GEAR 2030 Strategy 2015-2017 - Comparative analysis of the competitive position of the EU automotive industry and the impact of the introduction of autonomous vehicles

Final report

Written by Nick Asselin-Miller, Gareth Horton, Sofia Amaral, Hannah Figg, Dominic Sheldon (Ricardo), Christian Lutz, Markus Flaute (GWS), Peter Wells (CAIR)

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Contact: Aleksander Lazarevic

E-mail: Aleksander.LAZAREVIC@ec.europa.eu

European Commission
B-1049 Brussels

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GLOSSARY OF TERMS

Abbreviation	Definition
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ACEA	European Association of Automobile Manufacturers
ACEM	European Association of Motorcycle Manufacturers
ADAS	Advanced Driver Assistance Systems
AEB	Automatic Emergency Braking
AECC	Association for Emissions Control by Catalyst
AHO	Automatic Headlamp On
APAC	Asia-Pacific
API	Application Programming Interface
AV	Autonomous Vehicles
BEE	Bureau of Energy Efficiency, India
BEV	Battery-Electric Vehicles
BSD	Blind Spot Detection
CAAM	Chinese Association of Automotive Manufacturers
CAFC	Corporate-Average Fuel Consumption
CAFE	Corporate Average Fuel Economy
CARB	California Air Resource Board
CAV	Connected and Autonomous Vehicles
CBS	Combined Brake Systems
CFRP	Carbon-Fibre-Reinforced Polymer
C-ITS	Co-operative Intelligent Transport Systems
CNG	Compressed Natural Gas
CO	Carbon Monoxide
DDR	Driver Distraction and Drowsiness recognition
DG ENV	Directorate General for Environment of the European Commission
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and SMEs of the European Commission
DG MOVE	Directorate General for Mobility and Transport of the European Commission
DSRC	Dedicated Short Range Communication
EAPC	Electric Assisted Pedal Cycle
EBD	Emergency Braking Lights
EC	European Commission
ECE	United Nations Economic Commission for Europe
EDR	Event Data Recorder
EEA	European Environment Agency
EMIS	Emission Measurements in the Automotive Sector
EPA	Environmental Protection Agency
ESC	Electronic Stability Control
EU	European Union
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FCA	Fiat Chrysler Automobiles
FCEV	Fuel-Cell Electric Vehicles

Abbreviation	Definition
FCW	Forward Collision Warning
FMVSS	Federal Motor Vehicle Safety Standards
FTP	Federal Test Procedure
GDI	Gasoline Direct Injection
GDP	Gross Domestic Product
GEMIS	Global Emissions Model for Integrated Systems
GHG	Greenhouse Gas
GINFORS-E	Global inter-industry forecasting system – energy
GM	General Motors
GPS	Global Positioning System
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model
GVWR	Gross Vehicle Weight Rating
HC + NOx	Combination of Hydrocarbons and NOx
HCHO	Formaldehyde
HEV	Hybrid Electric Vehicle
HFET	Highway Fuel Economy Test
HMI	Human-Machine Interfaces
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ICT	Information and Communication Technologies
IEA	International Energy Agency
IFEU	Institute for Energy and Environmental Research
IMF	International Monetary Fund
IMMA	The International Motorcycle Manufacturers Association
IO	Input-output
ISA	Intelligent Speed Advice
JAMA	Japan Automobile Manufacturers Association
JLR	Jaguar Land Rover
KMVSS	Korean Motor Vehicle Safety Standard
LCA	Lifecycle Analysis
LCVs	Light Commercial Vehicles
LDW	Lane Departure Warning
LEV	Low Emission Vehicle
LEVA	Light Electric Vehicle Association
LEZ	Low Emission Zones
LKA	Lane Keeping Assist
LPG	Liquefied Petroleum Gas
LSEV	Low-Speed Electric Vehicles
MaaS	Mobility-as-a-Service
MAI	Motor Approaching Indication
MEP	Ministry of Environmental Protection, China
METI	Ministry of Economy Trade and Industry, Japan
MIIT	Ministry of Industry and Information Technology, China
MLTI	Ministry of Land Infrastructure Transport and Tourism, Japan
MoE	Ministry of Environment, South Korea

Abbreviation	Definition
MOTIE	Ministry of Trade, Industry and Energy, South Korea
MPG	Miles per Gallon
NA	Not Available
NACE	Statistical classification of economic activities in the European Community
NCA	Nickel-Cobalt-Aluminium
NCAP	New Car Assessment Programme
NEDC	New European Driving Cycle
NEV	Neighbourhood Electric Vehicle
NHTSA	National Highway Traffic Safety Administration
NMC	Nickel-Manganese-Cobalt
NMHC	Non-Methane Hydrocarbons
NMOG	Non-Methane Organic Gas
NOx	Oxides of Nitrogen
NV	Night Vision
NVH	Noise, Vibration and Harshness
OECD	Organisation for Economic Co-operation and Development
OEMs	Original Equipment Manufacturers
OICA	The International Organisation of Automotive Manufacturers
OLS	Ordinary Least Squares
PA	Park Assist
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
PN	Particulate Number
R&D	Research and Development
RCTA	Rear Cross Traffic Alert
RDE	Real Driving Emissions
RPE	Retail Price Equivalent
SBR	Seat Belt Reminder
SCR	Selective Catalytic Reduction
SEC	Securities and Exchange Commission
SFS	Protection of far-side occupants in side impact collisions
SLD	Speed Limit Detection
SMMT	Society of Motor Manufacturers and Traders
SUV	Sport Utility Vehicle
THC	Hydrocarbons
TJA	Traffic Jam Assist
TPMS	Tyre Pressure Monitoring System
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
US	United States
US NEV	Neighbourhood Electric Vehicle
USGS	United States Geological Survey

Abbreviation	Definition
VAT	Value-Added Tax
VIN	Vehicle Identification Number
VRUs	Vulnerable Road Users
VSP	Voitures Sans Permis
VW	Volkswagen
WEO	World Energy Outlook
WHO	World Health Organisation
WLTP	World Harmonised Light Vehicle Test Procedure
WP.29	World Forum for Harmonization of Vehicle Regulations
WVTA	Whole Vehicle Type Approval
xEV	Electric Vehicles including Plug-in Hybrid, Battery and Fuel Cell Electric Vehicles
ZEV	Zero Emission Vehicle

EXECUTIVE SUMMARY

The EU automotive industry is a key contributor to EU economic prosperity. It represents 4% of the EU's GDP[1] and employs about 12 million people. It also has an important multiplier effect on the economy, being important for both upstream industries (material processing industries) and downstream industries (including ICT, repair, and mobility services).

Major changes are likely to affect the industry in the coming years and radically transform the automotive sector. In the context of growing air pollution levels, climate change concerns and ambitious safety targets, most markets are strengthening both safety and environmental regulations and pursuing harmonisation of the regulatory environment at the global level. This will be accompanied by a significant transition to e-mobility as countries and cities look at minimising their environmental impact. As urbanisation intensifies and congestion issues worsen, new mobility solutions for urban areas are likely to emerge. This could entail the introduction of large numbers of innovative, low-cost, smaller L-category vehicles. The increasing connectivity of vehicles and the advent of autonomous driving are also expected to play a major role in the future, improving safety, delivering significant driving efficiencies and potentially affecting ownership levels.

The definition and implementation of regulation in these fields will thus be crucial to shape how the industry responds and adapts to this new paradigm. The evolution of the EU regulatory environment but also the regulatory framework in the markets of current and future competitors will influence the ability of EU OEMs to maintain and grow its future market share both at home and abroad.

Regulation constitutes an additional source of costs for the industry in the short-run. On the other hand, maintaining a regulatory lead globally could help insulate the EU market from low cost, lower-technology external competition and provide opportunities for EU OEMs to respond to regulatory shocks abroad – thereby delivering significant benefits which, combined with additional societal benefits in terms of the achievement of important climate change, environmental and safety targets, could more than offset the initial costs of regulation. This study aims to identify the costs and benefits to EU OEMs of the EU taking the regulatory lead in this international context.

The analysis assesses the external competitiveness of the EU automotive industry to 2030 and beyond in the face of shifting market and regulatory drivers in six key competitive markets, comprising the EU, China, India, Japan, South Korea and the US. It covers seven vehicle segments comprising passenger cars (M1 category split into entry-level, mid-range and luxury segments), light commercial vehicles (N1 category) and L-category vehicles (split into light two-wheelers, two-wheeled motorcycles and light/heavy quadricycles).

