Factors affecting the CO$_2$ emissions performance of five EU car manufacturers

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Executive summary

Since 2010, the year that EEA started collecting data from all EU Member States, the officially reported CO₂ tailpipe emissions of new passenger cars, based on laboratory testing, have reduced substantially. The scope of this report is to estimate and assess the most important technologies and strategies contributing to the observed CO₂ reduction for selected car manufacturers based on new vehicles registered in the time period 2010 to 2018. These reductions can be attributed to both the overall improvement of vehicle energy efficiency as well as to a change in the mix of vehicle models sold in favour of more efficient powertrains/technologies. In particular, car manufacturers (OEMs) are using a broad spectrum of technologies to improve fuel efficiency for their vehicles in response to EU CO₂ targets. In summary, these technologies can be grouped in the following major categories:

- **Internal combustion engine (ICE) related technologies** (e.g. Downsizing/Turbocharging, Direct Injection)
- **Different degrees of hybridisation/electrification**
- **Transmission technologies**
- **Improved vehicle design and aerodynamics**

To this aim, five major car manufacturers were separately analysed, all in the top ranks in terms of new vehicle sales in the European market, taking into account aspects such as average yearly reported CO₂ trend, total new registrations in the EU area, and the promotion of low or zero carbon vehicles, e.g. plug-in hybrid vehicles (PHEV) or battery electric vehicles (BEV). Furthermore, the average trends regarding their car models with the highest number of registrations in the 2010-2018 time frame, as well as their respective SUV models, were separately analysed.

The primary driving force behind the achieved reductions in CO₂ are the improvements in conventional powertrains (incl. hybridisation) and the design of modern cars. Based on estimated results, all OEMs, followed the same general tactics and deployed similar concepts, during the examined time period (2010-2018). A notable example of this is the downsizing of petrol engines, via the use of turbochargers, which was deployed intensely by almost all OEMs, for petrol cars. However, there are also indications of diversification among OEM strategies, such as the promotion of hybridised instead of fully electrified powertrains. Another diversification example is the different unique technological packages and optimizations deployed in popular model variants aiming to further reduce CO₂ emissions.

Overall, the downward trend of average CO₂ emissions peaks around 2016 and is then gradually followed by a rising trend for most of the selected OEMs. Key factors that could have contributed to this shift are:

- **De-dieselisation effect (especially in the small passenger car category)**
- **Slow penetration of new HEV/PHEV/BEV**
- **Rising popularity of SUVs and the so-called Crossovers**

Such factors can decrease, to a certain extent, the environmental benefits (in terms of CO₂ emissions) achieved from efficiency improvement technologies and practices already deployed in cars in recent years.
1 Introduction

Transport in Europe is one of the major contributing sources of carbon emissions. Despite a temporary downward trend from 2007 until 2013 due to economic recession in Europe (EEA, 2019a), the demand for transport and hence emissions from 2013 onwards have been on the rise as shown in Figure 1.1 and are expected to continue growing. In 2017, 72% of total GHG emissions from transport (including international aviation and international shipping) derived from road transport activity. Of these, 44% were from passenger cars, 9% from light commercial vehicles and 19% came from heavy-duty vehicles (EEA, 2019a). In parallel, there is a continuous rise in annual sales of new passenger cars, which exhibit a noteworthy upsurge (of about 29%) from 2013 to 2018, based on official data on CO₂ emissions monitoring, as well as the exceedance of 15 million new car sales in 2017 and 2018 (Figure 1.2). Consequently, the automotive industry is a key sector in the effort to reduce GHG and to mitigate environmental consequences in the near future.

Figure 1.1: Total GHG emissions from the transport sector in the EU28

Figure 1.2: Total sales of new cars in the EU28
Overall, the officially reported CO₂ emissions of new passenger cars have reduced substantially since 2010, a year after that the EU introduced mandatory CO₂ standards for passenger cars. In fact, the automotive industry has already achieved since 2013 the target of 130 g CO₂/km set for 2015.

These reductions can be attributed to both the overall improvement of individual vehicle models energy efficiency as well as a change in the mix of vehicle models sold in favour of more efficient powertrains/technologies. In particular, car manufacturers use a broad spectrum of technologies to improve fuel efficiency for their vehicles in response to EU CO₂ targets. To this aim, this study discusses the most important parameters contributing to the observed CO₂ reductions for selected car manufacturers. These technologies can be grouped to the following general categories:

- **Engine technologies** (referring to pure ICE)
- **Different degrees of hybridisation/electrification** (e.g. stop-start)
- **Improved vehicle design and aerodynamics**
- **Transmission technologies**

Incorporating these technologies to a greater or lesser extent in new passenger cars has led to significant reductions in CO₂ emissions and the further development of these technologies (and/or the introduction of new technologies) will determine the future of CO₂ emissions from passenger cars.

That said, another noteworthy trend that has emerged in recent years in Europe is the increase in sales of Sport Utility Vehicles (SUVs). In Europe, SUVs (and the so-called crossovers) accounted for about one-third (34%) of all passenger car sales in 2018. The additional surge in demand meant that SUVs and crossovers grew to one-third of total European sales, up from 25.6 % percent in 2016, while in 2007 they held only 8% of the new passenger car market, according to JATO (JATO, 2019). This recent surge in SUV sales may be one of the key factors that contributed to the rise of new passenger car emissions by 2.0 g CO₂/km in 2018 as reported by latest data (EEA, 2019b).

## Methodology

The main objective of this study is to identify the most important parameters contributing to the observed CO₂ reductions from passenger cars, for selected major car manufacturers (Original Equipment Manufacturer – OEMs), since 2010.

As a first step, we provide an overview of the evolution of CO₂ emissions for each OEM and the main characteristics affecting the average CO₂ emissions from newly registered passenger cars, which include engine capacity, engine power and vehicle mass. By examining and analysing these trends for the period 2010-2018 we quantify the overall reduction in CO₂ emissions starting from 2010. Furthermore, the correlation between CO₂ emissions and vehicle characteristics, as averaged trends, is investigated in an effort to understand the direction that major OEMs are moving to. As a final step an estimated quantification of the key effects and technologies contributing in the reduction of average CO₂ emissions is made, largely based on publicly available data. This review is based on data officially submitted to the European Environment Agency (EEA) concerning the CO₂ performance of new passenger cars sold in the EU, in accordance with Regulation (EC) No 443/2009 (EU, 2009).

### 2.1 Selected OEMs

Five major car OEMs were selected for the analysis, all in the top ranks in terms of new vehicle sales in the European market. Other criteria taken into account for the selection include average yearly reported CO₂ emissions trends, market shares in HEV/PHEV/BEV, and use of innovative technologies. Overall, the aim was to select OEMs with diversified approaches regarding CO₂ reduction strategies. The selected OEMs are:
• **Volkswagen (VW):** Only the brand, not the group
• **Toyota:** combined data from the affiliated Manufacturer Names: ‘TOYOTA’, ‘TOYOTA MOTOR EUROPE’
• **BMW:** combined data from the affiliated Manufacturer Names: ‘BMW AG’, ‘BAYERISCHE MOTOREN WERKE AG’, ‘BMW GMBH’, ‘BMW M GMBH’
• **Ford:** combined data from the affiliated Manufacturer Names (Mh): ‘FORD WERKE GMBH’, ‘FORD-WERKE GMBH’, ‘FORD INDIA’, ‘FORD MOTOR COMPANY’
• **Renault**

Furthermore, for each of the above OEMs, the car model with the highest number of registrations in the 2010-2018 time frame, as well as their respective SUV models, were identified. This was done initially via desktop research, which provided more background details (e.g. the year of introduction of a new model variant) and then by selecting the appropriate models, separate data were collected for each model or group of SUV models via their ‘Commercial Name’ (Cn).

### 2.2 Key strategies and technologies

#### 2.2.1 Hybridisation/electrification

Electrified vehicles (xEVs) are gradually increasing their share in new passenger car sales nowadays, which are highly promoted in an effort to reduce emissions of CO\(_2\) and other pollutants such as NOx and PM. The term xEVs includes the following categories:

- HEV (Hybrid Electric Vehicles)
- PHEV (Plug-in Hybrid Electric Vehicles)
- BEV (Battery Electric Vehicles)
- FCEV (Fuel Cell Electric Vehicles).

Car OEMs have ambitious plans to roll out more and more electrified models in the near future, and there is a significant rise in xEVs (especially BEV and PHEV) over the last couple of years.

