (Charging/Filling)	★	★★★	★★★	★★★
Infrastructure	★★	★	★★★	★★

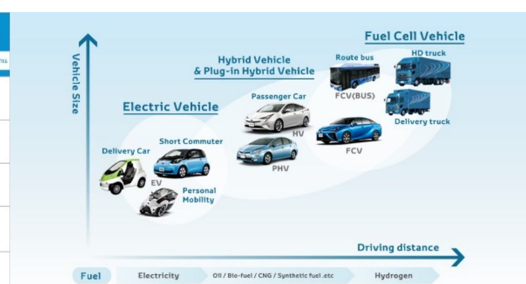


Figure 5 Characteristics of gasoline-alternative fuels evaluated by Toyota

3. Potential impact caused by innovation

3.1 Electric vehicle

3.1.1 Cost breakthrough and the fleet growth potential

From previous sections, it is evident that EVs are generally foreseen to play the key role of the alternative mobility technology in the coming decade. In this section, the potential capacity the EV owns to substitute the conventional ICE vehicles will be quantitatively assessed. Battery electric vehicles (BEVs) is the focus in this section. The assessment will be based on a global learning curve of the BEV industry. Learning curve reveals the relation between the production cost and the accumulative production of a certain industry. In this study, battery cost is argued as the proximity of BEV cost as the battery technology is the core for BEV and takes up more than one-third of the value of a typical EV (Schwartz 2018, 12). From the accumulative battery production, a global BEV volume as well as the EU BEV volume will be estimated. The results will also be applied in chapter 4 for assessing the forecast made by other parties.

Global BEV industry has experienced an exponential growth in recent years (*Figure 6*). Since the main vehicle OEMs have announced in their strategy to develop BEV models, it is reasonable to believe that this trend will last in the next decade.

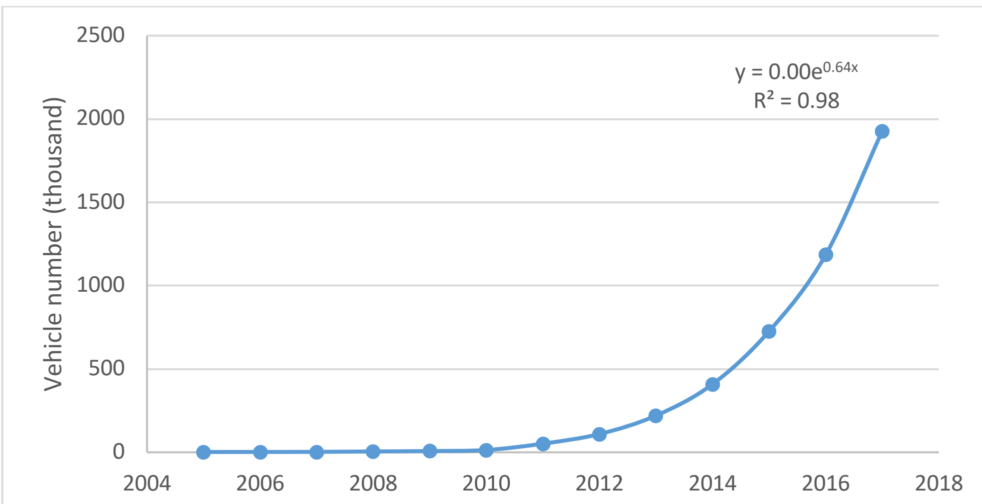


Figure 6 Global BEV stock (source: IEA EV Outlook 2018)

With the industry expanding and the production accumulating, production cost declines owing to economy of scale and technological progress. There is a relation between the production cost and the cumulative production of a product on temporal base, as *Equation 1* presents:

Equation 1

$$\frac{P_t}{P_0} = \left(\frac{C_t}{C_0}\right)^b$$

where P denotes the production price/cost, C denotes the cumulative production, b is a parameter, and 0 and t refer to the base time and the later time to which P and C belong. The curve drawn from this formula of the production cost against the cumulative production is called the learning curve. Learning rate can thus be derived from this relationship as in *Equation 2*:

Equation 2

$$LR = 1 - 2^b$$

where LR denotes the learning rate. According to *Equation 2*, learning rate is defined as the percentage of cost reduction when the cumulative production doubles. This factor is estimated from regression analysis on historical data and can be used to extrapolate future trend of production cost or cumulative production.

As reported by Nykvist and Nilsson (2015) and Schmidt, et al. (2017), learning rate for BEV battery packs is increasing and the cost of battery pack declines faster than anticipated. The cost of battery pack is the determinant factor for the commercialisation of BEVs. For the entire battery industry, it is commonly perceived that 150 $US\$_{2014}$/kWh is the threshold where BEVs gain economic competency against conventional ICEs (Nykvist and Nilsson 2015, Gaines and Cuenca 2000), given the oil price is 50 $US\$_{2014}$/bbl and the electricity price is 0.12 US$/kWh (Schmidt, et al. 2017). Up to 2016, the average cost of Li-based battery pack has approached 200 $US\$_{2014}$/kWh and continued to fall down (Schmidt, et al. 2017). The moment when BEVs can be fully commercialised is close. It is therefore of value to estimate the year when the break-through price is reached and available battery stock for BEVs.

Figure 7 Fuel taxes burden in EU28 and the US, Jan 2018 (source: EU Oil Bulletin, US EIA)

Forecast on the break-through year is calculated according to the learning curves and the growth rate of the cumulative production of BEV battery pack.

It is argued in this study that the condition for the cost threshold is also valid for EU. Although the electricity price in EU is 0.2 €/kWh, much more expensive than that in the US, EU fuel prices are almost equivalently higher than that in the US. Besides, the heavy tax burden on fuels in EU, as *Figure 7* illustrates, indicates that regulatory pressure rather than oil price determines the competitiveness of oil against electricity in EU. Concerning the price differences of electricity and fuels between EU and the US are in a proportionally similar, the threshold that 150 $US\$_{2014}$/kWh is adopted as the battery pack cost at the critical point when BEVs breakthrough in the market.