The study entailed the development of a modelling approach to understand the impacts of regulation in the EU and elsewhere on the automotive industry and the wider economy. This involved both a micro-economic and macro-economic modelling step. The micro-economic model was designed to parametrise the link between changes in regulatory trends and changes in vehicle costs, profit margins and material composition. To this end, the model draws on a variety of input data and background information from over 260 sources that provide an overview of the differing levels of future regulatory standards on environmental, air pollutant and safety aspects which are expected to vary through time. Representative vehicle types were defined to represent each of the vehicle segments considered for this study, and their production cost breakdowns and material composition were estimated in the baseline. This allowed us to evaluate differences in the production cost and material breakdown between the markets of interest to the study and how these are likely to change in the future as regulation changes in each market. The results from the micro-economic model were fed into the GINFORS-E macro-economic model, which is an economy-energy-environment model with global coverage that analyses and forecasts structural changes to the automotive industry from a top-down perspective, evaluating

[1] https://ec.europa.eu/growth/sectors/automotive_en

impacts on the economy, industry, global trade flows and other socio-economic dimensions.

The study assesses the impacts of the changes in regulation expected in the baseline but also models alternative scenarios representing the implementation of more ambitious regulation in the EU, at different stages, and with varying levels of ambition, as the EU increases its regulatory ambition to match or exceed the global leading regulatory standards. A scenario was also developed to understand the impacts for EU OEMs of a unilateral strengthening of regulations occurring in one of the EU's main export markets, China. It models the situation in which manufacturers from countries which match the regulatory ambition in China (including the EU in the higher-ambition EU regulatory scenarios) are able to adapt quicker to the regulatory shock, as they have already invested heavily in (for example) zero-emissions vehicle technologies. They would thus be well-placed to grow their market share and increase their revenues and profits significantly at the expense of other non-compliant foreign OEMs. An additional sensitivity analysis is also carried out to understand the repercussions of the EU's regulatory lead on the internal market. The implication here is that foreign manufacturers from countries where the regulatory level is not as tight as in the EU would not be able to comply with the stricter regulatory level and would thus have limited access to the internal market, thereby allowing EU OEMs to grow their presence in their home market.

The analysis reveals important findings on the opportunities and costs that the automotive industry will likely face in the context of rapid technological changes and an uncertain global regulatory environment. Based on these findings and associated conclusions, recommendations are proposed on how the EC can support the automotive industry in the EU in this period of change, focusing on M1/N1-category vehicles, L-category vehicles and the automotive supply chain.

M1/N1-category vehicles

1. **The additional costs from regulation can be offset by the attainment of large benefits for EU OEMs, the wider economy and society**

The definition and implementation of progressively more ambitious regulation in the EU is expected to have a negative impact on the economy at first as GDP drops compared to the baseline, but it is likely to recover after 2035, reaching a marginally positive overall impact on GDP. The scenario in which the EU matches the global leadership level of regulation in one go in 2030 seems to deliver the best results for the economy.

Widening the analysis to take into account the full impacts from regulation, the outlook is more balanced and demonstrates that more stringent regulation can generate positive gains for the economy. The internal market sensitivity analysis which evaluates the impacts of regulation in protecting the internal market from external competition concluded that EU OEMs could benefit from up to €29 bn in additional profits cumulatively, provided they are able to capture the market share of foreign OEMs which are not able to comply with the stricter regulatory level. For the wider economy, it represents an increase of approximately 0.5% of GDP in 2030 compared to the baseline, and €1,800 bn in cumulative gains in GDP between 2020 and 2050. More stringent regulation also delivers significant benefits in terms of reduced transport externalities. Important savings in CO_2 emissions are achieved by accelerating the transition to e-mobility. The cumulative reduction in CO_2 emissions reaches between 728 Mt and 1,206 Mt for the period between 2020 and 2050, which represents a benefit between €34 bn and €58 bn for society (using the carbon prices to quantify the value of savings in CO_2 emissions). Early electrification of powertrains also contributes to generate considerable reductions in pollutant emissions (3.3 kt - 7.9 kt for NOx and 54 tonnes - 112 tonnes for PM in 2030). Given the avoided health impacts, these reductions are likely to account for € 132 million and € 948 million for NOx and € 1.2 million to € 7.5 million for PM annually. More stringent safety regulation that mandates higher levels of vehicle automation can also bring about significant benefits by minimising human error in driving and thereby reducing accident rates (a reduction of 5% could result in benefits in the order of €7 bn annually).

Additionally, the EU's regulatory lead has also been demonstrated to be an advantage when responding to a regulatory shock in a foreign market. The China case scenario reflects the situation in which EU OEMs are able to gain additional market share in the Chinese market as the stringent regulatory environment in the EU enables them to adapt quickly to the strengthening of regulations in China, whilst OEMs from countries with lower regulatory ambition lose access to the market. A stronger presence in the Chinese market represents between €82-100 bn in additional profits for EU OEMs cumulatively, under the modelled scenario. For the wider economy, positive impacts on GDP are expected to increase over time, reaching 0.23% in 2050. In a scenario in which the EU's regulatory environment matches the highest level of ambition globally, EU OEMs are able to reinforce their presence in the internal market and gain additional market share in China, GDP is predicted to be 0.6% - 0.7% higher than in the baseline in 2030, reducing to 0.4% - 0.5% in 2050, compared to the baseline.

Recommendation 1: Ensure that additional costs to the EU industry are accompanied by benefits largely exceeding these costs for EU OEMs by (i) securing preferential access to the Chinese market as regulation is tightened, and (ii) ensuring that standards prevent low costs new entrants from accessing the EU market.

2. **Profitability differences between the EU and foreign markets reveals new sources of revenue and growth opportunities but also underlying weaknesses in the EU automotive industry**

The analysis predicts that the profitability of EU OEMs in the EU is expected to suffer at first as regulation is tightened but will recover over time with the transition towards electrification of powertrains which contributes to increase average profit, despite the relatively low profit margins observed. The analysis assumes vehicle demand remains unchanged and is able to accommodate the changes in prices resulting from higher regulatory costs.

The analysis also reveals that as regulations converge to EU levels, the difference in costs between the EU and the other markets declines over time. This effect is heightened by the expected increase in labour costs in China and India relatively to EU levels. Regulation is thus key to levelling the playing field between the EU and the other markets over time. Nevertheless, production costs in the EU are anticipated to remain the highest until 2050 which indicates the presence of other underlying issues at play. This is likely to be associated to the high indirect costs incurred by EU OEMs relatively to foreign OEMs. This, in turn, affects profitability in the EU market characterised by very low profit margins.

On the other hand, profitability is relatively high in foreign markets across all vehicle segments but particularly in the luxury vehicle market. This represents an important growth opportunity for EU OEMs in the context of a stagnating internal market. Markets such as China and India, on the other hand, have high growth prospects and thereby present a golden opportunity for EU manufacturers.

Recommendation 2: Help support profitability in the EU automotive industry by (i) supporting continued demand in the EU automotive industry so as to ensure increased absolute profits accompany increased costs, (ii) supporting the EU industry to reduce uncompetitive overheads, and (iii) helping the EU industry to secure access to high-margin foreign markets.

3. **Electric vehicles are expected to achieve substantial cost reductions enabling these powertrains to become competitive with ICE vehicles in the long-run**

The analysis concludes that the production costs of xEVs are expected to become lower or on a par with costs of producing ICE vehicles in the longer term, in particular compared to diesel vehicles and for the smaller segments. This is driven by cost reductions stemming from learning effects and economies of scale in the production of these powertrains. For larger segments, safety costs are anticipated to be greater, as higher levels of automation are mandated for these vehicles, which tend to outweigh the cost reductions associated to learning effects.

Recommendation 3: Focus efforts on cost reductions initiatives whilst maintaining ambitious plans for regulation by (i) targeting xEV cost reductions, and (ii) supporting R&D efforts on CAV technologies

Automotive supply chain

4. **The transition to e-mobility is expected to have substantial impacts on the trade of commodities required to produce these powertrains**

The increasing share of xEVs in production will require access to scarce and non-native raw materials, such a lithium and manganese. This will lead to increased reliance on a small number of extracting and producing countries, whose political instability can lead to significant supply risks in the future.

Recommendation 4: Minimise risk from increased reliance on non-native materials linked to e-mobility, through (i) securing reliable supply, (ii) supporting domestic production capacity and (iii) maximising recycling rates as part of initiatives to support the circular economy.

5. **The shift towards e-mobility and CAV is likely to transform the balance of power in the automotive supply chain as the content on vehicles derived from OEMs and traditional Tier 1 suppliers is reduced and software takes an increasingly high proportion of the value in vehicle production**

The advent of e-mobility and CAVs will generate important value for the automotive industry. A rough estimate indicates the market potential for e-mobility could represent up to $339bn, and for CAVs $273bn between 2020 and 2030. How much of these benefits traditional players (such as OEMs and Tier 1 suppliers) are able to capture, as opposed to new entrants, will largely depend on their efforts to develop and apply the new required capabilities – heralding the need for new partnering arrangements and cross-industry consolidation.