#### 2.2.2 Engine technologies

Key technologies commonly adopted by several OEMs over recent years include:

**Stop-start**

Stop-start functionality is one of Europe’s increasingly rising technologies. It is estimated that the market share of new vehicles with stop/start is about 75% in 2017 (ICCT, 2018). The basic concept of a stop-start system is that it automatically shuts down the engine when the vehicle is stopped to reduce fuel consumption and eliminate emissions during idle operation. Afterwards, it restarts the engine automatically when the driver releases the brake pedal or presses the clutch. This technology has the highest impact when waiting in traffic lights or frequently coming to a stop in traffic jams, hence it can reduce fuel consumption during urban driving. The range of the achieved reduction depends on the extent to which the technology is used and the specific driving conditions.

**Downsizing/Turbocharging**

One of the most important strategies to reduce CO\(_2\) was the replacement of large engines with smaller ones with high power density, the so-called *engine downsizing*. This method serves the purposes of both providing the needed power (Patil et al., 2017) and is also a cost-effective technique to increase fuel economy, which makes it attractive to the car OEMs (Leduc et al., 2003). The benefits that downsized engines can bring are:

- Reduction in fuel consumption through increasing the efficiency of powertrain, most importantly with measures like turbocharging and lower friction by the use of less cylinders. This results to a reduction in CO\(_2\) emissions.
• Reduction in engine block weight: In general, downsizing an engine is associated with a reduction to the number of cylinders. This helps to reduce the weight of the engine and thus reduces the engine load.

The increased performance in a downsized engine is achieved by adding a forced aspiration device (turbocharger or supercharger), without sacrificing engine performance (i.e. engine power).

**Direct Injection (DI)**
In a fuel injection system, the fuel is highly pressurised and injected directly into the combustion chamber of each cylinder, as opposed to conventional multi-point fuel injection that occurs at the intake port. The major advantages of a direct injection engine are increased fuel efficiency and better control of combustion.

Diesel vehicles have for long been using DI combustion. In recent years petrol (gasoline) vehicles are increasingly equipped with gasoline direct injection (GDI) engines.

**Variable valve timing (VVT) and lift (VVL)**
Variable valve actuation (VVA), also known as variable valve timing (VVT) and lift (VVL), is a generalized term used to describe any mechanism or method that can alter the shape or timing of a valve lift event within an internal combustion engine, improving its volumetric and thermodynamic efficiency (Posada and Facanha, 2015). It applies primarily to petrol cars and is often used to improve performance, fuel economy and emissions, however it is not that common in diesel cars (Triantafyllopoulos et al., 2017). As an example, *cam-phasing* is the simplest form of VVT, with more sophisticated systems also providing variable lift to further improve efficiency (Hill et al., 2012).

### 2.2.3 Transmission upgrade
Transmission technologies can contribute to fuel consumption reduction by enabling engine operation within a more efficient region of the engine map and by reducing the mechanical losses within the transmission system and its components. For the present analysis, the term transmission upgrade encompasses the following technological aspects:

**Increased number of gears**
In general, transmissions with more gears offer more opportunities to operate the engine more efficiently (EPA, 2019). Transmission systems in recent years have a higher number of gears and allow both for better engine operation and improved efficiency over older vehicles. This can lead to reduced fuel consumption and CO₂ emissions. In recent years, new cars are equipped with transmissions that incorporate at least 6 gears, compared to five gears 10 years ago.

**Continuously variable transmissions (CVT)**
CVT is a type of automatic transmission that can change seamlessly through a continuous range of effective gear ratios, unlike a typical manual transmission that provides only a few discrete gear ratios. CVT allows the engine to operate more frequently closer to its peak efficiency, providing more efficient average engine operation and a reduction in fuel usage. Today, CVTs are an emerging automotive transmission technology, increasingly used in passenger cars.

**Automatic transmissions, Dual-clutch Transmissions (DCT)**
Over recent years, a new generation of fully automatic transmissions have been developed with higher number of gears, lower friction materials, lightweight design, optimized cooling and computer-controlled gear change points. Today, automatic transmissions are increasingly used over manual transmissions, especially in larger cars.

Transmission systems have also developed from simple manual and automatic gearboxes, to include developments such as auto-shift manual and dual clutch systems (Varma et al., 2011). An automatic
manual transmission (AMT) is based on a manual, which has mechanical efficiency similar to a manual transmission but with automated gear shifts to optimize engine speed.

Dual clutch transmissions (DCTs) are essentially automatic transmissions that operate internally much more like traditional manual transmissions. The two main advantages of DCTs are that they can shift very quickly, and they can avoid some of the internal resistance of a traditional automatic transmission by eliminating the torque converter (EPA, 2019).

2.2.4 Other improvements

Other notable CO₂ reduction technologies or practices adopted by OEMs in modern cars include:

**Lightweight design**
Lightweight design of a passenger car has been an important topic across the automotive industry in the recent years. Carmakers are constantly trying to reduce the weight of their vehicles as this also means a reduction in fuel consumption and hence in CO₂ emissions. To give an insight into how much fuel consumption is affected by the weight of a passenger car, studies have shown that for an additional mass of 50-200 kg over various cycles and operating conditions, the increase in fuel consumption ranges from 5 to 9 % (Fontaras et al., 2017). The main materials commonly used in lightweight design are advanced high-strength steels, magnesium alloys, carbon fibre composites, aluminium, titanium, and composites (EERE, 2016). An optimized body design based on aluminium and its alloys can be up to 40% lighter over a traditional steel frame (Triantafyllopoulos et al., 2017).

**Improved aerodynamics and low rolling resistance tyres**
Aerodynamics refers to the shape and design of the car and its projected frontal area (Zacharof and Fontaras, 2016). Improvement to the vehicle’s overall aerodynamics can be achieved through improvements to its shape as well as using other options, such as smoother undercarriages, aerodynamic hub caps/wheels, etc (Hill et al., 2012).

Rolling resistance refers to the energy loss occurring in the tyre due to the deformation of the contact area and the damping properties of the rubber. Low rolling resistance tyres are designed to minimise rolling resistance whilst still maintaining the required levels of grip.

**Engine thermal management and friction reduction**
Engine thermal management includes a range of possible technical options, such as: charge motion systems (decreased combustion duration), fast warm-up, insulation (coolant). Friction reduction typically refers to the usage of low friction components for reducing friction in the engine and transmission (e.g. low-tension piston rings, low friction coatings, improved lubricants).

**Brake Energy Recuperation (BER)**
This system is used to recuperate part of the vehicle's kinetic energy is recuperated during deceleration (Triantafyllopoulos et al., 2017). Using a smart alternator this energy can be stored in a battery in order to provide electrical power to the car’s auxiliary systems. This reduces the need for energy to be collected directly from the engine operation, improving overall system efficiency.

2.3 Technology data

2.3.1 Market share/penetration of key CO₂ reducing strategies and technologies

In order to quantify the impact of key technologies or engineering practices on CO₂ emissions of new cars, one needs the penetration of each technology in the annual new registration fleet for each OEM.
In general, there is very limited public information available for such data, as only the OEMs can fully account for all CO₂ reducing technologies implemented on their new models and record their exact market share in their new car sales. Nevertheless, after extensive desktop research, data from ICCT publications were identified as the most reliable source and form the basis of the calculations of the present study. The market share/penetration data are shown in Figure 2.1 and Figure 2.2 below.

**Figure 2.1: Market share of vehicles with stop-start and GDI, by brand (ICCT, 2018)**

**Figure 2.2: Market share of new passenger car technology in EU (and US) (Wolfram et al., 2016)**

### 2.3.2 Effect on CO₂ reduction

The second step in order to quantify the effect of various technologies is to estimate the average CO₂ reduction potential of each technology over the NEDC. The NEDC is chosen because until 2018, the CO₂ reported data are based on this cycle.
Hence, key relevant studies were taken into account (Dimaratos et al., 2016; Ernst et al., 2013; FEV, 2015; Ricardo-AEA, 2015; TNO, 2012) that estimate CO$_2$ reduction effects of different technologies, in terms of the NEDC. For simplification reasons, the combination/aggregation of the above studies produced estimated values that were used in the present analysis, as summarized in Table 2.1.