Records of learning rate, production cost and accumulative production are adopted from Nykvist and Nilsson (2015) and Schmidt, et al. (2017), as can be seen in *Table A- 1* in appendix. The growth rate of cumulative production is estimated by regression analysis on the global BEV stock as in *Figure 6*. To link the BEV volume with the cumulative total battery capacity, an average BEV size is needed. This information is estimated based on the data of top 10 selling BEVs in EU as illustrated in *Table A- 2*. Results of the forecast is presented in *Table 8* below.

Table 8 Forecast on the BEV breakthrough

LR	Breakthrough year	Battery size (kWh)	Global fleet (thousand)	Cumulative EV fleet in EU (thousand)		
				15%	12%	10%
9.0%	2026	82	196,204	29,431	23,545	19,620
10.1%	2024	71	70,654	10,598	8,478	7,065
12.0%	2024	68	52,449	7,867	6,294	5,245
16.0%	2022	59	18,368	2,755	2,204	1,837
20.0%	2020	54	10,025	1,504	1,203	1,003
* the results of EU are based on the scenarios of the EU market share in the global market						

As indicated in the results, the mass commercialization of BEVs will probably occur in between 2020 to 2025. Learning rate was reported 9.0% in 2015 and rose to 16.0% in 2017. The learning effect was accelerating at a high rate due to technological progress. On a long-term perspective, it is reasonable to consider the average learning rate to be in 12.0% to 16.0% interval. The share of EU BEV fleet in the global fleet peaked in 2013 at 21% and then dropped to current 16% (see *Figure 8*). This is probably due to the dramatic expansion of BEV fleet in China. As discussed in chapter 1, China has implemented a number of policies to facilitate the penetration of BEVs. The measures are effective as indicated in *Figure 8*. Additionally, China's automakers are enthusiastic in developing introducing the BEVs. Therefore, China will probably hold its leadership in global BEV market and its share of BEV fleet will continue to increase. On the other hand, EU's BEV fleet share would continue to shrink for a few years. It is thus argued that 12% would be the share of EU's BEV fleet in the world. In this sense, the breakthrough year is more likely to be 2021 or 2022 when there will have been 2.2 to 6.3 million BEVs produced for EU since 2010 cumulatively.

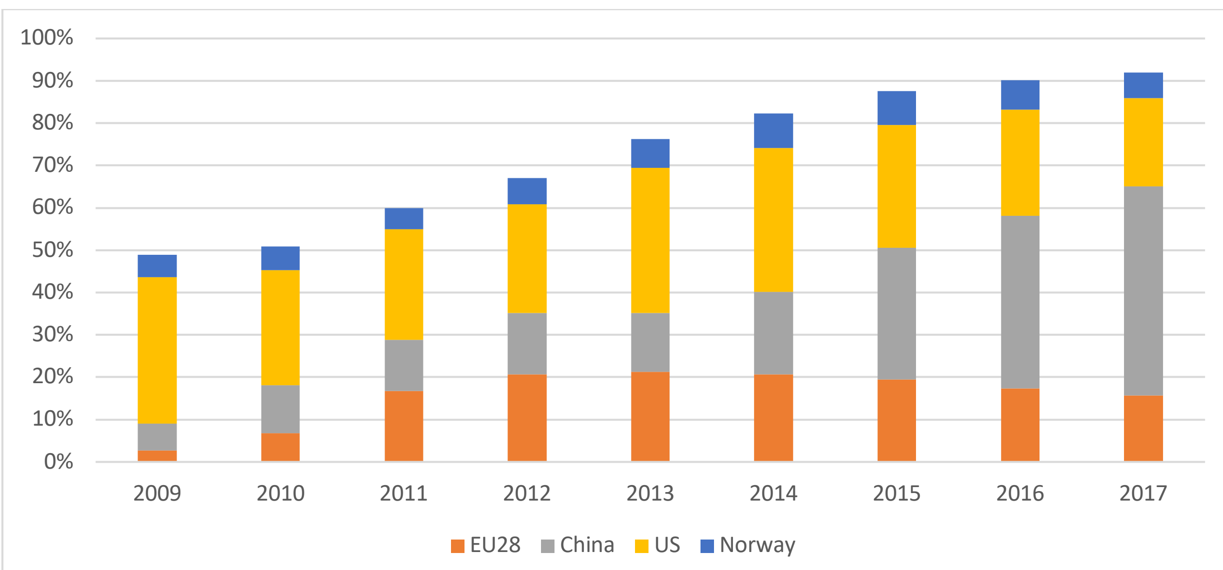


Figure 8 BEV fleet share of leading regions (source: IEA EV Outlook 2018)

3.1.2 Substitution effects on the gasoline and diesel vehicles

So far, it has been commonly agreed that EVs will replace the conventional ICE vehicles. However, the impacts of EVs on the phase-out of the gasoline and diesel vehicles have been rarely discussed. *Table 9* shows the economic comparison between gasoline cars, diesel cars and EVs, which is estimated based on Volkswagen Golf models. A general situation in vehicle market is that vehicles with diesel engine are more expensive than vehicles with gasoline engine, and EVs cost more to buy. In this sense, it is reasonable to argue that the fixed costs of vehicles follow the rank of purchase prices. Another part of the costs is the variable cost that is dependent on the driving mileage of a vehicle. This cost is determined by fuel cost. In fuel market, diesel is cheaper than gasoline in Europe and electricity is cheaper than fossil fuels in road transportation.