In particular, non-automotive electronics companies are anticipated to become major players in the supply chain of alternative powertrains which require a much higher proportion of electronics relatively to ICE vehicles. In the CAV field, companies in the ICT and telecommunications industries are poised to benefit from the increased connectivity of vehicles, and create significant value in the automotive sector as it shifts from hardware to software capability. It is worth noting that the major global players in both these fields (e.g. large electronics companies based in Asia or major technology firms based in Silicon Valley) tend to be located outside the EU.

Recommendation 5: Support the development of a technologically-advanced e-mobility supply industry in the EU, supporting partnerships where necessary

Recommendation 6: Support the development of a technologically-advanced industry associated to CAVs in the EU, supporting the development of cross-industry partnerships and new business models

L-category vehicles

6. **Strong regulatory ambition has helped to protect the internal market from low-cost competition but also maintain access to foreign markets as EU vehicles are accepted worldwide**

The analysis concludes that the EU is leading in the setting of progressively stricter regulation for L-category vehicles which has helped to shield the EU industry from low-cost competition in their home market. It has also enabled EU OEMs to remain competitive in foreign markets as EU production is internationally recognised as a high-value, high-technology offering, thriving in the premium segments. The EU's role at the global level has supported the harmonisation of an otherwise fragmented market which is vital to further expand the market opportunities for EU OEMs externally.

EU OEMs are expected to continue to prosper in the higher-value, higher technology powered two-wheeler sector. A progressively more ambitious regulatory environment could be the driving force for continued innovation in the segment as other markets tend to catch up.

Recommendation 7: Given the EU's leading role in global harmonization, ensuring high standards are followed and supporting other world regions do not "cherry pick" requirements

7. Important growth opportunities can be found outside the EU as the internal market stagnates and is threatened by low-cost production

The analysis demonstrates that the powered two-wheeler market associated to specialist 'lifestyle' products where EU OEMs have traditionally thrived has limited growth potential which could significantly affect EU OEMs' profitability. On the other hand, this sub-segment could be an export opportunity as spending power in emerging markets (China, India) is increasing. These countries, on the other hand, have traditionally been characterised by a strong light two-wheeler industry based on low-cost production. As the market for this sub-segment is expected to grow rapidly, the transition to e-mobility and CAVs could be an opportunity for EU OEMs to exploit their technology- and design- innovation capabilities to increase their presence in this sub-segment.

Conversely, imports from China and India into the EU could increase in the future as the countries catch up and implement more stringent regulations, particularly in the context of the emergence of e-bikes in China. China's lead in developing e-bikes for the global market could present a threat to the EU light two-wheeler market, as imports from China substitute in part sales of other L-category vehicles.

Recommendation 8: Seek removal of barriers to trade in key powered two wheelers markets, enabling EU OEMs to access foreign markets

Recommendation 9: Implement market surveillance requirements foreseen in Regulation 168/2013, to ensure fair competition, a level playing field and consumer protection, preventing non-complying products (e.g. low quality products from Asia – mainly China) from entering the EU market [this principle applies also to electric bicycles]

Recommendation 10: Support research in vehicle technology, for electric L- category vehicles (dedicated batteries and battery management systems)

Recommendation 11: Support ITS developments targeting L-category vehicles

In summary, significant challenges lie ahead for the EU automotive sector, but a very positive picture is painted if regulation is tightened in the EU alongside appropriate support from the EC in this period of change and uncertainty, in order for the industry to be able to capitalise on the opportunities presented. This will also require an ambitious vision from EU OEMs and their supply chains, in order to adapt, partner where necessary and capitalise on the disruptive innovations and tightening regulations which will redefine the sector in the coming years.

1 OVERVIEW AND CONTEXT

1.1 Background

The EU is among the world's biggest producers of motor vehicles and the sector represents the largest private investor in research and development (R&D) in the EU. As such, the automotive industry is crucial for Europe's prosperity. It provides jobs for 12 million people (3 million in manufacturing, 4.3 million in maintenance and 4.8 million in transport) and accounts for 4% of the EU's GDP[2]. Additionally, the automotive industry has an important multiplier effect on the economy, being important for upstream industries such as steel, chemicals and textiles, as well as downstream industries such as ICT, repair, and mobility services.

Historically the ability of the EU industry to bring innovative technology to market ahead of other competitors has rested on a strong 'premium' brand presence, allowing sufficient margins for advanced technology costs to be amortised and a strong regulatory regime backed by informed consumers. To-date, it has also successfully exported these premium brands and advanced technologies to external markets such as China, where higher margins and a growing market present a very attractive growth opportunity for EU Original Equipment Manufacturers (OEMs).

Whilst this approach remains relevant, the global automotive industry is in a state of flux with a range of drivers leading to significant changes in how the industry operates. It is crucial that the EU industry maintains its competitiveness on the global stage in the face of strong competition from automotive manufacturers in both developed and emerging economies, and in light of dramatic changes in societal pressures and demands with respect to mobility and transport.

Issues which are likely to affect the EU automotive industry going forward include:

- Changes in car ownership levels, both an increase in car ownership in emerging markets as purchasing power increases and a potential decrease in developed markets as Mobility as a Service and car sharing schemes take an increasing market share.
- Strengthening regulations on both safety and environmental impact from all major markets, with emerging markets rapidly catching up to the EU industry's leading position in these fields
- A significant shift towards e-mobility, as nations across the world move towards reducing their environmental impacts (e.g. greenhouse gases) and as cities in particular aim to tackle increasing air pollution levels. Here, radical new business models are being developed by new entrants into the industry; for example the Tesla approach of raising large amounts of capital both from the state and from the private sector and using this to pursue an aggressive growth strategy despite ongoing losses, in order to build market share with the intention that profits will eventually flow.
- The increasing connectivity of vehicles and the advent of autonomous driving. This has wide-ranging implications for the automotive industry, from potentially significantly reduced vehicle sales and ownership levels to new business models, but perhaps most importantly the gradual merging of the automotive, ICT and telecommunications industries. Connected and autonomous vehicles (CAVs) have the potential to bring completely new entrants with vast financial resources to the market (such as Google, Uber or Apple) and to transform the way in which automotive manufacturers monetise their customers.
- The introduction of large numbers of innovative, low-cost, smaller L-category vehicles providing mobility solutions in urban areas particularly in emerging markets, as these become more crowded and polluted with the global urbanisation of the population. For example there are 200 million e-bikes in China, a market that

[2] https://ec.europa.eu/growth/sectors/automotive_en

has rapidly built from nothing and in which the EU automotive industry has little presence. Furthermore, a number of global OEMs have also displayed and demonstrated innovative pod-type single or dual occupancy vehicles that have the potential to dramatically reduce the material resource requirements of future passenger vehicles.

These are just a few of the major changes which are likely to cause a paradigm shift in the global automotive industry; these changes will mean that the industry will need to rapidly adapt to the next phase of its existence.

Added to the above, there is concern that some of the differentiators that European vehicle manufactures have enjoyed, such as leading performance on comfort, environmental impact and safety, are declining as other manufacturers (particularly from emerging markets) gain ground in these areas. When combined with significant state-backed investments in developing home-grown automotive industries by countries such as China, who are keen to fund significant R&D and capital expenditure to take a meaningful slice of their massive home markets, as well as seeking to enter developed markets to gain a foothold there, there is a clear risk to the global competitiveness of the EU automotive industry.

In such a situation and with 80% of expected growth in the sector expected to come from outside the EU, cost leadership and a continued lead in new technology areas such as Industry 4.0 and CAVs, will become more important if the EU is to maintain and grow its future market share. One key contributor to competitiveness in the future, will be the evolution of the regulatory environment within the EU, but also how regulations are expected to vary in the different major global regions.

Indeed, regulation in the EU can be seen as a double-edged sword; in the short-run, the cost pressures from continually increasing regulation is seen by the automotive industry as having a detrimental effect on margins, with the industry claiming that regulations between 2015 and 2020 will add €1,000-2,000 to the cost of manufacturing a vehicle in the EU, whilst also severely impacting on profitability in the EU market (ACEA, 2015); on the other hand and in the long-run, the strict regulation in the EU ensures that the EU automotive industry continues to develop cutting-edge premium products, whilst being in a strong position of regulatory leadership from the point of view of both protecting the internal market, but also maximising opportunities to access external markets such as China as they rapidly ramp up their regulations – thereby potentially taking market share away from other foreign OEMs who don't currently produce vehicles to such high standards.

Hence, it is important to build an understanding of how major market, technological and regulatory changes in the various major global automotive markets are likely to impact market access conditions and the cost of manufacturing vehicles in the various markets, associated profitability levels, as well as opportunities presented from maintaining a global regulatory leadership position in the EU auto industry.