<table>
<thead>
<tr>
<th>Estimated CO$_2$ emission reduction (NEDC-aggregated average)</th>
<th>min/max range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-stop functionality</td>
<td>5%</td>
</tr>
<tr>
<td>Transmission upgrade</td>
<td>3.7%</td>
</tr>
<tr>
<td>Gasoline Direct Injection (GDI)</td>
<td>4.8%</td>
</tr>
<tr>
<td>Improved aerodynamics &amp; tyre rolling resistance</td>
<td>2.4%</td>
</tr>
<tr>
<td>Variable Valve Timing - Lift (VVT/VVL)</td>
<td>3.7%</td>
</tr>
<tr>
<td>Downsizing &amp; Turbocharging</td>
<td>16.8%</td>
</tr>
</tbody>
</table>

Other studies, such as Triantafyllopoulos et al. (2017), estimate lower CO$_2$ benefit for start-stop technology, transmission-related upgrades and improved aerodynamics/tyre rolling resistance than the assumed values in Table 2.1 but generally fall within the overall min/max range provided. It is acknowledged that the above quantification depends also on other factors such as driving style or car size. It also may vary across OEMs, due to different technologies and engineering practices.

2.4 Calculations and assumptions

As presented in section 2.3.1, the technology market share data are not always split between fuel types (petrol/diesel). For example, the start-stop technology refers on the total new car registrations, hence it is not possible to distinguishing the quantified CO$_2$ reductions from start-stop, per fuel type. While there is information on certain key petrol engine improvements (direct injection, downsizing), this is not the case on diesel new registrations.

Due to the lack of data for certain years, assumptions were made for the purpose of the present analysis. Typically, this involved projections mainly based on linear regression (as a continuation of previous trends), as well as other relevant indications from available literature.

Furthermore, an effort was made to identify certain unique technological packages used by OEMs, to produce cleaner variants of selected car models, typically the most popular ones. Some examples of such practices, explored in the present analysis include:

- ‘Bluemotion’ by VW
- ‘Efficient dynamics’ by BMW
- ‘ECOnetic’ by Ford
- ‘ECO2’ by Renault

However, it should be mentioned that the exact market share of such variants in the annual new registrations is not reliably known, and was largely estimated, partly relying on the CO$_2$ monitoring database.

**Overall, it should be considered that the present analysis is based on estimations and expert judgement. Hence, the quantification of the different key effects on CO$_2$ reduction is not based on official OEM data, it is therefore subject to uncertainty.** Furthermore, it is expected that there are additional technological improvements implemented by selected OEMs but these cannot be analysed due to the lack of data.
3 OEMs’ strategies analysis

This section examines the major technologies and strategies implemented by the selected OEMs.

3.1 Volkswagen

3.1.1 Overall trends

Following the Dieselgate in 2015, in the EU there was a generalised decreasing tendency of the share of new diesel registrations, which also affected VW. Between the years 2010 and 2018:

- Diesel new registrations decreased by about 22%
- Petrol car market share increased by about 55%

Also, after 2015, VW increasingly sold more PHEV/BEV cars, while it did not roll out HEV passenger cars. In fact, BEV/PHEV registrations in 2017 reached 2.3% of total new registrations, while in 2014 their share was only 0.6%.

Figure 3.1: Share of new registrations (VW)

As illustrated in Figure 3.1, overall, a downsizing strategy was pursued by VW as the average engine capacity was reduced by 7% from 2010, whereas the engine power increased by 11% from 2011. This was primarily affected by the downsizing of petrol vehicles and their larger market share over the years.
Both petrol and diesel cars became heavier in recent years, as average mass increased by 1.8% in the 2013-2018 period. Hence, mass reduction was not a primary strategy for CO₂ reduction. Average mass increase seems to correlate with the average CO₂ emissions, especially during recent years, as both follow a similar (increasing) trend between 2016-2018. Hence, the increase in average mass (for both diesel and petrol) is one of the main reasons the average CO₂ emissions increased after 2016. The increased mass can be also attributed to the increasing popularity of SUVs which are typically heavier and larger than conventional sedans or hatchbacks.

As shown in Figure 3.3, after a steady decline from 2010 to 2016, the latter being the year that VW recorded the highest reduction (16%), average CO₂ emissions from new passenger cars followed an increasing trend in 2017 and 2018. Despite the steady rise of CO₂ emissions from VW diesel cars in recent years the overall emissions primarily correlates with the CO₂ emissions of petrol cars, especially after 2014, as their market share in new sales rapidly increases. In fact, in 2018, almost 58% of new
VW cars were petrol fuelled, while 39% were diesel ones. The same numbers in 2010 were 42% and 56%, respectively.

Although one would expect that the decline in diesel share would negatively affect the overall CO$_2$ emissions, this is not the case for VW. Based on data on the 2010-2018 period, on average, new VW diesel cars are 24.3% heavier and have increased engine capacity by 42.2%, compared to their petrol counterparts, resulting in higher average CO$_2$ emissions, as shown in Figure 3.3. Hence, the smaller diesel share of new sales has a positive effect on the average CO$_2$ emissions (implying registration of smaller vehicles).

### 3.1.2 CO$_2$ technology reduction effects

Figure 3.4 below illustrates the market share of certain mainstream CO$_2$ reduction technologies or strategies, incorporated on new VW cars on an annual basis. As mentioned in section 2.4, the penetration data shown is largely based on ICCT publications and additional estimations. The market share is presented in terms of conventional ICE vehicles (diesel and petrol) or petrol only vehicles.

![Figure 3.4: Penetration of key CO$_2$ reduction technologies/strategies (VW)](image)

There is a clear rise in most of the technologies or strategies shown from 2010, with start-stop standing out as the most rapidly evolving technology, as most VW conventional cars sold in the last couple of years come with start-stop functionality.

Concerning transmission upgrades, VW often utilizes a dual-clutch gearbox (DCT) for cars with automatic transmission. VW claims that DCT gearbox shifts faster and operates more fuel efficiently than the conventional automatic gearbox with hydraulic torque converter. In fact, in 2018, the DCT installation rate for the Golf is over 40%, 30% for the smaller Polo and about 60% for the Passat (Volkswagen, 2018a).

Bluemotion is a trademark for certain VW car model variants with improved fuel consumption characteristics. This includes start-stop, regenerative braking, improved aerodynamics, low-resistance tyres. In fact, the latest Bluemotion Golf variant includes a coasting engine off function, which claims to improve fuel consumption. This technology combined with a DCT, makes it possible for drivers’ coast...
with the engine off at speeds of up to 130km/h simply by lifting their foot from the accelerator, while brakes and steering systems remain active (Volkswagen, 2018b).

**Figure 3.5: CO₂ reduction effects (VW)**

In order to visualize the CO₂ average reductions since 2010, a no-improvement scenario was created, assuming the 2010 CO₂ emissions remain unchanged up until 2018. Evidently, the dominant factor in CO₂ reduction, in the case of VW, is the improvement of powertrain and overall efficiency of conventional vehicles (petrol, diesel). After 2014 the effect of xEVs becomes more noticeable, due to the steady increase in PHEV/BEV sales. This clearly indicates the strategic decision of VW to launch and promote electrified model variants, such as the e-Golf (BEV) and Golf GTE (PHEV), in 2015. VW also sold a limited number of vehicles running on non-conventional fuels (LPG, NG, E85), over the same time period, however the effect is minimal.

Based on CO₂ monitoring data, the greatest reduction in the average CO₂ emissions from VW cars, was achieved in year 2016, compared to the baseline year (2010). As mentioned in the previous section there is an increasing trend after 2016, however it is highly unlikely that this is attributed to the deterioration of engine performance or overall vehicle fuel efficiency. One can argue that OEMs have no real motivation to roll back already established/proven CO₂ reducing technologies and practices, used in their new cars. Hence, this is likely more related with consumer preferences, such as the increasing popularity of SUVs and larger luxury cars.
Figure 3.6: Estimated CO₂ reduction per technology/strategy in 2018 (VW)

- xEVs effect: 1.7%
- Alternative fuels effect (NG/LPG/E85): 0.2%
- Downsizing/Turbocharging (petrol): 3.1%
- Start-stop: 3.7%
- Transmission Upgrade: 1.8%
- Bluemotion: 0.8%
- Direct Injection (petrol): 1.8%
- Other improvements: 1.3%

Powertrain & vehicle efficiency improvements, 12.6%
Figure 3.6, shows a snapshot of the VW technologies that contributed the most in the reduction of the average CO₂ emissions. The share of each effect on the CO₂ reduction (in NEDC terms), is calculated largely based on available data but is subject to variations, as stipulated in Sections 2.3 and 2.4. That said, it is evident that start-stop and petrol engine fuel efficiency optimization have a predominant role in the CO₂ reduction of new VW cars. Start-stop has a high impact on the NEDC cycle and as VW traditionally relies heavily on installing turbocharged, downsized petrol engines with direct injection (Volkswagen calls this TSI – Turbo Stratified Injection).