Table 9 Cost portfolio of the gasoline, diesel and electric vehicle models

Mode	Fuel	Fuel economy	Fuel price	Variable cost (€/100km)	Purchase price (€)
VW Golf Highline 1.5 TSI	Gasoline	5.1 L/100km	1.45 €/L	7.4	26425
VW Golf Highline 2.0 TDI	Diesel	4.3 L/100km	1.35 €/L	5.8	29200
VW e-Golf	Electric	12.7 kWh/100km	0.2 €/kWh	2.54	35900
Sources: www.volkswagen.de, EU Weekly Oil Bulletin, and Eurostat					

Based on the assumptions in last paragraph, *Figure 9* presents the substitution effects of EVs to ICE vehicles in terms of economic consideration. Cost competitiveness of the three vehicle models varies according to their driving mileage. Gasoline vehicles are the cheapest option at the first stage from 0 km to M1 km; diesel vehicles are advantageous in a moderate range from M1 km to M2 km; and EVs are favourable for a long driving range beyond M2 km. In other words, diesel vehicles are more economical for the consumers who drive more often, compared with gasoline vehicles, and so as for EVs against diesel vehicles. This consequence is due to the opposite ranking between the fixed costs and the variable costs. The driving distance M3 denotes the maximum distance that a prospective car owner may drive. Economic comparison should be conducted within M3 as the consumer will never drive beyond the distance. The point M3 is a threshold for market breakthrough of the product.

By applying the data of VW Golf models displayed in *Table 9*, it can be figured out that M1 is about 17,500 km per year and M2 is 20,500 km per year, given a 10-year lifecycle period. The results are consistent with real-world records (*Table 10*) that a diesel vehicle normally travels further distance than a gasoline vehicle. Difference among countries can be due to the difference in fuel prices and the real vehicle fleet, of which the costs vary largely, of the country, same as for the exact travel range. Even so, the diagram of the substitution effects of EV on the gasoline and diesel vehicle is sufficient to demonstrate the mechanism.

Table 10 Average travel distance per vehicle (km per year per car)

	Austria	Belgium	France	Hungary	Netherlands	Sweden
Gasoline	10,964	8,962	7,714	12,400	10,498	9,660
Diesel	14,815	18,841	13,821	14,700	23,067	17,390
*data per country spans from 2009 to 2014						
**fuel prices vary from countries						
Source: (ACEA 2017, 17)						

EVs will gain economic competency against ICE vehicles only when the cross point of the grey line (cost line for diesel vehicles) and the green line M2 moves below M3. Technological progress in battery packs lowers the fixed cost of EVs, which is represented in the diagram by downward shifting of the green line (cost line for EVs). In this situation, M2 moves left towards M3, which diminishes the advantageous space of diesel vehicles. In conclusion, the technical advance of EVs will replace diesel vehicles in the first place with respect to economic consideration. From this perspective, it is reasonable to foresee that the introduction of EVs will first threaten the market share of diesel vehicles rather than gasoline vehicles.

Raising the ratio between diesel tax and gasoline tax may increase diesel price relative to gasoline price. This effect can be represented in the diagram by that the grey line turns upward around its fixed cost point. The consequence of this change is that the range where diesel vehicles are favourable shrinks in the way that the point M1 moves right and the point M2 moves left. As a result, both ranges expand where EVs and gasoline vehicles are advantageous respectively. EVs and gasoline vehicles are therefore more competitive in the market. Increasing the tax rate on diesel has the effect to promote the market penetration for both EVs and gasoline vehicles.

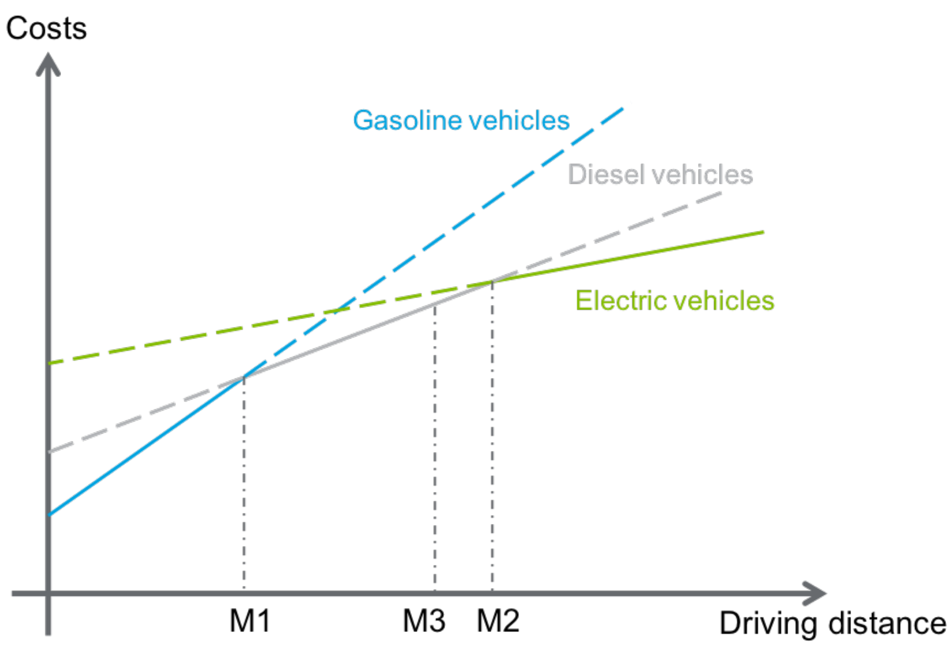


Figure 9 Substitution effect of EVs with ICE vehicles

The convenience of infrastructure for recharging would be a critical consideration for consumers. On one hand, it needs to increase the deployment of recharging points for the rising demands and to develop fast charging technology to shorten the charging time. In the study of ACEA, three main barriers are identified for the penetration of EVs: affordability, infrastructure availability, and lack of investment. The gap between the actual achievement and the social expectation in these three dimensions, together with the unbalanced distribution of EV charging points, could detrimentally impede EU from its CO_2 reduction targets (ACEA 2018). Besides, new business model, e.g. the "battery-car unbundling" scheme, would accelerate the uptake of EVs. On the other hand, people may need to shift their driving habit to get accustomed to EVs. Due to physical limit, recharging time of battery may never become as fast as gasoline or diesel refuelling. This may not be worrisome in at least daily commuting, as an overnight charging at home, which can cover around 200 km mileage under current battery technology, can cover urban commuting for a couple of days. EV transport range is still far from compatible with ICE cars (200km for EV vs. 500km for ICE). In this context, range anxiety, the fear that an EV will run out of power before reaching charge point, are broadly concerned among consumers. Existing evidences indicate that society and consumers have not yet prepared to embrace the era of EVs.