DG GROW has therefore commissioned this study to assess the external competitiveness of the EU automotive industry to 2030 and beyond.

1.2 Purpose and scope of the study

This is the final report for the study entitled 'GEAR 2030 Strategy 2015-2017 - Comparative analysis of the competitive position of the EU automotive industry and the impact of the introduction of autonomous vehicles', hereafter referred to as 'the study'. The report has been submitted by Ricardo, the consultants appointed to conduct this study and has been prepared with contributions from our subcontractors Cardiff Business School's Centre for Automotive Industry Research (CAIR) and Gesellschaft für Wirtschaftliche Strukturforschung mbH (GWS).

DG GROW commissioned Ricardo to undertake this study, in order to assess the external competitiveness of the EU automotive industry in the face of shifting market and regulatory drivers in six key competitive markets, comprising the EU, China, India, Japan, South Korea and the US.

The study initially builds up a picture of how differing levels of future regulatory standards on environmental, air pollutant and safety aspects are expected to vary through time, as well as the major technological changes that may be largely driven by these regulations, such as the shift towards e-mobility, lightweighting and CAVs. The study then goes on to evaluate how current and future OEM production costs and margins in the six key markets of interest (the EU, China, India, Japan, South Korea and the USA) will be affected in the baseline to 2050, by the changing regulatory environment, as well as the impact of these changes on materials demand and overall economic impact and trade flows.

Having assessed the impact of the changes expected in the baseline, the study then assesses a number of scenarios in which the EU increases its regulatory ambition to match or exceed the global leading regulatory standards, at different rates through time. It provides an understanding of the direct impact on the EU automotive industry of these changes, as well as the wider macroeconomic impacts in terms of GDP, consumption, employment and trade flows. Finally, a scenario is developed representing a technological and regulatory shock in one of the EU's main export markets China. The implication here is that those manufacturers that have already invested heavily in (for example) zero-emissions vehicle technologies would be well-placed to grow their market share and increase their revenues and profits significantly. The study will analyse this using a case study approach and will quantify any changes in market shares, revenues and profits for EU manufacturers (as well as wider economic impacts) on the basis that they have invested and deployed the relevant new technologies in advance of the hypothetical regulatory shock.

The findings from this analysis will help the automotive industry to better understand the changes that are expected across a rapidly changing and highly uncertain future in a global and fluctuating environment. The study presents both the costs and opportunities associated with taking early technological leadership in advance of potentially major structural changes that will affect the whole of the mobility sector.

The scope of the study includes seven vehicle segments comprising passenger cars (M1 category split into entry-level, mid-range and luxury segments), light commercial vehicles (N1 category) and L-category vehicles (split into light two-wheelers, two-wheeled motorcycles and light/heavy quadricycles). Note that due to a lack of data, the L-category analysis does not go to the same level of quantitative detail as the M- and N-category analyses.

This final report includes the following sections:

- Section 1: Overview and context (this section).
- Section 2: Methodology and modelling environment. This section describes the methodological approach for assessing the likely market, regulatory and technology trends in the various markets of interest, as well as the approach adopted for quantifying the impact of these trends on the production costs, margins, materials composition and wider economic indicators, in the baseline and across a range of modelling scenarios.
- Section 3: Baseline and scenario definition. This section describes in detail the modelling baseline and scenario definitions and the main observations from the trends analysis that led to the specific designs being adopted.
- Section 4: Assessment of impacts. This section includes an overview of the key modelling outputs for the baseline and scenarios, based on both the outputs of the micro-economic model (which assesses the direct impact on the automotive industry) and the macro-economic model (which assesses the impacts on the wider economy). This section also includes our qualitative assessment of the impact of the e-mobility and CAV trends on the Tier 1 supplier industry.
- Section 5: Analysis of the L-category market. This stand-alone section includes all of the analysis related to L-category vehicles, including the market and regulatory trends overview and the competitiveness assessment.
- Section 6: Conclusions and recommendations. This section includes the main conclusions drawn from the main quantitative analysis, as well as those from the Tier 1 supplier analysis and the L-category analysis. Finally, it includes a series of

recommendations for the EC aimed at ensuring that the EU automotive industry can maximise its global competitiveness going forward.

2 METHODOLOGY AND MODELLING ENVIRONMENT

2.1 Overall project methodology and objectives

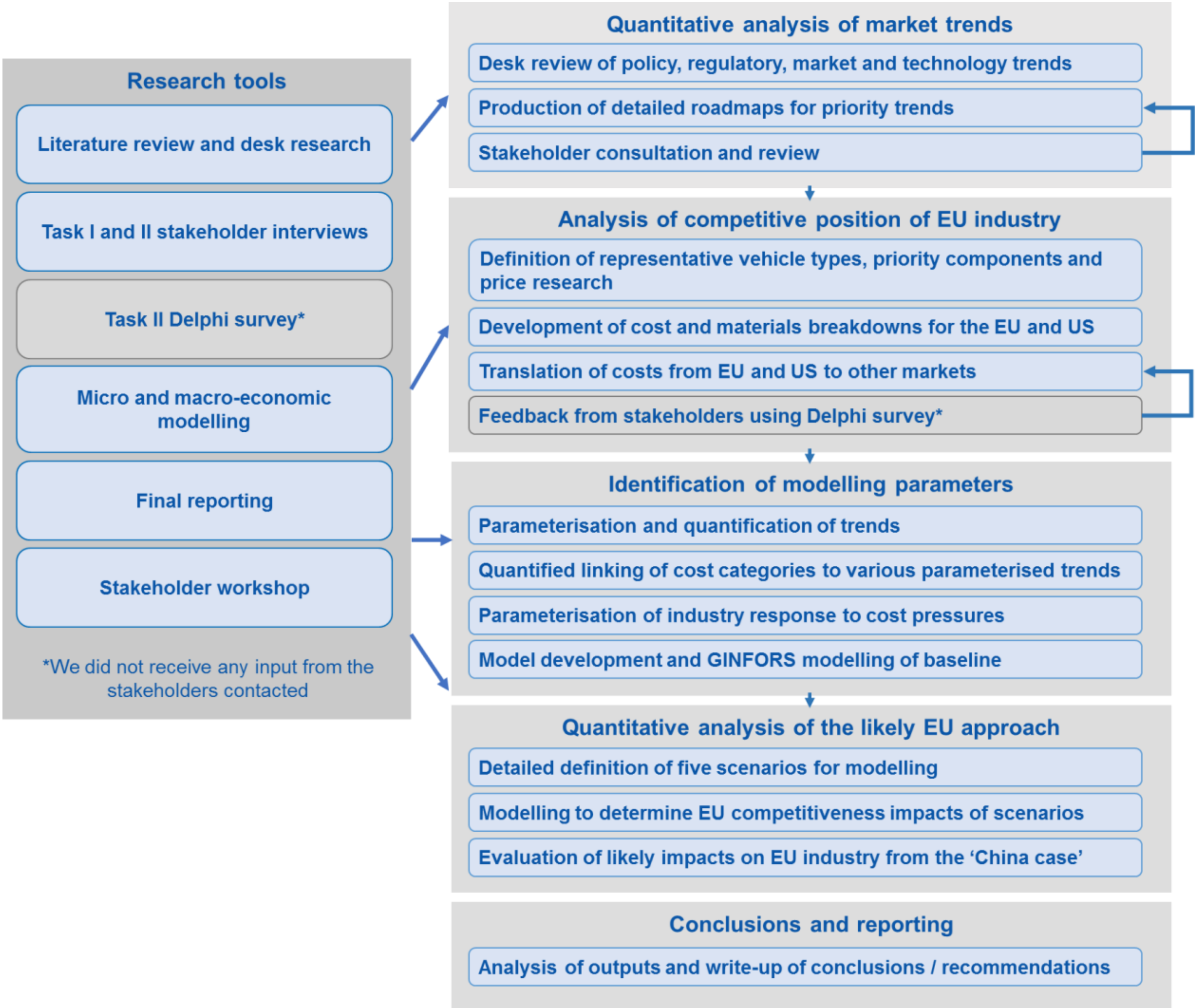
The main objective of the study was to assess the external competitive position, challenges and opportunities for the EU automotive value chain up to 2030 and beyond for European vehicle manufacturers compared to their competitors from major developed markets. The study also aimed to identify and quantify the main drivers of external competitiveness, including cost and productivity gains.