Other technological improvements that VW implemented can be grouped in general categories. These include but are not limited to:

- Variable valve timing and lift (VVT/VVL)
- Engine thermal management or friction reduction (use of advanced materials)
- Diesel engine optimizations (TDI engines)
- Improved aerodynamics & tyre rolling resistance (apart from Bluemotion variants)
- Brake energy recuperation systems on mild hybrid cars (considered as conventional)

### 3.1.3 Most popular model: Golf

The most popular model of VW (in terms of annual sales) is as expected the VW Golf. In fact, it is the most popular car model in Europe, as it accounted for about 3% of all new vehicle sales in the EU in 2017 (ICCT, 2018).

An effort was made to analyse its characteristics and average trends through the years. This was done via distinguishing the Golf annual new registrations via their ‘commercial name’ (Cn), from the EEA database.

**Figure 3.7: Average CO₂ emissions of VW Golf model**

In all years, the average CO₂ emissions for the diesel variants of Golf are lower than petrol, indicating the improved fuel efficiency that diesel engines (in VW’s case TDI engines) offer. That said, after 2014, the emissions from diesel cars record a small increase (5.5%) while the petrol emissions stabilize. This can be mainly attributed to their increased engine power, as shown in Figure 3.8.

In November 2012 a new VW model was introduced, the Golf Mk 7, and until April 2013 new registrations included both the older version Golf Mk 6 and the new. The introduction of the new
model along with the PHEV (Golf GTE) and BEV (e-Golf) versions in 2015, both contributed in the overall reduction of the average CO₂ emissions.

**Figure 3.8: Vehicle characteristics of the VW Golf model**

![VW Golf: Vehicle characteristics](image)

Figure 3.8 clearly depicts the downsizing strategy of VW on the petrol variant of Golf and the development/optimization of smaller turbocharged engines (such as TSI). In 2018, the engine power was higher from the 2010 level by about 17%, while its engine capacity remained relatively steady in the examined period.

### 3.1.4 SUV analysis

This section separately examines the trends of VW’s SUV models. The models identified as SUV, include VW’s Tiguan, Touareg, T-Roc and T-Cross models. Similarly, to the European trend in recent years, VW’s SUV models have increased their market share significantly in the new registration fleet, surpassing the 20% mark in 2018.
As shown in Figure 3.9, the average CO₂ emissions of VW SUVs follow a downward trend, recording almost a 20% reduction since 2010. Nevertheless, in absolute numbers the CO₂ emissions remain higher than small and medium sized cars. This downward trend encompasses the technological advances in modern powertrains and vehicle design regarding fuel consumption. Especially in more recent years, can be partly attributed to the introduction of smaller (both in vehicles and engine size) and more aerodynamically efficient SUV. Examples of such models are the newer T-Roc and T-Cross models, compared to the bulkier Tuareg and Tiguan.

3.2 Toyota

3.2.1 Overall trends

Toyota seems to move away from conventional powertrains, especially diesel, and strategically promote more hybridised powertrains. As a matter of fact, Toyota has completely phased out diesel cars since the end of 2018, due to limited demand and widespread uptake of hybrid alternatives (Toyota, 2018).

More specifically, in the 2010-2018 time period:

- Diesel new registrations decreased by about 70% (only 4.6% of total new regs. in 2017)
- Petrol new registrations decreased by about 17% since 2010.
There was a significant boost in HEV registrations, which in 2018 reached approximately 56% of total new registrations, while there is a complete absence of BEV, up until now. It is also worth mentioning that Toyota is the only one from the selected OEMs that sold an FCEV model (Mirai model), in recent years, although in very limited numbers to make a meaningful impact.

As illustrated in Figure 3.11, overall, engine downsizing was not a prime strategy for Toyota as the average engine capacity of Toyota cars increased by 6% since 2010. In the meantime, average mass seems to correlate closely with the average engine power, especially during recent years.

Despite Toyota increasing the engine size of its vehicles, the overall reduction in average CO₂ emissions was about 20% in 2018, from the 2010 baseline. This can be largely attributed to the increase in HEV sales. This is evident in Figure 3.12, in 2018 despite the abrupt rise in CO₂ emissions of diesel cars, the overall emissions are significantly lower, mainly due to the fact that the diesel share is rather small and the presence of HEV registrations is more dominant in the new registrations fleet over the years.
3.2.2 CO₂ technology reduction effects

In the case of Toyota, certain key CO₂ technologies are not as dominant, as was the case of VW. As depicted in Figure 2.2, the percent of petrol cars with DI or turbocharged engines is minimal, at least up to 2014, this is assumed that this trend extends up until 2018.

Figure 3.13: Penetration of key CO₂ reduction technologies/strategies (Toyota)

Toyota implemented improved/optimized transmission technologies which includes 6-speed transmissions as standard equipment, automated manual transmission (MultiMode) and CVT (MultiDrive S), optimized for quietness and fuel economy (Toyota, 2012).
Variable Valve Timing (VVT) is a fundamental technology of Toyota’s engines (e.g. VVT-i, Valvematic), however it is used since the late 1990s (Toyota, 1995), and is also confirmed by Figure 2.2 in the US market. Hence the impact on CO₂ reduction existed before well before 2010, thus not analysed.

The penetration of start-stop technology, shown in Figure 3.13, refers only to pure ICE vehicles (petrol/diesel), therefore it appears relatively low. However, overall, Toyota has a high penetration of start-stop, mainly due to the significant rise of HEV registrations (over 50% of total new registrations in 2017), as start-stop systems are typically a standard feature for such vehicles. Hence, the effect for HEV is already incorporated in the ‘xEVs effect’.

Toyota is planning to introduce a range of BEV models worldwide by the early 2020s, starting from China, before gradually entering other markets such as India, United States and finally Europe (Toyota, 2019).

*Figure 3.14: CO₂ reduction effects (Toyota)*

![Toyota: CO₂ reduction effects](image)

Toyota’s prime strategy for CO₂ reduction (11% for 2018 compared to 2010 level) is the full hybridisation of petrol engines. The whole range of the hybridisation technologies are trademarked under the Hybrid Synergy Drive (HSD) label, aiming to make cars more fuel-efficient (Toyota, 2015). Toyota invested in hybridisation early on, by launching the popular Prius model. That said, it supplemented its strategy by the improvement of conventional powertrain and engine efficiency, such as upgrading transmissions systems in all available models.
Figure 3.15: Estimated CO₂ reduction per technology/strategy in 2018 (Toyota)

The other improvements portion, depicted in Figure 3.15, can be categorised in larger groups. These include but are not limited to:

- Improved engine thermal efficiency (thermal management) and optimized combustion: e.g. higher compression ratio, rapid combustion (Toyota, 2014).
- Friction and pumping loss reduction: e.g. modified piston surface, lower friction bearings, low-viscosity oil, enhanced Exhaust Gas Recirculation (EGR).
- Further optimization of VVT technology (e.g. electronic VVT).
- Enhanced diesel direct injection: new generation piezoelectric injectors control the fuel volume and the timing of the injection more accurately.
- Improved aerodynamics and vehicle design.

3.2.3 Most popular model: Yaris

The most popular model of Toyota in the European market is the Yaris. Following a similar methodology as the VW Golf, a short analysis of its characteristics and trends is presented below. In line with Toyota’s overall strategy, Yaris has a HEV variant (petrol fuelled), which was launched in 2012, and is becoming increasingly popular, as seen in below. Also, in 2011, Toyota introduced the 3rd generation Yaris, which is produced until today, with various improvements and updated features.
The diesel share in new Yaris registrations is gradually decreasing since 2010. More precisely, in 2018 the split of new Yaris registrations was as follows:

- 42% petrol
- 56% hybrid-petrol
- 2% diesel

Hence, the average CO₂ emissions are clearly affected primarily by petrol and petrol-HEV registrations. The HEV effect is clearly beneficial in terms of CO₂ emissions; from 2011 (the year before the hybrid Yaris was introduced) the average CO₂ emissions decreased by 20% per 2018 data.
Since there is one type of hybrid variant of Yaris, the average characteristics remain the same over the years. However, concerning the conventional (pure ICE) variants of Yaris (petrol ones being the strong majority), after 2016, conventional Yaris engines seem to become larger and more powerful. This is a prime example of Toyota not implementing downsizing on its petrol car models.