3.2 Shared mobility

Shared mobility has emerged to offer travellers a flexible and on-demand personal transportation without car ownership. With the development of ICT, consumers are now allowed to quickly make and respond to requests for mobility services. More importantly, technology has reduced transaction costs, making sharing mobility cheaper and easier than ever before. This is the underline basis for the popularity of shared mobility in recent years. Shared mobility is developing under different schemes that can be grouped into three main categories as proposed by OPEC (2017, 141): car sharing, carpooling and ride hailing. No matter in what the forms are they, the core idea highlighted by shared mobility is to improve the utility of passenger cars by either sharing the use of private owned cars or providing personal transportation by collectively managed car fleets.

The effects of this new mobility option on oil demand are currently not fully understood and could be complex. It is argued that shared mobility has the potential to reduce the number of vehicles. Innovative platforms on the Internet allow an unprecedented efficiency in view of managing a fleet of shared vehicles to provide the user with car availability close to conventional car ownership. Some people might avoid buying a car for personal use and instead opt for a shared mobility scheme. Study shows that a shared vehicle has the capacity to replace 4 -10 cars in Europe and 9 - 13 cars in North America (Shaheen and Cohen 2013). The difference may result from the strong public transportation in Europe compared with that in North America. However, some personal transportation activity, which may be dominant, has no elasticity to be supported by fewer cars. For example, it may not be efficient to provide daily commuting by a shared fleet. People who drive to work have a scheduled timeslot for transportation activity. They normally have highly diversified routes otherwise public transportation could be viable. This means an equivalent volume of shared vehicle fleet to the private owned fleet needs to be maintained to support this transportation activity. Commuting transportation is obvious the main part in urban transportation. Additionally, the privacy for the ownership of a private car is hard to be replaced by shared vehicle fleet. Therefore, the effect to reduce private vehicle numbers would be limited. The substitution from personal car use to shared mobility services would be more effective on a second or third car purchase.

On the other way around, shared mobility may spur the interest to own a private car. This group of people drive their own cars less often than the normal car owners since either public transportation or shared vehicle fleet can fulfil their necessary traveling demand. Their driving activity with private cars is only for the purpose of instant and leisure traveling. Therefore, transport range of these cars is shorter than the majority car fleet. As illustrated in *Figure 9*, smaller driving range is in favour of gasoline vehicles relative to diesel vehicles and EVs. It is preferable for these novel car owners to purchase gasoline vehicles. Consequently, the market share of gasoline passenger cars may rise due to this effect.

The shared use of car is a double-edged sword to the amount of passenger kilometres travelled. It could reduce the total miles driven as increasing carpooling and car sharing will predominantly substitute private vehicle use. The transportation offered by shared car fleet is expertly managed hence more activity can be made under optimal travel distance. Some studies estimate that car sharing reduces the total miles travelled between 6% and 16% per household (Martin and Shaheen 2016). However, it could also be argued that widespread use of shared mobility services may prompt additional miles travelled resulting from the substitution for public transportation and biking and walking trips among not only the adults but also juveniles and the olds who are not able to drive.

Shared vehicles tend to be utilised more as a result of higher travel demand services with a smaller car fleet. Faster vehicle replacement is required as these vehicles reach their usable lifetime earlier. This would prompt a more rapid turnover of the car fleet that could accelerate the penetration of new technologies. EVs become preferable for shared mobility in this context owing to its lower variable cost. Moreover, collective management on the fleet is more suitable to deal with the limitation of recharging time and the range anxiety that exist among current technology level.

Forecasts on the effects of shared mobility on energy consumption are generally positive but conservative as well. BP (2018, 38) estimates the human-drive shared mobility will gradually increase to 3% of the global vehicle kilometres from current 2% in 2030. It is believed that shared mobility will boom up in 2035 when autonomous will have matured. OPEC anticipated the possible implication of shared mobility on oil demand in China and OECD America by 2040 through the Mobility as a Service (MaaS) case where travellers need not to own vehicles themselves. Given that the increasing use of shared mobility schemes will limit growth in the passenger car fleet, vehicle fleet in OECD America and China are respectively 2.9% and 4.3% lower than in the Reference Case in which car sharing is moderately adopted (OPEC 2017, 143). The share of EVs (both PHEV and BEV) in both regions would increase with four percentage points due to the wider adaptation of shared mobility. In terms of driving mileage distribution, both regions follow the same trend that non-EV miles drops while EV miles rises (OPEC 2017, 144). China would be affected more profoundly where non-EV miles drops by 14% and EV miles are 38% more than in the Reference Case. Overall, as can be observed in *Figure 10*, oil demand in the passenger car segment would be reduced by 7% in OECD America and by 11% in China by the increasing adoption of shared mobility (OPEC 2017, 145-146). The effect in China is higher in relative terms because of the expected rapidly expanding car fleet that could foster a faster adoption of new technologies and services. Shared mobility in Europe was not investigated because, as argued by the OPEC, its market value only accounts for one-fourth of that in either China or the US, and because the higher regulatory pressure and the developed public transportation system in OECD Europe confine the potential for the penetration of mobility services.