The main elements of the study carried out to achieve the objectives were as follows:

- Assessment of current and likely future market trends in the automotive sector for the six markets of interest, to understand current and future vehicle sales and production rates, manufacturer market shares and the size of any future opportunity presented to EU manufacturers.
- Development of detailed direct and indirect cost break-downs and pricing for all seven vehicle categories relevant to the study based on evaluating the production costs of a series of representative vehicle types, in each of the markets of interest.
- Development of a series of roadmaps representing the likely regulatory, policy, market and technology trends expected in the various markets of interest. This was followed by the development of parameterised relationships between these trends and the costs and prices described above, and building these into a micro-economic model of the baseline scenario, which was then linked to the GINFORS-E macro-economic model to determine the EU-wide impacts of different scenarios (see below).
- Development and modelling of scenarios representing both increased regulation in the EU to achieve world-leadership standards on environmental and safety performance, as well as a scenario to represent a future regulatory 'shock' in China. The impacts of each of these scenarios on the EU and global automotive industry's competitiveness was also assessed.
- Analysis of the outputs from the scenario modelling and provision of guidance to the European Commission on the most effective approaches for maintaining the competitiveness of the EU automotive industry.

These elements are also summarised in Figure 2.1 below.

Figure 2.1: Overview of methodology



2.2 Identification of trends and data collection activities

In order to undertake the modelling required to assess the impacts of varying regulation on the competitiveness of the EU automotive industry, it was necessary to first collect a range of information on the various market, regulatory and technology trends affecting the six geographical markets of interest (EU, China, India, Japan, South Korea and the USA), as well as data on the production cost breakdown for different types of vehicles in each of these markets.

Specifically, this entailed an extensive data collection exercise on market trends regarding the number of vehicles produced and sold in the different markets of interest, as well as a wide-ranging literature review of over 260 sources, that covered the various regulatory, policy and technology trends expected to affect the production of vehicles in the future up to 2050. Research on representative vehicle types was also conducted and their baseline costs and material composition were estimated. Further information on these tasks is provided below.

Market trends

Understanding current and future market trends in terms of production and sales of vehicles is essential to assess the future competitive position of EU manufacturers. It provides an understanding of the size of the current market at home, as well as export markets, but also an overview of the expected growth in the EU market and in the markets of current and future competitors. To this end, we carried out an assessment of projected vehicle production and sales up to 2050 for passenger cars, light commercial vehicles (LCVs) and L-category vehicles (including light two-wheel powered vehicles, two-wheel motorcycles and light/heavy quadricycles – note all analysis related to L-category vehicles is included in Section 5 below) for the EU and the five other countries of interest to the study.

For this and the subsequent quantitative analysis carried out in the remainder of this study, passenger cars were further split into 'entry-level', 'mid-range' and 'luxury' cars (broadly representing small, medium and large vehicles) based on passenger car segment market shares, as provided in more detail in Appendix A.1. These market shares were based on IHS Production data (IHS Automotive, n.d.) which provides forecasts until 2024. After this year, market shares were assumed to remain constant.

Market shares in both production and sales by manufacturer nationality were also analysed for the same vehicle classes and countries. This provides an overview of the presence and relative importance of EU and foreign manufacturers in the different markets. The analysis was undertaken for China and the EU only due to the importance of both these markets for the study. In particular, China is used as the representative foreign market to build a case study scenario reflecting the potential opportunity for EU manufacturers should China take unilateral action to become the most heavily regulated market in the future. Therefore, it is important to understand the Chinese market in detail.

More information on the data sources, methodology and analysis used to determine the market trends is provided in Appendix A.1.

Regulatory, policy and technology trends

To assess the competitiveness of EU manufacturers it is also necessary to understand the trends in regulation, policy and technology in the various markets of interest, in order to evaluate their impacts on vehicle production costs and sales volumes both today and in the future. By doing this, it is possible to gain a more in-depth understanding of the degree to which EU manufacturers are equipped to respond to changes in regulation, policy and technology in these markets compared to their local competitors.

The competitiveness of EU manufacturers and their international competitors will be largely influenced by the costs of producing vehicles and the capacity to sell them in the different markets. Stricter regulations have an impact on the types of vehicles sold and on the costs of producing them to the extent that they impose mandatory specifications which can require manufacturers to incorporate more advanced, higher cost technologies. Technology trends, often driven in turn by regulatory trends or a desire to produce a technologically advanced, differentiated product, affect the types of vehicles produced, the costs of production and the materials used in vehicle components, which also have an impact on costs.

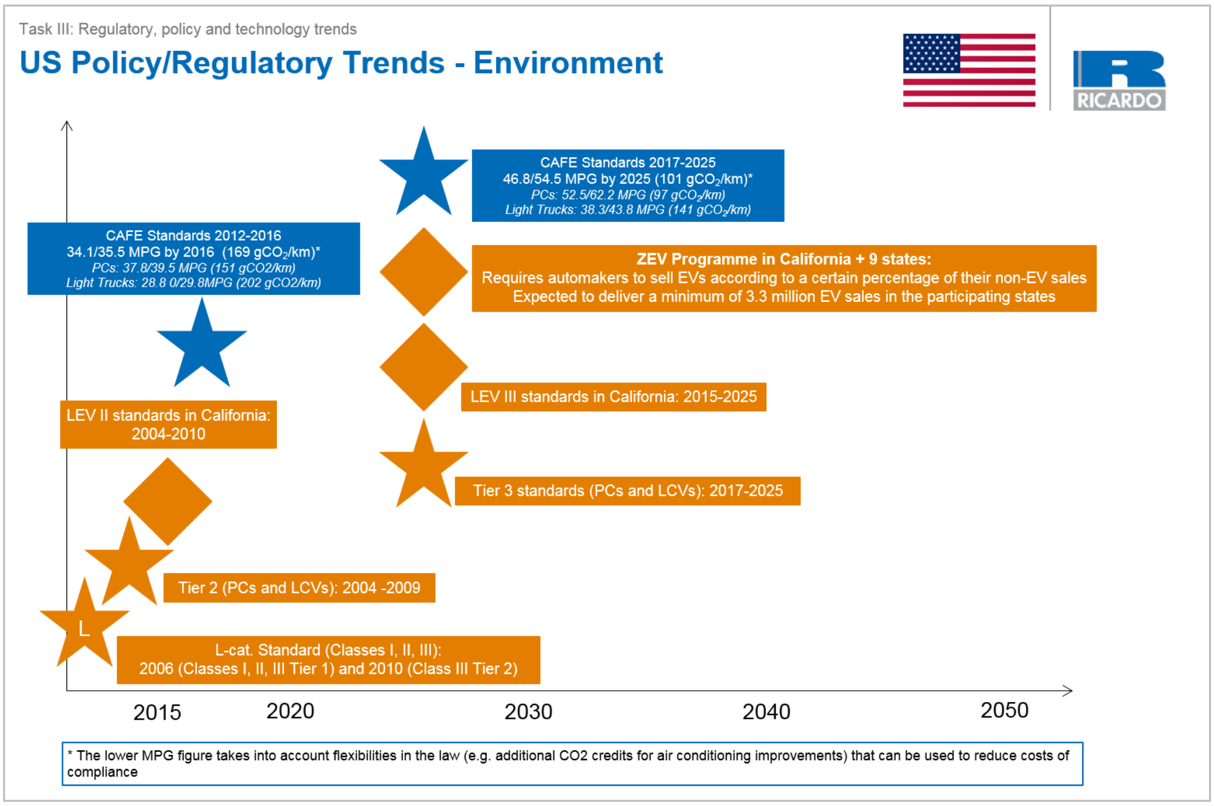
The following main trends were assessed for all six markets covering the time period up to 2050 for passenger cars, LCVs and L-category vehicles:

- Regulatory and policy trends: environment, safety, and autonomous vehicles (AV)
- Technology trends: e-mobility, lightweighting, and connected and autonomous Vehicles (CAV).

Whilst the technology and regulatory trends were treated separately in the qualitative analysis, for the quantitative modelling we have considered them to be inextricably linked and consequently we have not modelled them as independent trends.

The outputs from this analysis were used as a key input to defining the modelling baseline and scenarios, as described further in Section 2.4.2 below. An example of a typical output from the analysis of qualitative trends is provided in Figure 2.2 below. The full outputs from this analysis can be found in Appendix A.4.

Figure 2.2: Example of outputs from the policy and regulatory trends analysis



Baseline vehicle production cost breakdowns

The first step in determining the detailed direct and indirect production cost breakdowns was to define a series of representative EU vehicle models, for each of the vehicle types of interest – i.e. 'entry-level', 'mid-range', 'luxury' passenger cars and light commercial vehicles (LCVs). The aim in selecting representative vehicles was to identify popular models made by EU-headquartered OEMs which are sold in the majority of the global markets considered in the study. These representative vehicles have been used as a basis for establishing the final cost breakdowns.