In terms of mass, the conventional Yaris has become lighter on average, recording almost a 3% reduction in 2018 compared to 2010 levels. Also, the effect of larger batteries and hybridisation technology systems, in terms on mass is evident as the mass of the hybrid Yaris is higher than the conventional versions.

### 3.2.4 SUV analysis

In Toyota’s case the models identified as SUV, include the RAV-4, Landcruiser, and C-HR models. The analysis also includes the Lexus SUV models such as the Lexus UX, NX, and RX series, as Lexus is the luxury vehicle division of Toyota. As evident in Figure 3.18, there was a significant boost in hybrid SUV sales, especially after 2013.

Toyota’s strategy in SUV has some diversification from the other selected OEMs, as early on (before 2010) it introduced hybrid variants for its SUV models. In fact, the share of new hybrid SUV in the total SUV new registrations fleet (Toyota and Lexus combined) in 2011 was about 11% while in 2018 it climbed to over 80%. Hence, this clearly affects the average CO$_2$ EF, especially during recent years.

Overall, the average EF of Toyota/Lexus SUV, including both conventional and hybrid, follows a downward trend, and is reduced by 35% in 2018, compared to 2010 levels. In the case of Toyota, this contributes directly in negating the tendency of SUV to emit, on average, more CO$_2$ than sedans or hatchbacks, due to higher mass, large frontal areas and higher aerodynamic drag coefficients.

**Figure 3.18: Average CO$_2$ emissions of Toyota SUV models**
Figure 3.19: Vehicle characteristics of Toyota SUV models

The mass of conventional SUV doesn’t appear to have significant fluctuations and is not a primary factor for the CO₂ reduction over the years. However, hybrid SUV have become 28% lighter since 2010, (in 2018). This can be attributed to the gradual change in the SUV genre, which from heavier and bulkier designs with higher powered engines, has today moved on to smaller chassis and downsized ICE as both average engine capacity and power is significantly reduced. Also, another potential effect on weight reduction is the development and further optimisation of battery and hybridisation components.

3.3 BMW

3.3.1 Overall trends

In 2013, diesel share of new BMW sold cars reached its peak (approximately 74%), representing a time were diesel cars were very popular in the EU market. After 2015, BMW also follows the general de-dieselisation trend, but not as aggressively as other OEMs (e.g. Toyota). In parallel there was a promotion of PHEV/BEV cars. In summary, between 2015-2018:

- Diesel new registrations decreased by about 24%
- Petrol new registrations increased by about 71%.
- The xEV (mainly PHEV/BEV) share in 2018, was above 6%, while in 2015 it was only 1.4%. In fact, xEV new registrations almost quadrupled since 2015.
While new petrol cars increased their market share significantly, reaching almost the same level as diesel, BMW records one of the highest shares of new diesel cars among major OEMs. As a notable example, in 2018, VW had a market share of diesel vehicles of approximately 39% while BMW’s diesel share was almost 10 percentage units higher (48%), in terms of total annual new registrations.

Compared to the other OEMs selected, BMW has the highest average mass, engine capacity and engine power by a large margin. This is expected as BMW historically produces larger, more luxurious, and high-performance cars (e.g. X and M series) rather than small, moderately priced cars. For example, the smallest available BMW model, the Series 1 hatchback, can be considered as a C-segment vehicle (not a supermini). As a result, this directly affects the average CO\textsubscript{2} emissions, which are highest for all years between the five selected OEMs, during 2010-2018 time period.

That said, as evident from Figure 3.21, engine downsizing was a strategy promoted by BMW, primarily on petrol cars, as the average engine capacity was reduced by 8% during 2010-2018, while average
engine power was increased by 3%. The average mass, also follows an increasing trend, recording a rise of almost 3% compared to 2010 level.

Concerning the average CO₂ emissions, they decreased significantly (almost 15%) from 2010 to 2017. For the larger part, this can be directly attributed to powertrain efficiency and vehicle design improvements, most notably smaller, turbocharged, more efficient engines (downsizing). This will be further analysed in the following section.

Figure 3.22: Average CO₂ emissions (BMW)

The overall CO₂ emissions are clearly more influenced by the emissions of diesel cars, because as mentioned above the diesel share is significantly higher than petrol, through the years 2010-2017. In recent years (2017, 2018) the increase of PHEV and BEV registrations positively affect the average CO₂ emissions.

That said, in 2018 there was an abrupt surge in the average CO₂ emissions, by almost 5%, compared to 2017. The possible explanations of this increase are the following:

- Increase of average mass, 3% for diesel cars, about 2% for petrol cars, compared to 2017
- Increase of average engine capacity of diesel cars, 1.5% more than 2017
- The high share of new diesel cars in 2018 (close to 50%)
- The surge in new SUV sales (will be analysed in more detail later on)

3.3.2 CO₂ technology reduction effects

In the case of BMW, certain key CO₂ technologies are not as dominant, as was the case of VW. As depicted in Figure 2.2, the percent of petrol cars with DI or turbocharged engines is minimal, at least up to 2014, this is assumed that this trend extends up until 2018. The market share is presented in terms of conventional ICE vehicles (diesel and petrol) or petrol only vehicles.
Since 2010, BMW has already a high penetration rate for certain technologies such as direct injection and start-stop.

The most notable increase from 2010, is the usage of turbochargers in petrol engines, considering that turbocharged petrol engines are typically downsized. Although BMW in relied more on naturally aspirated engines for its cars, this is a clear indication of the downsizing strategy promoted over recent years.

Regarding transmission system upgrades, in the case of BMW this involves mainly the use of automatized transmissions. This is supported by the fact that BMW has already implemented higher number of gears (6+) and CVT gearboxes in almost all of its new cars, even before 2010, as evident from ICCT publications (shown in Figure 2.2), and it was assumed that this trend continued until 2018. Hence, the reduction effect on CO₂ emissions of transmission technological upgrades, was considered lower.

Additionally, based on the same ICCT data (Figure 2.2), it seems that BMW has installed VVT/L technology in all of its new cars even before 2010, in the US market. It was assumed that the same applies to the EU market up until 2018. Hence, such a technology was considered for the present analysis. Examples of such technologies used in BMW cars, is the VANOS, which is a VVT system and the Valvetronic, which is VVL system.

Efficient Dynamics refers to the strategy developed by BMW to minimise fuel consumption and CO₂ emissions while simultaneously increasing dynamics and driving pleasure. It is a comprehensive technology package that encompasses the engine and vehicle design. More precisely it includes the following technologies (BMW, 2019):

- Automatic start-stop functionality
- Coasting function (see section 3.1.2)
- BES
- Electric power steering
Compared to the 2010 baseline, most important parameter of the CO\textsubscript{2} reduction is attributed to the improved efficiency of powertrains and enhanced vehicle design. Similarly to VW, the effect of xEVs (in BMW’s case only PHEV/BEV) in reducing the average CO\textsubscript{2} emissions, becomes more significant after 2015.

Only for the BMW case, the analysis of the CO\textsubscript{2} reduction per strategy (Figure 3.25), was done for 2017, instead of 2018. This is because of the abrupt rise of the CO\textsubscript{2} emissions in 2018 (compared to 2017), by almost 5%, which would eliminate some the benefits achieved by the examined strategies and technologies until 2017.

The rise of the CO\textsubscript{2} emissions is primarily related to market factors, such as the rising popularity of SUVs or average mass, and not because an OEM would suddenly decide to discontinue certain CO\textsubscript{2} reducing technological achievements.

As already mentioned, petrol engine downsizing was the most impactful strategy utilized by BMW to reduce CO\textsubscript{2} emissions over the years. After that, two important parameters are the start-stop functionality and the boost in new PHEV/BEV sales. More precisely, BMW launched the largely popular i3 BEV model, quite early, in 2013.
3.3.3 Most popular model: Series 3

The most popular model of BMW in the European market is the Series 3. The methodology followed was the same as the previous OEMs. For the present analysis the data on ‘M’ version of Series 3 were not included, as it represents essentially a sports car rather than a normal passenger car.

As shown in Figure 3.26 below, the Series 3 average CO₂ emissions follow the same trend as the overall BMW new registrations. Also, in 2012, the new Series 3 model was introduced.

Figure 3.25: Estimated CO₂ reduction per technology/strategy in 2017 (BMW)
In all years, the average CO₂ emissions for the diesel variants of Series 3 is lower than petrol, indicating the improved fuel efficiency that diesel engines offer. That said, in 2018, the overall emissions rise, especially for new diesel cars the increase is over 7%. This can be attributed to their increased engine power, as shown in Figure 3.27.