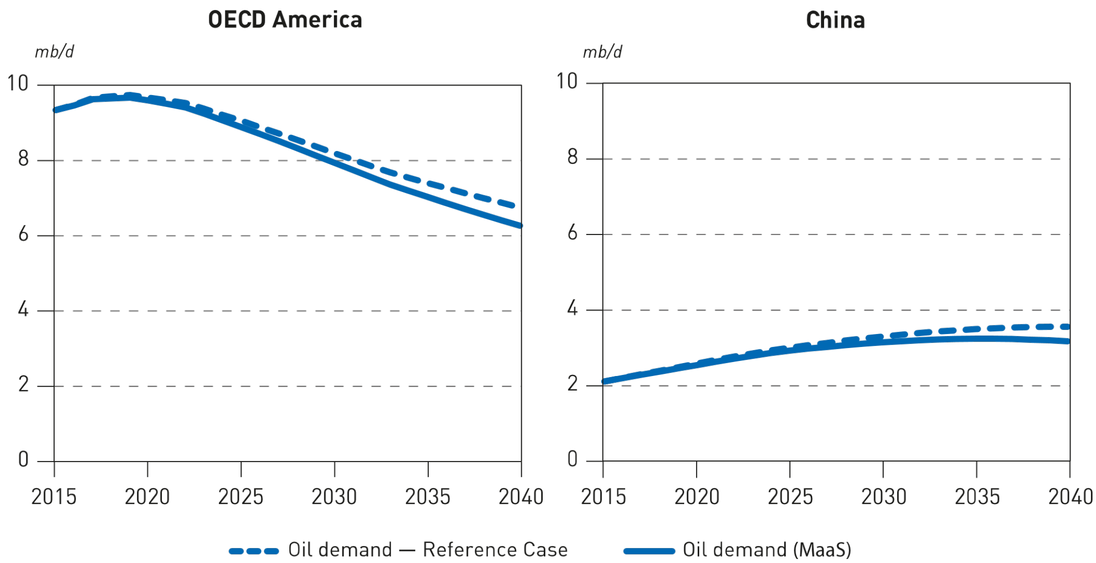


Figure 10 Oil demand in the passenger car segment in the Reference Case (dotted line) and in the MaaS case (solid line)

In conclusion, there are still many uncertainties remain for shared mobility in EU of either adoption or effect on oil demand. Therefore, a close monitoring of developments in these areas will be essential. Based on the analysis on current situation, shared mobility may improve the fuel efficiency of total vehicle fleet and at the same incur travel activity on passenger cars. As a result, a limited reduction of up to 3% on EU oil demand for passenger car transportation is anticipated for the 2030s. It is thus recommended to consider this factor in the forecast through longer term.

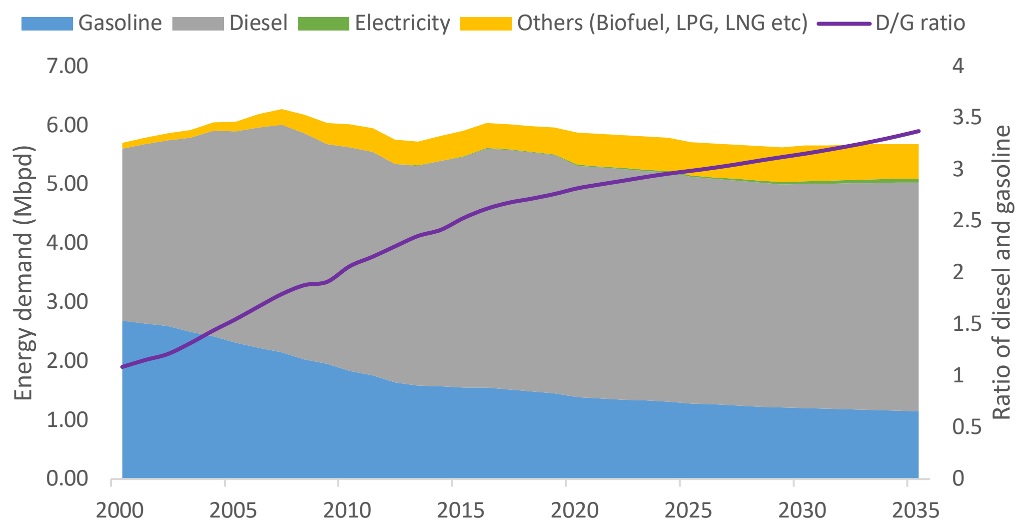
4. Forecast through 2035

This section will discuss the forecast through 2035 on fuel consumption of EU's road transport segment. The forecast will be based on EU reference scenario 2016 and Wood Mackenzie's demand outlook. EU reference scenario 2016 represents a general trend under the current EU policy as discussed in chapter one. Wood Mackenzie's outlook provides detailed information on the portfolio of energy type consumed in EU road transportation. By introducing the influential factors taken from the three main driving forces that have been discussed in previous chapters, the external forecast will be assessed. Furthermore, a new forecast will be derived with the consideration of those factors, including the implementation of relevant EU policy, the implication of OEM's strategy, and the substitution effect of EV penetration. Shared mobility has not been involved into the new forecast since, as estimated in section 3.2, its impact is still insignificant until 2035 for EU market.

4.1 The forecast from EU commission and Wood Mackenzie

EU reference scenario 2016 projected the energy supply and demand over the EU through 2050 under the condition where current policies remain in force. It provides a projection for road transport segment concerning a full range of relevant policies. Policies in *Table 1* are involved. As there will not have been any new regulation to be enacted until up to 2020, it is argued in this report this scenario represents an outlook from the policy perspective. Overall, the result suggests that current policies are neither sufficient to drive down energy consumption to the Union's 2050 objective in road transportation nor to significantly promote electrification (Capros, et al. 2016, 62). Improvement in energy efficiency, resulting from realizing the standards set by current regulations, is compensated by the enhance of transport activity due to economic growth. A stricter and more ambitious policy package is therefore recommended in the study. Unfortunately, the result does not reveal the detailed information of the demand for specific fuels such as gasoline and diesel.

Wood Mackenzie generated another outlook of energy supply and demand through 2050 for the Greater Europe[4]. The forecast provides detailed information about vehicle types and liquid fuel types specifically for road transportation. As estimated according to the reference scenario, the road fuel demand of EU28 account to 70% of Greater Europe, and the future trend of the total amount in both forecasts are consistent. It is therefore assumed in this study that EU follows a similar pattern of variation proposed by Wood Mackenzie over the prediction period. A forecast of road transport energy demand as well as the vehicle fleet portfolio over the EU is derived by combining the two outlooks, as illustrated in *Figure 11* and *Figure 12* respectively.