Following the definition of the representative vehicles, a detailed cost breakdown for each vehicle type, as manufactured in the EU, was determined based on the retail price equivalent (RPE) multipliers available from the literature. Two main studies reported on the breakdown of light vehicle major cost elements for a range of manufacturers in the US and EU, and were therefore chosen for the analysis:

- International Council on Clean Transportation (ICCT): 'Light Duty Vehicle Technology Cost Analysis European Vehicle Market Updated Indirect Cost Multiplier Methodology' (ICCT, 2013)
- US Environmental Protection Agency (EPA): 'Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers' (EPA, 2009)

These multipliers and other data on direct cost breakdowns[3], were used to split price into direct costs (broken down by labour and materials costs), indirect costs (broken down by production overhead, corporate overhead, selling, and dealer costs) and profit margin.

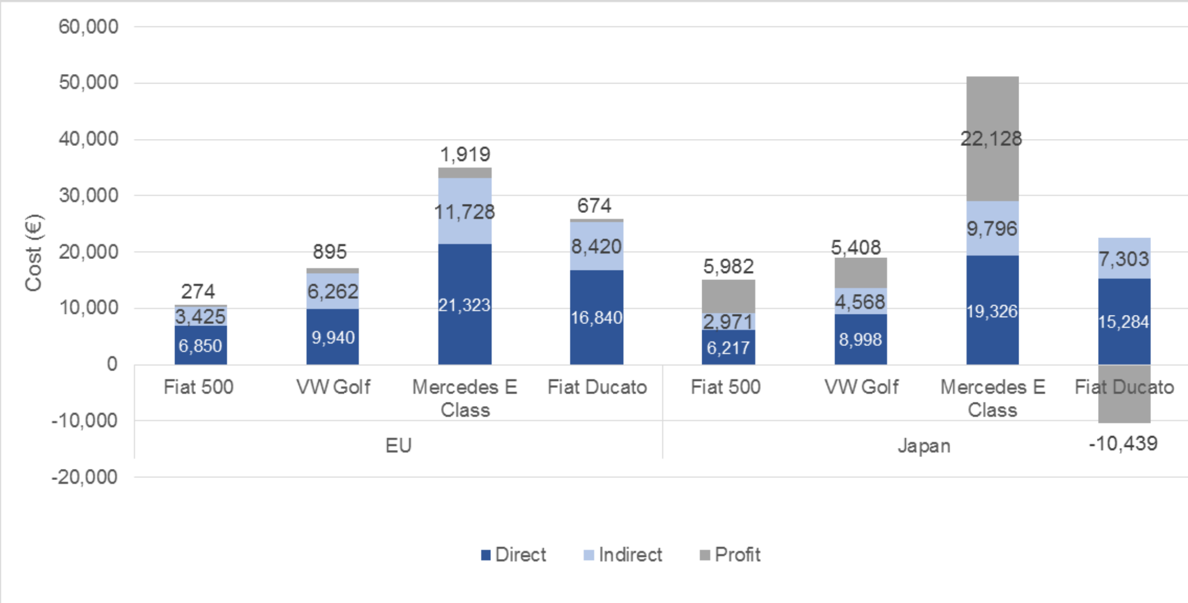
Based on the EU cost breakdown, the production costs of the representative vehicles were then translated to the other relevant markets, assuming that all vehicles are locally produced. The main factors taken into consideration when translating to other markets were the differential labour and steel costs between markets, as well as the differences in

[3] Unlike for the indirect cost components, the RPE multipliers did not provide insights on the breakdown of direct costs. Instead, top-down sources (including Market Realist, (2015)) were used to obtain an overall cost split between materials and labour costs for the various vehicle types in the EU.

typical indirect cost levels for manufacturers based in the different markets of interest. This allowed a translation of costs today, but also in the future, given that for example relative labour costs are likely to vary through time.

The outputs from this analysis were used as a key input to determining the likely impact of future regulatory changes on vehicle production costs in the different markets of interest, as described further in Section 2.4.2 below. An example of a typical output from the cost breakdown analysis is provided in Figure 2.3 below. A more detailed description of the methodology applied to determine the cost breakdowns, as well as the full outputs from this analysis can be found in Appendix A.2.

Figure 2.3: Example of detailed production cost breakdown analysis outputs

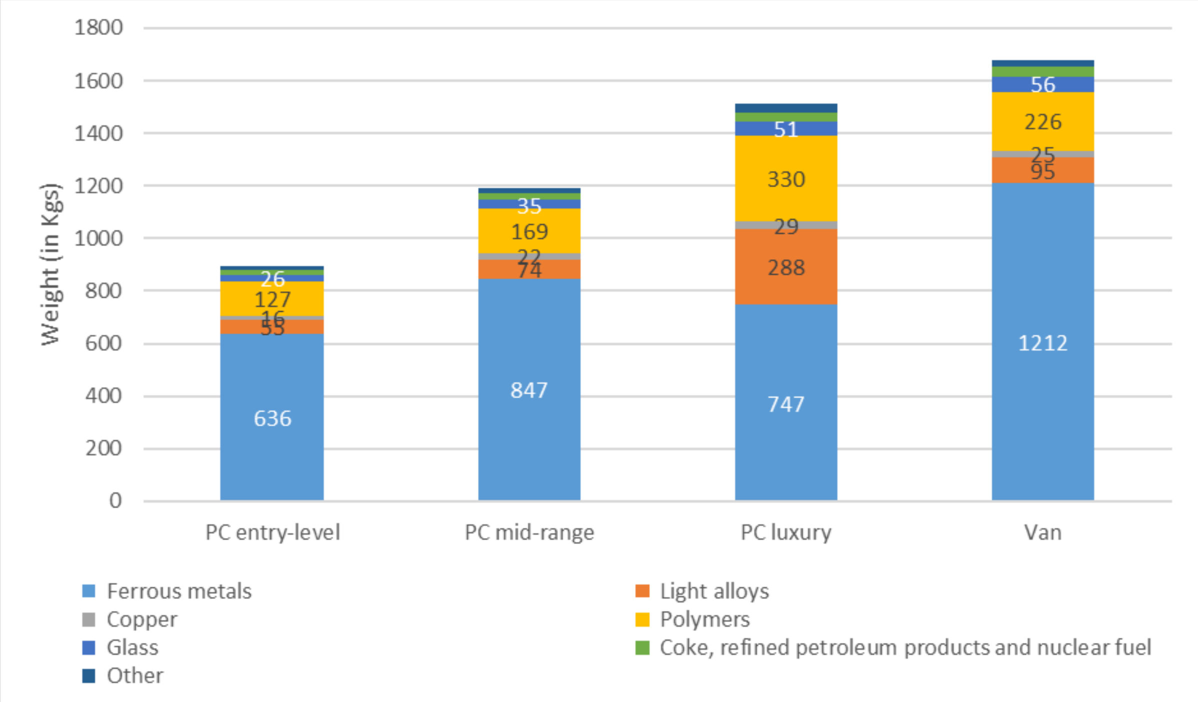


Baseline vehicle material breakdowns

In parallel to the cost breakdown analysis, the input materials breakdown was estimated for each of the representative vehicle types (and their equivalent alternative-drivetrain alternatives) today and in the future, using the GREET2 model (Argonne National Laboratory, 2007) as a basis. This model provided data for an internal combustion engine passenger car, an equivalent of an LCV and plug in hybrid (PHEV), battery electric (BEV) and fuel cell (FCEV) variants of each these vehicles. The shares of the different materials were applied to the total mass of the representative vehicles in order to obtain the material breakdown for the different sized representative vehicles and to obtain a diesel variant of the petrol baseline. Data from a recent Mercedes-Benz lifecycle analysis (LCA) (Mercedes-Benz, 2016) was used to update the luxury representative vehicle's material composition from GREET with more up-to-date data, recognising the already-extensive use of lightweight materials in the luxury vehicle segment. Finally, in order to project changes in materials composition through time, data from an IFEU materials database (Zimmer, et al., 2016) was used to estimate changes related to lightweighting (covering all vehicle types), whilst battery efficiency gains (covering mainly BEVs) through time are based on changes in battery mass estimated for a recently updated in-house analysis building on the work conducted to develop the CO_2 costs curves produced by Ricardo for DG CLIMA (Ricardo Energy & Environment et al, 2016), using more recent expectations for future battery cost projections and BEV electric ranges (described in more detail in section 2.4.4.1).

The outputs from this analysis were used as a key input to determining the likely impact of future regulatory changes on vehicle materials composition in the different markets of interest, as described further in Section 2.4.3 below. An example of a typical output from the cost breakdown analysis is provided in Figure 2.4 below. The full outputs from this analysis can be found in Appendix A.3.