The engines of petrol fuelled Series 3 have become smaller since 2010. More importantly, after 2014, the average engine power rises, the average engine capacity remains relatively constant. This clearly indicates a certain extent of downsizing of the Series 3 petrol model.
3.3.4 SUV analysis

In BMW’s case the models identified as SUV (or crossovers), include the Series X models (X1, X2, X3, X4, X5, X6). BMW often brands certain X models as Sport Activity Vehicles (SAV) rather than SUV (e.g. the X5), to highlight its on-road ability despite their size. Typically, BMW’s X line represent a more executive and luxurious set of vehicles, with emphasis on performance. The share of diesel in the annual SUV (Series X) registrations of BMW is significantly higher compared to petrol, until recent years.

Figure 3.28: BMW SUV registrations share

As evident in Figure 3.29, there was a significant boost (63% increase) in annual SUV registrations between 2015-2018, in the EU area. A reason contributing to this was the introduction of more models in the BMW X-series. Adding to the existing X1, X3, X5, X6 models, the X2 (2018) and X4 (2014) models where added to the X line-up. This acts as a reaction to cope with the rising demand in more SUV options and versatility by European consumers.

Figure 3.29: Average CO\(_2\) emissions of BMW SUV models
The CO$_2$ EF (Figure 3.29) is understandably more affected by diesel registrations than petrol, due to their increased market share described above. In absolute terms, compared for example to VW’s SUV, the average CO$_2$ emissions are higher, which is supported by the fact that BMW SUVs are on average heavier.

Overall, there is a clear decreasing trend in the CO$_2$ emissions over the years and in 2017 the average value was reduced by about 22% since the 2010 baseline. The reduction was more severe in new petrol SUV (about 35%). However, even in 2018, where petrol and diesel CO$_2$ emissions are almost aligned, the average combined value (140.7 gr/km) is significantly higher than the overall EF of all new BMW cars in 2018 (127.3 gr/km), or the Series X (131.3 gr/km).

**Figure 3.30: Vehicle characteristics of BMW SUV models**

Excluding 2015, new petrol SUV of BMW are becoming lighter, in fact in the 2010-2018 period their average mass was reduced by almost 8%. The same applies for their engine capacity, which was reduced by almost 30% since 2010. This indicates the emergence of smaller (and lighter) petrol SUV, such as the X1 and X2 models, with turbocharged engines.

In 2015, there is an abrupt surge in average mass, engine capacity and engine power. This can be possibly attributed to consumer choices and available model variants sold at the time, in the EU. Also, a completely new X-line model (X4) was introduced in 2014.

### 3.4 Ford

#### 3.4.1 Overall trends

Ford registrations area are also characterized by a de-dieselisation effect, and in 2013, the market share of new petrol cars surpassed diesel registrations. Up until 2018, the market share was stabilized in an almost even split. In summary, between 2010-2018:
• Diesel new registrations decreased by about 38%
• Petrol new registrations increased by 32%.
• xEVs registrations were very low even in 2018 (0.2% of total registrations), which was mostly HEV.

*Figure 3.31: Share of new registrations (Ford)*

Out of the selected OEMs, Ford records the lowest PHEV/BEV registrations (shown in Figure 3.33), by a large margin. Hence, in the European market, Ford arguably got off to a late start on the road to electrification powertrains.

As illustrated in Figure 3.32, Ford relied heavily on the downsizing of the engine, without sacrificing performance, especially for petrol cars. In fact, the average engine capacity decreased by 17% between 2010-2018, while average engine power increased by 28% compared to 2011 levels.

*Figure 3.32: Overall average trends (Ford)*
Hence, this downsizing effect largely contributed to the reduction of the average CO$_2$ emissions, up until 2015 (by 16% compared to 2010 data). After 2015, there seems to be a close correlation between the CO$_2$ emissions and the average mass. While the average CO$_2$ increased by 3.6% between 2015-2018, the average mass also increased by 5.7% during the same period. The increase in average mass can be directly linked to the significant rise of SUV registrations.

**Figure 3.33: Average CO$_2$ EF (Ford)**

![Average CO$_2$ emissions](image)

The distinct trends of average CO$_2$ emissions of diesel and petrol cars are closely intertwined, and until 2015 both are decreasing. However, during 2015-2018, diesel cars become heavier (+8%), on average, thus the diesel emissions follows an increasing trend, before eventually aligning with petrol (in 2018).

3.4.2 CO$_2$ technology reduction effects

In the case of Ford, Figure 3.34 below illustrates the market share of certain mainstream CO$_2$ reduction technologies or strategies, incorporated on new Ford cars. The market share is presented in terms of conventional ICE vehicles (diesel and petrol) or petrol only vehicles.

Based on ICCT data, (Figure 2.2), Variable Valve Timing (VVT) techniques were adopted by Ford for most of its models since 2010, in the US market. In fact, in 2012 all Ford new cars came with VVT technology. Assuming that this is also the case in the EU market, the impact on CO$_2$ reduction can be considered less critical after 2010, thus most benefit in CO$_2$ is already achieved early on, hence is not presented in the analysis.
Apart from Toyota (start-stop effect is mostly present in the HEV effect), in Ford’s case, the start-stop technology seems to have the lower penetration (in terms of conventional cars) in recent years compared to the other OEMs analysed in recent years, as an example in 2017:

- VW: 89% (of conventional cars)
- BMW: 95% (of conventional cars)
- Renault: 82% (of conventional cars)
- **Ford: 57% (of conventional cars)**

‘ECOnetic’ is a special label for certain diesel models variants produced by Ford (in Europe). This technological package aims to reduce CO₂ emissions, typically via:

- Stop-start and regenerative braking
- Improved aerodynamics: redesigned frontal area (e.g. smaller grill), lowered suspension, rear spoiler
- Lower resistance tyres: thinner tyre with lower rolling resistance
- Friction reduction: Engine's bearings are replaced with lower-resistance versions, use of low-friction transmission oil

The peak in CO₂ reduction occurred in 2015, recording a total reduction of about 13% compared to the 2010 value. In 2018, the CO₂ EF is increased by almost 4% compared to 2015 levels, however this more related to consumer behaviour trends, such as the increasing popularity of SUV and crossovers or, possibly, the addition of on-board components for added comfort/entertainment. This is backed by the increase in average mass, as depicted in Figure 3.32.
In the case of Ford, one noteworthy difference in the CO₂ reducing effects, is the non-existent effect of xEVs, due to the very small market share. Hence, this means that Ford relied solely on improving the fuel efficiency of ICE and the whole powertrain (incl. transmission systems), as well as the aerodynamic design of vehicles. Also, this indicates that the increase in total average mass is not influenced by the introduction of typically heavy PHEV/BEV models.

The most common practice, in the case of Ford, is the downsizing petrol engines. This is trademarked under the ‘EcoBoost’ commercial name. EcoBoost (petrol) engines are not only turbocharged but they also incorporate DI technology (GDI), designed to produce power and torque equivalent with those of larger-displacement (cylinder volume) engines, aiming to achieve better fuel efficiency. In essence, these engines are smaller and lighter but retain the desired performance. EcoBoost engines are broadly available in most of Ford’s cars (Ford, 2019). Hence, largely due to the launch of EcoBoost engine technology, the biggest impact (6.4%) in the CO₂ reduction for Ford cars is the downsizing of DI petrol engines (Figure 3.36).

From early 2018 on, Ford (Ford, 2016) announced that the 1.0L EcoBoost petrol engine variant will have cylinder deactivation capabilities, automatically stopping one of the engine’s cylinders when full capacity is not needed, such as when coasting or cruising with light demand on the engine. As an example of other improvements, Ford focused on developing more lightweight vehicle designs with the use of advanced/composite materials, as part of their research activities (Ford, 2014).
3.4.3 Most popular model: Fiesta

The most popular model of Ford in the European market is the Fiesta model. It is one of the top-selling car models in the EU-28 (fourth after the VW Golf, Polo and Renault Clio), as it accounted for about 1.7% of all new passenger car sales in the EU in 2017 (ICCT, 2018).

In 2013 the first Fiesta models with Ecoboost engines were sold in the EU, while an ECOnetic diesel variant of Fiesta was also available since 2010. Ford introduced the next generation of Fiesta (7th generation) in 2017, that became available with Ecoboost engines across the board.