Source: Eurostat, Forecast: EU reference scenario 2016, Woood Mackenzie

Figure 11 An outlook on EU road fuel demand

[4] Including all European countries and the countries in North Africa around the Mediterranean

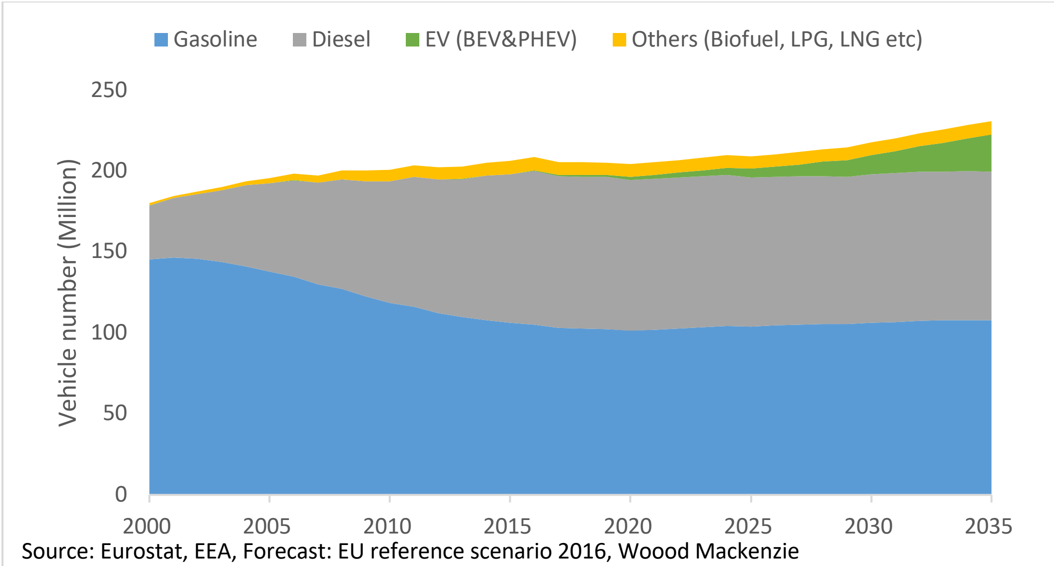


Figure 12 An outlook on EU vehicle fleet

It was estimated that total road transport fuel demand would drop in 2016 with a limited amount from 6.06 Mbpd then stabilise at 5.68 Mbpd in 2035. Road diesel demand was forecast to grow steadily over the next few years primarily due to rising commercial transport demand as the economy grows. The growth slows by 2020 as the rate of increase in the diesel passenger car stock slows and commercial freight movements stabilise while at the same time vehicle fuel efficiency continue to improve. The diesel car share of total sales has grown rapidly over the past 15 years, although the dieselisation process has now reached a plateau. It was expected that diesel's share of the new car market to continue to decline during the remainder of the forecast period. Gasoline demand has been falling steadily since 2000 as steered by the policy for dieselisation and the increasing efficiency of the vehicle fleet. Following on from a near term boost due to low oil prices, gasoline demand continues to decline longer term as a result of further improvements in fuel efficiency alongside a growing share of electric vehicles. As a result, the ratio of diesel demand and gasoline demand will keep on rising from 2.7 at present to 3.5 in 2035. The dieselisation process was forecast to continue. Electricity takes up trivial proportion in road energy consumption through 2035 despite the EV fleet are growing steadily and will boost from late 2020s onwards. Both the energy demand and the vehicle fleet of other alternative vehicles will stabilise at a limited portion of the total amount. This phenomenon can be due to either the limited capacity to substitute conventional technology as of LPG and LNG or the infant stage where the technology locates so far, such as the hydrogen fuel cell.

However, by examining the outcomes and the underlined indicators, the forecast is found arguable. As indicated by Eurostat record, total energy consumption of road transportation has been growing since 2013 and the trend maintains. There is no evidence for a disruptive event that can reverse this tendency. Diesel vehicles are facing stricter regulation from EU policy in both exhaust emission standard and tax burden on the fuel price. As introduced in chapter 1, it is a common problem of diesel vehicles that the on-road NOx emission deviates greatly from the standard even though the performance in test conforms with the standard well. Taxes is the main driving force on fuel prices in EU, so it is powerful to determine the demand. Taxes rate of diesel has risen after 2016 to approach that of gasoline apparently. Although the gross tax burden on diesel is still higher than on gasoline, the switch in the relative tax rate of diesel and gasoline should have some impacts on the consumption of both fuels. Regulatory pressure on diesel shows the resolution to cease the dieselisation process over the EU, which seems to be ignored by the forecast. In addition, market penetration of EVs may be underestimated as the exponential growth of the fleet has just occurred in the recent two years. Due to technological progress, the cost of EVs will soon become economically competitive against conventional vehicles as discussed before. Many OEMs have disclosed or renewed their future strategy since 2016 to involve EV into the principal objectives. The penetration of EVs would accelerate after that and the replacement of conventional vehicles with EVs is likely to happen. Based on the theory in chapter 3.1.2, it should be noted that EVs will substitute diesel vehicles rather than gasoline vehicles in a first place in terms of total cost for ownership and utility. A forecast should accord with the general growth trend of road fuel demand as the EU economy has recovered from the 2008 financial crisis. Moreover, diesel will be enduring heavier pressures from regulation and the market invasion of EVs than what the outlook expected.

Even so, this forecast provides a valuable implication that policy alone is insufficient either to curb the road fuel demand or to alter the structure of road fuel consumption. This may be rendered by the lack of alternative vehicle option that owns the potential to take over ICE vehicles.

4.2 An outlook on road fuel demand through 2015 made by MITI AOC

A new forecast is made from modifying the EU reference scenario 2016 and Wood Mackenzie outlook with stricter regulatory pressure on diesel fuel and the expansion of EVs backed by technological progress and automakers' strategy. It is suggested in the overview of EU policy and automakers' strategy that electricity is the alternative fuel of choice in most countries and vehicle manufacturers. EVs are forecast to replace ICE vehicles where diesel ones will be replaced with priority during EV penetrating the market. The consequence of other alternative fuel transportation other than electricity remains the same as the original outlook. *Figure 13* presents the result on fuel demand of the new outlook and *Figure 14* shows the forecast on vehicle fleet.