Figure 2.4: Example of outputs from the materials breakdown analysis



2.3 *Overview of modelling approach*

To assess the external competitiveness of the EU automotive industry in the EU and five other key international markets, a modelling approach was developed to understand the impact of regulatory changes on vehicle production costs and material composition occurring at different rates, in different markets, through time. The modelling involved both a micro-economic modelling step and a macro-economic modelling step, as described below.

The micro-economic model was designed to parameterise the changes in regulatory trends over time, linking a quantified version of these trends in the different markets to changes in specific on-board vehicle technologies and, in turn, production costs, margins and materials breakdown for the various vehicle types of interest. This model also estimated the changes in market shares for the different drivetrains through time in the different markets, based on the likely strength of environmental regulation in each market. The micro-economic model is described in more detail in Section 2.4 below.

Outputs from the micro-economic model were fed into the GINFORS-E macroeconomic model, an economy-energy-environment model with global coverage which analyses and forecasts structural changes to the automotive industry from a top-down perspective in relation to:

- Its position in the national economy for selected indicators like production, labour, value added, costs, prices etc.
- Its position in global bilateral trade flows differentiated between exports/imports and between intermediate and final products
- Its direct and indirect effect on the economy
- Its contribution to emissions, energy consumption etc.

A full description of GINFORS-E model and its use in the overall modelling approach is provided in Section 2.5 below.

2.4 Microeconomic model

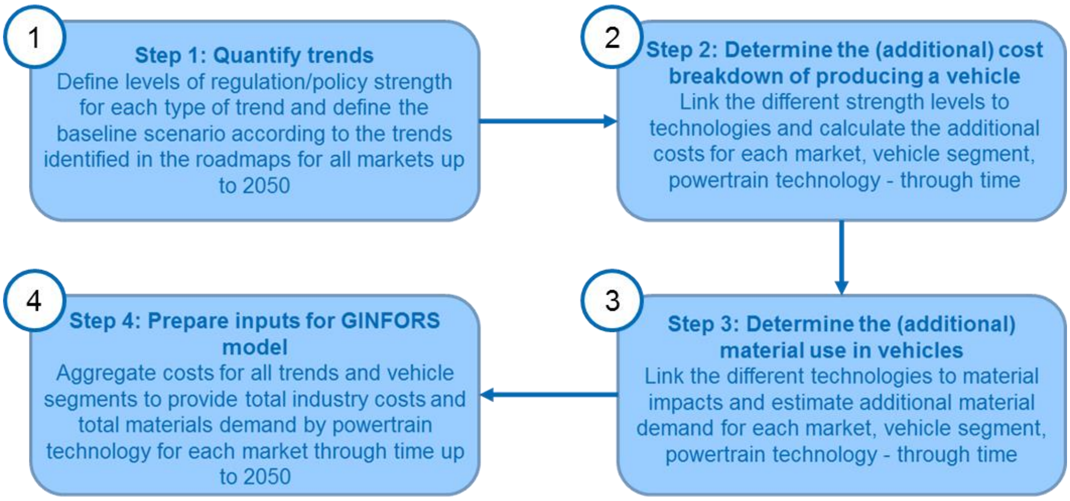
2.4.1 Model overview

As described above, a microeconomic model was developed to assess the impacts of trends in regulation, policy and technology on the costs of producing vehicles in the various markets of interest through time, as well as on their material composition.

The ultimate aim of the model is to obtain the average and total production costs in each direct and indirect cost category, associated profit margins and total material demand across a range of key materials in each market over time, in order to provide these data as inputs for the GINFORS-E macroeconomic model.

Figure 2.5 provides an overview of the modelling approach adopted, with each step described in detail in the next sub-sections.

Figure 2.5: Overview of modelling approach



2.4.2 Input data

The micro-economic model draws on a range of input data collected, as described in Section 2.2 above. Key input data for the model includes:

- Vehicle production forecast data between 2017 and 2050 in 5 year intervals from 2020 for all six markets of interest, broken down by vehicle type (i.e. entry-level, mid-range and luxury car, as well as light commercial vehicles).
- Representative vehicle prices for each vehicle category in each market, as well as the breakdown of production costs for today's vehicles in the EU and the US across all the key direct and indirect cost categories, as described in Section 2.4.4.2 below.
- Conversion ratios to convert the costs of the baseline EU vehicles to costs in other markets, based on labour cost ratios, differential materials pricing (e.g. steel), as well as the differences in indirect cost ratios between markets, drawing on the analysis described in Appendix A.2.
- Detailed materials breakdowns for each vehicle segment and powertrain technology, as described in Appendix A.3.
- The relative 'strength' of trends in regulation, policy and technology for all markets that are anticipated to have an impact on vehicle production costs, as described in detail in Appendix A.4.
- Data on the cost of specific technologies required to meet different regulatory levels (see Section 2.4.4 below for further details), including:
    - Safety equipment: costs of equipment ranging from passive measures such as seat belt reminders and ABS, to active measures including different levels of autonomous driving up to Level 4

- Emissions control equipment: in particular, equipment required to meet increasingly stringent air pollutant limits, such as Selective Catalytic Reduction (SCR) technology
- Efficiency / CO_2 reduction technologies: here the analysis was based on a series of CO_2 cost curves previously developed for the EC by Ricardo, which provide the additional cost of achieving different CO_2 reduction levels, as well as the cost of alternative drivetrain vehicles.

The detailed methodologies for collecting these data and the data itself are discussed in more detailed in the Appendices.

2.4.3 Step 1: Quantification of trends

Step 1 of the micro-economic modelling approach described above concerns the quantification of the trends identified previously in the roadmaps, as described in Appendix A.4. It entails the definition of discrete levels of policy strength in order to develop the baseline and other scenarios based on the trends researched previously and expectations of future developments in the different markets. The quantification of these trends thereby enables a direct comparison of the regulatory strength in different markets through time, as well as providing the quantification necessary to parameterise the link between regulatory strength and production costs / material composition in the different markets through time.

One key observation that resulted from the previous research is the clear link between the technology trends identified and the regulatory trends. The analysis is thus focused on three main regulatory trends:

- Environmental trends – CO_2 emissions/fuel efficiency regulations and policies (including lightweighting and e-mobility technology trends)
- Environmental trends – air quality/local pollutant limit regulations and policies
- Safety trends (including CAV technology trend)

For each type of trend, between nine and eleven policy 'strength' levels were defined, ranging from very low to very high, with each strength representing a different level of regulatory ambition for that particular regulation. Criteria were established to define the different levels of ambition, as follows:

- For CO_2/fuel efficiency policy trends: linked to CO_2 limit/efficiency standards and electric vehicle (EV) market share
- For air quality/local pollutant policy trends: linked to Euro emission standards
- For safety trends: linked to the inclusion of passive safety features and varying levels of vehicle automation

The definition of the various regulatory strength levels is described in further detail below. The criteria described above were used to define discreet levels of regulatory strength, which aim to represent a continuous progression of regulatory trends. Some subjectivity was applied in developing these levels, based on an understanding of current and future disparities between markets and in order to allow sufficient future progression in each regulatory area, up to 2050.

2.4.3.1 CO_2 emission/fuel efficiency regulatory strength definitions

CO_2/fuel efficiency policy trends were linked to the evolution of fleet average CO_2 emissions limits, as well as the xEV market share of new sales (split into PHEV and ZEV – including BEVs and FCEVs). NEDC-equivalent conversions were calculated for the non-EU markets, in order to present comparable regulatory strengths in all the markets of interest.

The initial lower levels from levels 0 to 3 were based on existing or announced emissions standards and expected near-term market shares for xEVs. The higher 'strength' levels assume an increase in stringency, both through reduced emissions from ICEs, but also a key contribution from increasing the market share of xEVs, with the highest level 10 including 100% ZEVs. The range of levels and their limits were chosen, in order to be able to differentiate between the various markets' regulatory ambitions over time. The definition of the xEV market shares associated with the higher levels is particularly important as it enables the achievement of the CO_2 standard defined for that level. The CO_2 standard represents a fleet average (of all powertrains) and as such the achievement of the tightest CO_2 targets requires both improvements in ICE vehicle technology (to reduce gCO_2/km driven) and an increasing share of zero emission vehicles. Indeed, it is assumed that the CO_2 performance achieved by ICE vehicles in each year (as given by the CO_2 costs curves described in section 2.4.4.1) needs to be complemented by the production of xEVs such that the average CO_2 performance of the fleet produced in a given year complies with the overall CO_2 standard set for the relevant level. Table 2.1 and Table 2.2 respectively describe the CO_2 emissions levels for passenger cars/LCVs, and the corresponding market shares of xEVs, for each regulatory level considered.