A direct result of the EcoBoost engine introduction for the Fiesta in 2013, as illustrated in Figure 3.37 and Figure 3.38, was that both CO₂ emissions and engine capacity (for petrol) were significantly reduced, while a noteworthy increase in engine power was achieved. The decreasing trend of engine capacity continued but not as aggressively, while engine power continued to rise, achieving a 25% increase in 2018 (compared to 2011). In the same time, the CO₂ emissions for the petrol model stabilized, before decreasing, probably due to the introduction of the new generation of Fiesta, despite the abrupt rise in average mass of the petrol variant (+7% since 2016), indicating the increased size of the new model. For the diesel model, the acute rise of average mass, between 2017-2018, potentially lead to the rise of CO₂ emissions, in the same period.
3.4.4 SUV analysis

The Ford models identified as SUV (or crossovers), include the EcoSport, Edge, Kuga, and Escape. Ford also follows the increasing trend of SUV in recent years. Between, 2015-2018, annual SUV sales surged, increasing by about 85%, in the EU.

In the case of Ford, the average share of diesel SUV during 2010-2017, is around 70%. Hence, the overall average CO₂ emissions gravitate more towards the diesel average emissions. However, in 2018, there is a notable change, as the diesel share drops to around 45%, balancing the overall average CO₂ emissions in a somewhat evenly split between petrol and diesel.
In 2015, following a downward trend, average CO₂ emissions from Ford SUV hit their lowest mark, decreasing by 15% since 2010. An important factor that contributed to this decrease was the fact that the engines of diesel SUV (which represent the majority of annual sales) became smaller in terms of capacity (-2.5%) and power (-7.7%), hence emitting less CO₂.

Focusing on the petrol SUVs, average engine power was considerably reduced from 147 kW in 2011, to 100 kW in 2018 (32% decrease) while engine capacity followed a more smoother decreasing trend.

What is notable is that in the same time frame average mass of petrol SUV is increasing considerably, up by 30% in 2018, compared to 2010 levels. This strongly indicates that the SUV became heavier not because of larger and more powerful engines, but due to other parameters not related to the engine, such as body design, larger chassis, exhaust aftertreatment components, added electronics or comfort-related components (infotainment, navigation systems, etc).
3.5 Renault

3.5.1 Overall trends

In 2012, the diesel share of new Renault sold cars peaked (about 63%), reflecting a period when diesel vehicles were popular on the European market. Since 2015, Renault is also affected by general trend of de-dieselisation, which becomes more apparent in recent years (after 2016). In parallel, Renault focused on promoting the sale of BEV vehicles, while no PHEV were sold. In summary, for the 2015-2018 period:

- The number of new diesel passenger vehicles declined by around 3%.
- Petrol new registrations grew by around 62% percent.
- The share of new xEVs (only BEV in Renault’s case) was almost 3% in 2018, while it was just 1.2% in 2015. Since 2015, BEV new registrations have more than doubled (up by 116%). Renault records the highest number of cumulative BEV registrations than all other selected OEMs, over the 2010-2018 time period.

Figure 3.41: Share of new registrations (BMW)

Although new petrol cars significantly increased their market share, surpassing diesel cars in 2018, Renault still records one of the highest shares of new diesel cars, from the selected OEMs. As a notable case, VW had nearly 39% market share of diesel vehicles in 2018, while the diesel share of Renault was nearly 7% higher (45% in total) in terms of total annual new registrations.

As shown in Figure 3.42, overall, a downsizing strategy was deployed by Renault as the average engine capacity was reduced by 12% from 2010, while the engine power increased by 5% from 2011. The downsizing affected both diesel and petrol vehicles. Furthermore, the decreasing market share of diesel cars, which have traditionally higher engine capacities, contributed to the decrease of the overall average engine capacity, especially over recent years.
Regarding CO₂ emissions, from 2010 to 2018, the total emissions significantly decreased (nearly 18%). This is related to latest innovations in powertrain efficiency and vehicle design, most notably smaller, turbocharged, more efficient engines (downsizing).

After 2013, the downward trend of average CO₂ emissions becomes smoother before it stabilizes, a decisive factor for this is the simultaneous increase trend of average mass in the same time period.

On top of that, a notable rise in the average CO₂ emissions occurred in 2018, nearly 4% compared to 2017. Possible explanations for this rise are:
• Engine Capacity: Rise in average engine capacity of petrol cars, 1.5% more than 2017.
• The de-dieselisation effect. As seen in Figure 3.43, the average diesel CO\textsubscript{2} emissions is always lower than petrol indicating the improved performance of diesel engines, in terms of CO\textsubscript{2} emissions and fuel efficiency. The share of new diesel cars decreased by 5% (45% in total), while petrol increased 5% (51% in total), between 2017-2018.
• Increase in new SUV sales (see section 3.5.4)

3.5.2 CO\textsubscript{2} technology reduction effects

Figure 3.44 shows the market share of some conventional technological innovations or methods for reducing CO\textsubscript{2} introduced annually on new Renault passenger cars. The penetration data displayed, as noted in section 2.4, are largely based on ICCT publications and additional assessments.

Figure 3.44: Penetration of key CO\textsubscript{2} reduction technologies/strategies (Renault)

The start-stop systems penetration, in terms of refers to conventional vehicles, can be singled out as the most rapidly implemented technology. Start-stop functionality in new Renault cars increased drastically between 2010-2018, eventually plateauing around 80% of new cars sold in 2018.

Renault early on developed turbocharged and downsized petrol engines under the commercial name TC\textsubscript{e} (Turbo Control Efficiency). In fact, in 2012, Renault (2012) launched its second generation of petrol TC\textsubscript{e} engines (Energy TC\textsubscript{e} family), which also incorporated DI (in line with Figure 3.44) and reduced number of cylinders (3-cylinders instead of 4). Renault predicted that the new Energy TC\textsubscript{e} engine family will account for 85% of the brand's petrol engine sales in Europe by 2015.

Concerning transmission upgrades, Renault (2010) has developed a new, six-speed, dual clutch transmission (DCT) gearbox entitled Efficient Dual Clutch (EDC), aiming to reduce fuel consumption and CO\textsubscript{2} emissions. The EDC is a combination of two parallel half gearboxes, which work together and are both designed like a traditional manual gearbox.
For several Renault car models, the ECO2 label identifies certain variants per model having the lowest CO2 emission levels. These versions achieve lower fuel consumption through aerodynamic tweaks, optimized transmissions, low-resistance tyres, etc.

Figure 3.45: CO2 reduction effects (Renault)

Similarly to the rest of OEMs, a no-improvement scenario has been developed to illustrate the average CO2 emission reduction from 2010, considering that the 2010 CO2 emissions remain stable until 2018. In the case of Renault, during the earlier years (2010-2013), the CO2 emissions were greatly reduced by almost 18%. The main factor in CO2 reduction is the powertrain improvement and the total increased efficiency of conventional vehicles (petrol, diesel). After 2013, due to the rapid rise in BEV sales, the impact of xEVs becomes more noticeable. This clearly reflects Renault’s corporate decision to launch and promote electric powered model variants in 2012, such as Zoe (BEV), in order to meet the CO2 targets.

Based on the retrieved data from the CO2 monitoring database, the highest decline in Renault passenger vehicles' average CO2 emissions was observed in 2016 relatively to the base year (2010). As stated in earlier, there is a rising trend in the average CO2 levels since 2016, essentially reaching the level of 2013. This is not, however, due to a deteriorating engine performance, in terms of CO2, or the downgrading of existent fuel efficiency techiest implemented on cars.
Figure 3.46: Estimated CO₂ reduction per technology/strategy in 2018 (Renault)

Figure 52 demonstrates a snapshot of Renault innovations that contributed most to the decline of the average CO₂ emissions, in 2018. The proportion of each CO₂ decrease effect (in NEDC terms) is generally estimated on the basis of available data but is subject to variations as specified in Sections 2.3 and 2.4. That said, it is obvious that the downsizing, via turbocharging of petrol engines (TCe engines) has a predominant role in the overall CO₂ reduction. Start-stop technology due to its high penetration is also an important factor as it also benefits from the NEDC cycle characteristics (i.e. longer stops).