On regulation aspect, fuel taxes, emission restrictions as well as the infrastructure policy are considered. Emission standards on CO_2 confines the fuel efficiency of the vehicle fleet. The emission restriction on NOx that diesel vehicles cannot conform well adds extra cost to the car price since there needs to install some advanced equipment to curb the emission. Alongside the increasing taxes on diesel both relative to gasoline and in absolute value, the reference growth of diesel vehicle should be more conservative than that in the abovementioned forecast. On compliance with the EU directive of alternative fuel infrastructure, overall EU member states have confirmed their deployment objective for publicly accessible EV charging points in 2020 to guarantee that on average ten EVs are served by one public charging point as recommended by EU Commission (T&E 2018, 5). This is applied to estimate the ceiling for the growth of EV fleet.

The fixed cost of BEV is forecast to break through the competency threshold in 2023 as calculated in section 3.1.1 where an accumulative fleet volume is also derived. Subtracting the scrapped stocks from the accumulative amount, the active BEV fleet volume is estimated. PHEV is treated as the accompanied product of BEVs according to the automakers' strategy. Its volume is forecast to be proportional to the BEV volume. The share of PHEV in EV declines while the technology of BEV is maturing.

It is forecast that total road transport fuel demand will persist to grow and will peak in 2024, one year after the EV break-through, at 6.45 Mbpd. Total fuel demand will then decline steadily to 6.25 Mbpd, higher than any annual demand before 2018. This outcome is in line with the current rising trend of road fuel consumption due to economic recovery and the reverse occurs because of the decline in diesel demand. Road diesel demand is forecast to grow in the same sense as the original outlook until 2023 when EV costs break through. The decline occurs in 2023 due to the shrinking diesel vehicle stock as well as the improving fuel efficiency. Diesel vehicle fleet diminishes as the result of the scalable penetration of EVs that replace diesel sustained transportation alongside the heavier regulatory pressure on diesel taxes and NOx emission that enhance both the fixed and variable cost of diesel cars. Gasoline demand has stabilised since 2012 as the consequence of regulatory pressures to halt the dieselisation process and the increasing efficiency of its vehicle fleet. Gasoline vehicle fleet steadily grows by 2030 steered by the policy for terminating the dieselisation process. It finally holds stabile after 2030 attributing to an expanding share of electric vehicles. Overall, the ratio of diesel demand and gasoline demand will grow gradually from 2.7 at present and peak at 2.79 one year after the cost of EV breaking through the threshold. It will then drop to 2.71 during the remaining forecast period. Electricity will continue to be the least proportion in road energy consumption over the next decade despite the uptake of EV is accelerating and will boost from 2023 onwards. Additionally, through 2035, gasoline demand will maintain above 1.4 Mbpd and diesel demand will be no less than 3.9 Mbpd, which still dominate the road fuel market.