Renault has instituted other technological advancements that can be divided into general categories. Those include but are not limited to:

- Variable valve timing and lift (VVT/VVL)
- Engine thermal management or friction reduction (use of advanced materials)
- Diesel engine (dCI engines) optimizations
- Improved aerodynamics & tyre rolling resistance
- Brake energy recuperation systems

3.5.3 Most popular model: Clio

As expected, the Renault Clio is the most popular Renault model (in terms of annual sales). It is the most popular model, after the VW Golf, as it accounts for over 2% of all new passenger car sales in the EU in 2017 (ICCT, 2018). Following the same methodology, an attempt was made to evaluate its features and general patterns over the years.
As illustrated in Figure 3.47, the CO₂ emissions for Clio diesel model variants is lower than petrol overall years, reflecting the enhanced fuel efficiency provided by diesel engines (in Renault’s case dCI engines).

Figure 3.47: Average CO₂ emissions of VW Golf model

The lowest value of CO₂ emissions (for new Clio registrations) is recorded in 2016, amounting to a total 21% reduction, since 2010. In 2013, there is a noticeable drop in average CO₂ emissions, especially for the petrol variants of Clio, which is probably related to the introduction of the new Renault IV model. The Clio IV is equipped with a new generation of downsized petrol engines (such as the Energy TCe 90) and diesel engines (such as the Energy dCI 90), which were introduced around the same time period and were designed to offer better fuel efficiency.

Despite that, after the diesel emissions show a small increase after 2016 (5.5%) while petrol CO₂ emissions stabilize. As shown in Figure 3.48, this may be due to their increasing average mass, as average engine capacity remains the same throughout the years.

Furthermore, the same figure clearly illustrates Renault’s downsizing strategy on Clio’s petrol version with development of smaller turbocharged engines that do not sacrifice power output. Although in 2018, the engine power of new petrol Clio registrations was reduced compared to 2017, it was still about 8% higher than the 2011 level, whereas the engine capacity in 2018 was about 17% lower since 2010.
3.5.4 SUV analysis

This chapter explores the trends regarding the SUV models of Renault. Among the models identified as SUV or crossover are the Duster, Kadjar and Captur models. As the rest of the OEMs analysed, Renault’s SUV models have significantly increased their market share in the new registration fleet, similarly to the European trend over the past few years. More importantly, in 2018, they represented the 35% of the total new car registrations of Renault, which is the highest market share recorded compared to the other OEMs examined in this study.

In Renault’s case, there are no SUV registrations in the CO₂ motoring database for the years 2010-2013, based on the model names mentioned above. This indicates that Renault was late to introduce its ‘pure’ SUV models, in the EU market, compared to the other selected OEMs.

Figure 3.49: Average CO₂ emissions of Renault SUV models
As shown in Figure 3.49, Renault SUV average CO₂ emissions follow a steady rise, with an increase of nearly 12% since 2013. This is directly tied to the fact that Renault SUV are becoming heavier and are equipped with larger engines, as depicted in Figure 3.50.

**Figure 3.50: Vehicle characteristics of Renault SUV models**

The average mass of both diesel and petrol fuelled SUVs follows an increasing trend, recording a combined 8% increase in 2018 compared to 2010. The same applies to engine capacity of petrol SUVs which increased by 14.3% compared to 2013 levels, which along with the increase in engine power, indicates that the SUV sold came with more powerful engines.

4 Concluding remarks

The lowest mean CO₂ emission value for each of the selected OEMs were observed at some point in the period 2015-2017. The continuous decline observed since 2010 clearly depicts the effort made by OEMs to develop and integrate CO₂ reduction innovations and technological improvements, in order to meet the regulatory emission targets. As a whole the car industry achieved below the 2015 target of 130 g CO₂/km, according to official data on CO₂ emissions monitoring (EEA, 2015).

The primary driving force behind the achieved reductions in CO₂ are the improvements in conventional powertrains (incl. hybridisation) and the design of modern cars.

In the present report, an effort was made to highlight the key strategies that led to the reported reduction in CO₂ emissions and estimate their approximate individual impact. The CO₂ reported values (from official data on CO₂ emissions monitoring) used for this analysis are based on NEDC testing. Figure 4.2 provides a summary of the estimated effects or technologies, that each OEM potentially implemented. The presented results focus on the latest year of available CO₂ data (2018), with the exemption of BMW. In BMW's case the abrupt rise of the average CO₂ emissions in 2018, was not related to a rollback of already established CO₂ reducing technologies but due to other factors related to consumer choices (e.g. rise of SUV, petrol sales), hence the effect of CO₂-reducing technologies would be smaller and hard to visualize.
Although the share of each effect in the CO₂ reduction is an estimation (as it is not based on official OEM data), in principle, all OEMs followed the same general tactics and deployed similar concepts, for the most part of the examined time period (2010-2018). For example, the downsizing of petrol engines via the use of turbochargers/superchargers has been deployed by most OEMs in recent years.

Nevertheless, there are also diversifications in the strategies followed. For example, the significantly higher share of xEVs for Toyota, mainly due to the systemic development and promotion of hybrid...
powertrains, compared to other OEMs. Another example is the different unique technological packages, deployed in popular model variants aiming to further reduce CO₂ emissions. These are labelled under different brand names such as Bluemotion, Efficient Dynamics, ECOnetic, ECO₂, which combine varying state-of-the-art features, a direct result of each OEM’s engineering judgement and R&D activities.

The exact identification of all relevant technological improvements and strategies implemented across the board, for improving fuel efficiency of new cars and their impact on CO₂ reduction, cannot be validated without receiving real data from the OEMs.

Despite the clear decline in reported CO₂ emissions by OEMs, in 2018 there was a turning point. For all selected OEMs, except Toyota, there was an increase in mean CO₂ emissions reported, compared to consistent reductions from 2010 to 2017. Certain key factors that could have contributed to this are:

- **De-dieselisation effect:** Based on official data on CO₂ emissions monitoring (EEA, 2019b) diesel vehicles constituted 36% of the new registrations, marking a drop of 9 percentage points from 2017, and 19 percentage points from 2011 when diesel cars peaked at a 55% share of new registrations. This trend is confirmed for all selected OEMs in the present analysis. It should be highlighted that the de-dieselisation has primarily occurred for small passenger cars, while larger or luxury cars were not affected as much. This may also explain why for certain cases (VW, Toyota, Ford), the average CO₂ emissions of diesel cars were very close to those of petrol cars, especially for the more recent years.

- **Slow penetration of HEV/PHEV/BEV:**
  - **HEV:** From the selected OEMs, only Toyota strongly pushed for HEV in an effort to reduce CO₂ emissions, which is reflected in the annual registrations (over 50% of total new registrations in 2018).
  - **PHEV/BEV:** It was arguably slower than originally anticipated. Only in the case of Renault out of the selected OEMs, the market share of BEV in 2018 surpassed the 2% mark. In fact, Ford and Toyota, in 2018, did not deploy a noteworthy number of new BEV/PHEV cars.

- **Rising popularity of SUV:** In recent years, buyers’ preferences have shifted towards new SUV (or so-called crossover) models. The OEMs have responded to this market shift and have made available such models in a range of sizes and power output. As a result, the share of SUVs for the selected OEMs surged in the last year analysed (Figure 4.3). This tendency results to a continuous increase in average mass for all selected OEMS in the 2015-2018 time frame.

The market trend to move towards larger SUVs than smaller family or compact cars decelerates the decrease of CO₂ that would be expected by the advanced technologies introduced. In 2018, this even has reversed the decreasing trend. Market forces will need to be monitored for an early recognition of factors that may provide obstacles to the reduction of CO₂ emissions.
Figure 4.3: Market share of new SUV compared to total new registrations

![SUV market share (new registrations)](chart.png)
5 References


Ricardo-AEA, 2015. Supporting analysis on improving understanding of technology and costs for CO2 reductions from cars and light commercial vehicles in the period to 2030: Technology Results Data Fiche.


6 Abbreviations

BEV  Battery Electric Vehicle
CVT  Continuously Variable Transmission
DCT  Dual-Clutch Transmission
DI  Direct Injection
EERE  Office of Energy Efficiency & Renewable Energy (US)
EPA  Environmental Protection Agency (US)
E85  Fuel with ethanol blend of 85%
FCEV  Fuel Cell Electric Vehicle
GDI  Gasoline Direct Injection
GHG  Greenhouse Gas
HEV  Hybrid Electric Vehicle
ICE  Internal Combustion Engine
LPG  Liquified petroleum gas
NG  Natural gas
OEM  Original Equipment Manufacturer
PHEV  Plug-in Hybrid Electric Vehicle
R&D  Research and development
SUV  Sport Utility Vehicle
VVA  Variable Valve Actuation
VVL  Variable Valve Lift
VVT  Variable Valve Timing