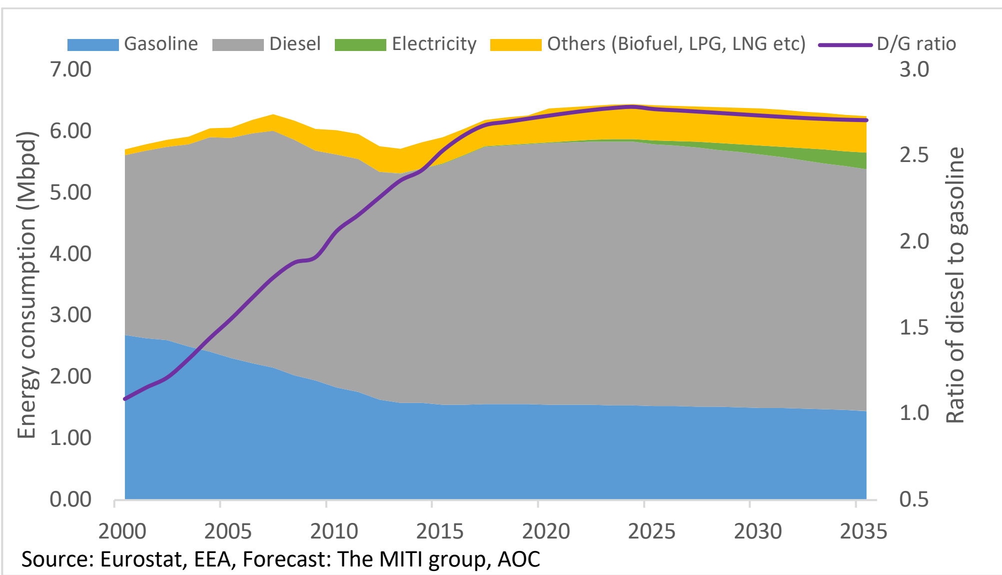


Figure 13 A new outlook on EU road fuel demand

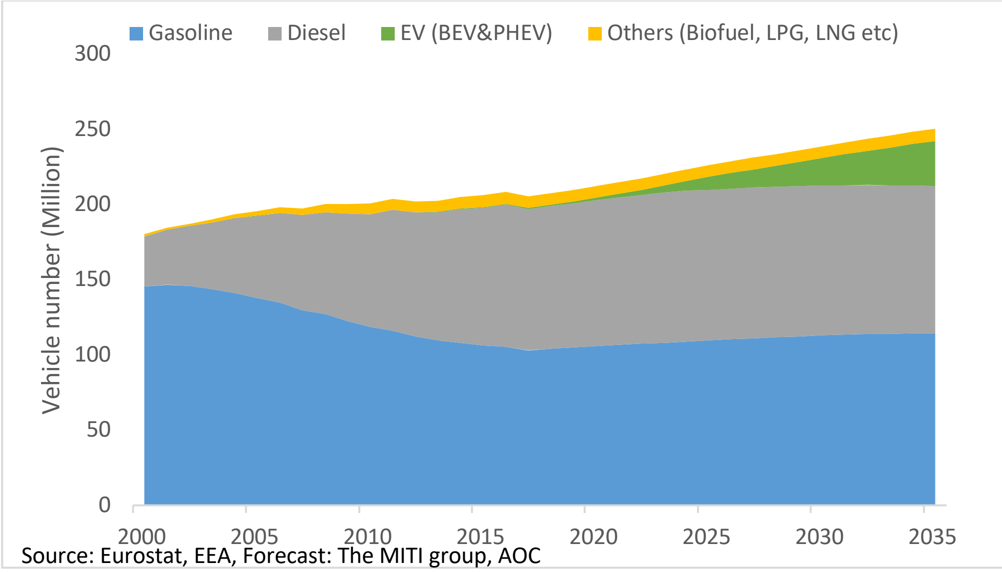


Figure 14 A new outlook on EU vehicle fleet

The new outlook indicates that EV, coordinating with policies, has a strong potential to reform the road fuel demand of EU. Significant effects may occur when the cost of EV becomes competitive against conventional ICE cars. EVs are in favour of ceasing the dieselisation process for which may replace diesel vehicles with priority in terms of economic concerns.

Conclusion

From the review on the EU policies, it is found that the EU is intensifying regulatory pressure on diesel consumption and promoting EVs as the principal option to substitute conventional ICE vehicles. Road diesel is encountering stricter regulation on its exhaust pollutant, especially on NOx emission. Additionally, taxes on diesel is growing faster than on gasoline, which reflects the resolution of EU member states to rebalance the demand for gasoline and diesel, i.e. to reduce the market share of diesel. On the other hand, the EU's policy is in favour of facilitating the uptake of AFVs, especially the EVs, into the EU vehicle market. Electricity has become the preferential alternative fuel in most EU countries. Vehicle manufacturers reply to the policy to promote EVs actively. Most European automakers have established their strategy for the next decade that contains developing EV relevant technology. Despite the emphasis on EV development varies over the manufacturers, those strategies as assembly cover the complete EV industry chain, involving the battery, charging technology, BEV and PHEV, spanning from passenger car to the HDV. In light of this, the EV was selected in this study as the main alternative mobility option for ICE vehicles for the forecast.

Based on the learning curve method, EVs are estimated to penetrate the vehicle market in the sense of economic competency in 2023. The penetration of EVs will substitute diesel vehicles first in term of economic concern. Apart from the cost of EVs, factors such as running range, charging time and the access to charging point still exist that hinder the expansion of EV market share.

With respect to the impact of regulatory pressure and the development of EVs, a trend of road fuel demand different from the outlook made by EU reference scenario 2016 and Wood Mackenzie was discovered in this study. Oil fuel demand will eventually scale down, but it may not happen at the moment. With respect to the ongoing recovery of EU economy, oil fuel demand would maintain its growth, which has initiated since 2013, for the next few years. The dieselization process would also continue gently but slow down mainly due to the pressure from regulations. On the other hand, a critical point may appear when the cost of EV gains economic competency against conventional ICE vehicles. It is forecast to happen in 2023 when the market breakthrough of EVs will happen. With EVs penetrating into the vehicle market, diesel vehicles will firstly be replaced to an extent where road diesel demand switches to decline. Additionally, a significant growth of EV fleet will also happen after that, although the growth is restricted by the definite deployment capacity of charging points. Despite the breakthrough year for EV cost, 2023, is not too optimistic among common expectations, the result that EVs begin to overturn the conventional fuel demand could be earlier than anticipated. Furthermore, the demand structure of fossil fuels would also change accordingly. The dieselization process will finally terminate after 2023 when EVs commercially penetrate into the market. Overall, diesel and gasoline in total will still account for 86% of road energy demand and the diesel share remains as high as it is today in 2035, but the disruptive change on them will have been initiated by EVs at that time.

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Appendix: Ancillary Data and Assumptions

Table A- 1 Data for learning curves

LR	Uncertainty	P0	Currency	C0 (MWh)	P_t	Currency	C_t (MWh)	Source
7,9%		600	$2014	604	150	$2014	71121450	Nykvist and Nilsson (2015)
9,0%	±1,1%	600	$2014	604	150	$2014	16067417	
10,1%		600	$2014	604	150	$2014	5017880	
12,0%		191	$2015	1000000	151	$2015	3575836	Schmidt, et al. (2017)
16,0%	±4%	154	$2015	1000000	151	$2015	1081349	
20,0%		124	$2015	1000000	151	$2015	542302	

Table A- 2 Annual cumulative sales of the top 10 popular BEVs in EU

Ranking	Make	Model	Battery size (kWh)	2017	2016	2015	2014	2013	2012	2011
1	Nissan	Leaf	30	84112	66652	48051	32705	18014	7120	1737
2	Renault	Zoe	41	90529	59846	38496	19930	8901	68	0
3	Volkswagen	e-Golf	24.2	33729	20827	14149	2979	48	48	0
4	BMW	i3	33	36705	22143	12673	6456	998	0	0
5	Tesla	Model S	100	58262	42701	30176	13525	3975	0	0
6	Smart	Fortwo ED	17.6	15783	10592	10269	8232	5287	1936	907
7	Hyundai	Ioniq Electric	28	7269	1143	0	0	0	0	0
8	Tesla	Model X	100	16393	3756	0	0	0	0	0
9	Kia	Soul EV	30.5	16450	10894	6410	598	0	0	0
10	Smart	Forfour ED	17.6	1480	0	0	0	0	0	0
Others	/	/	/	68430	55535	42490	30591	20681	16406	6859
Total	/	/	/	429142	294089	202714	115016	57904	25578	9503
Average battery capacity of the fleet (kWh)				43	42	41	38	34	26	25
Source: EAFO (http://www.eafo.eu/vehicle-statistics/m1)										

At current stage, increasing battery size can pull down the battery cost in manufacture (IEA 2018, 64). Therefore, it is reasonable to argue an increasing average battery size for the whole EV fleet. An annual growth rate of 7% is estimated through regression analysis on the historical record. This value is assumed in this study for the average battery size.