Table 2.1: CO_2 emissions / fuel efficiency regulatory levels used in modelling

			Criteria (in gCO_2/km)	
Level	**Description**	**Abbr.**	**PC**	**LCV**
0	Very Low	VL	135	190
1	Low	L	120	170
2	Low+	L+	105	150
3	Low/Medium	L/M	90	130
4	Medium	M	75	110
5	Medium/High	M/H	60	90
6	High	H	45	70
7	High +	H+	30	50
8	High ++	H++	20	30
9	High+++	H+++	15	20
10	Very High	VH	0	0

Table 2.2: Market shares for passenger cars and LCVs respectively, for each different regulatory level

Passenger cars				LCVs			
Level	**ICE**	**SI PHEV**	**ZEV**	**Level**	**ICE**	**SI PHEV**	**ZEV**
0	99.50%	0.3%	0.2%	**0**	99.50%	0.3%	0.2%
1	99.40%	0.4%	0.2%	**1**	99.40%	0.4%	0.2%
2	98.70%	0.7%	0.6%	**2**	98.70%	0.7%	0.6%
3	86.50%	12.5%	1.0%	**3**	87.00%	12.0%	1.0%
4	68.00%	25.0%	7.0%	**4**	70.00%	23.0%	7.0%
5	50.00%	35.0%	15.0%	**5**	53.00%	33.0%	14.0%
6	34.50%	35.0%	30.5%	**6**	39.00%	34.0%	27.0%
7	18.50%	35.0%	46.5%	**7**	25.00%	34.0%	41.0%
8	10.50%	28.0%	61.5%	**8**	13.70%	24.8%	61.5%

Passenger cars				LCVs			
Level	**ICE**	**SI PHEV**	**ZEV**	**Level**	**ICE**	**SI PHEV**	**ZEV**
9	10.50%	14.5%	75.0%	**9**	10.00%	15.0%	75.0%
10	0.00%	0.0%	100.0%	**10**	0.00%	0.0%	100.0%

2.4.3.2 Pollutant emission regulatory strength definitions

Trends in vehicle air pollutant emissions were linked to Euro standards, given the wide-ranging adherence to (or replication of) these standards in different markets globally – Euro standards thereby provided an ideal discreet measure of the strength of regulation in the different markets. The only market which deviates significantly from this is the US, where Euro-level equivalents of the announced Tier 2 and Tier 3 regulations were determined based on specific emissions limits.

Levels defined assume an increase in stringency of the regulation, moving incrementally from Euro 3 to the current Euro 6 RDE, followed by China 6b and US Tier 3 regulations which are stricter than Euro 6 RDE, and finally a future 'Euro 7' which was not fully defined. Table 2.3 presents the resultant pollutant emission regulatory strength levels used in the micro-model.

Table 2.3: Pollutant emission regulatory levels used in modelling

Level	Description	Abbr.	Criteria
0	Very Low	VL	Euro 3 and below
1	Low	L	Euro 4
2	Low/Medium	L/M	Euro 5
3	Medium	M	Euro 6
4	Medium/High	M/H	Euro 6 RDE
5	High	H	China 6b & US Tier 3
6	Very High	VH	Euro 7

2.4.3.3 Safety regulatory strength definitions

Safety trends were linked to the requirement for specific safety features to be fitted to new vehicles.

Guidance on the specific technologies to include in each strength level was drawn from both UN Regulations endorsed by the World Health Organisation (WHO) and Global NCAP as well as NCAP recommended technologies as specified in Appendix A.4. Given the fact that world reference regulations are developed by the UNECE, the lower levels of safety regulations were defined based on the technologies which allow OEMs to meet the minimum safety levels as defined by key UN Regulations and recommended by the WHO and Global NCAP (seat belts, air bags, etc.), whilst for the more advanced safety measures, these were derived from current best-practice safety features which have been announced in the developed countries but have yet to enter into force in these markets (e.g. rear-view cameras, eCall). Future regulatory strength levels were mainly linked to active measures aimed at improving driving and minimising human error – in particular increasing levels of automation ranging from Level 1 to Level 4, which provided a convenient, discrete set of levels to be used to define regulatory strength in this case. It is expected that active safety measures will become increasingly relevant over time – they may even substitute other passive safety features in the long-run as the probability of certain accident types decreases with decreasing human intervention in driving. Table 2.4 presents the safety regulatory strength levels used in the micro-model.

Table 2.4: Safety regulatory levels used in modelling

Level	Description	Abbr.	Criteria
0	Very Low	VL	Minimum safety features
1	Low	L	Very Basic Safety Features
2	Low+	L+	Basic Safety Features
3	Low/Medium	L/M	Intermediate Safety Features
4	Medium	M	Level 1 Automation: Warnings
5	Medium/High	M/H	Level 1 Automation: Vehicle taking control of pedals or steering
6	High	H	Level 2 Automation
7	High +	H+	Level 3 Automation
8	Very High	VH	Level 4 Automation

2.4.3.4 Defining regulatory strength levels for the baseline definition and scenarios

Having developed definitions for the different policy strength levels, the progression of regulatory strength in each market through time was defined based on the trends identified in the roadmaps described in Appendix A.4.

The baseline scenario is thus defined by the trend lines for each market in terms of the timewise progression for the three regulatory trends described above. The result is a series of graphs showing when the different markets are expected to achieve the different levels of policy strength and at what pace. Variations on these trend lines were developed in order to model the impacts of multiple scenarios on the competitiveness of the EU automotive industry. More detail is provided in Section 3 on the baseline and scenario definitions.

2.4.4 Step 2: Estimation of additional vehicle production costs and profit margin

Step 2 of the micro-economic modelling approach described above is aimed at parameterising the link between the regulatory strengths defined in Step 1 and the inclusion of specific technologies on board vehicles, in order to estimate the production cost impacts (and in Step 3 the materials impacts) of moving from one regulatory strength level to the next. This step also includes an estimation of the impact of changes in costs on the pricing and profitability of producing vehicles. Finally, additional costs associated with moves between increasing regulatory strength levels are broken down for the EU between the various cost categories (described in Appendix A.2), with this cost breakdown then being converted to estimate production cost breakdowns in all six of the markets of interest. Further detail on the methodology applied is provided in the sub-sections below.

2.4.4.1 Technologies and incremental costs

The move from one regulatory strength level to another was linked to specific technologies on board vehicles which allow manufacturers to achieve compliance with the next regulatory strength level for that particular area of regulation. Production costs were then determined for each step change between the regulatory strength levels in the EU market.

CO_2 emissions regulations

Cost changes associated with improvements in CO_2 emissions performance/fuel efficiency were defined based on CO_2 cost curves linking cost with the achievement of specific reductions in gCO_2/km over and above a baseline vehicle. These curves were originally developed by Ricardo for DG CLIMA to support the development of the EU's car and LCV

CO_2 emissions regulations for the post-2020 time period[4] and were constructed using industry data and published information on existing and emerging technologies and uptake rates, then validated using an extensive stakeholder consultation exercise (Ricardo Energy & Environment et al, 2016). The curves indicate the least-cost way of achieving CO_2 emissions fuel efficiency improvements, based on the use of a wide range of technologies, including (for example) lightweighting, improvements in engine efficiency, powertrain hybridisation and full electrification of powertrains.

Cost curves were available for all four vehicle categories relevant to the study (i.e. small, medium and large passenger cars and LCVs) and provided for the years 2015, 2020, 2025, and 2030. For the year 2017, costs were calculated based on interpolation between costs in the previous and following years for which a cost curve was available. Beyond 2030, costs curves for the petrol and diesel powertrains were not available and therefore costs for all vehicle types were extracted from the 2030 cost curve, such that they allow OEMs to achieve the higher level of CO_2 standard mandated in the future (i.e. cost obtained from the same 2030 cost curve to achieve a higher CO_2 reductions in line with future regulation).

Given the different vehicle size categories of interest for the passenger car analysis, the current mass-based formula for calculating manufacturer-specific emissions targets (from Regulation No 443/2009/EC (2009) and amended by Regulation (EU) No 333/2014 (2014)) was used to convert each regulatory strength level's fleet average CO_2 emissions limit for internal combustion engine (ICE) vehicles into specific limits for the entry-level, mid-range and luxury passenger car segments. As the curves are defined relative to a series of 2013 baseline vehicles, all changes beyond 2013 were estimated to contribute to additional production costs over and above the 2013 baseline vehicles.

Note that given the limits to fuel efficiency improvements on current ICE vehicle, the CO_2 emissions regulatory strength levels were also linked to changes in market shares for the following specific powertrain technologies:

- ICE vehicles: petrol and diesel vehicles including mild hybrids
- PHEVs: petrol only
- Zero Emission Vehicles (ZEVs): BEVs and FCEVs

The production costs of these different drivetrains were also determined based on specific CO_2 cost curves for each of these drivetrain options. The cost curves for these alternative powertrains were recently updated building on the work develop for DG CLIMA (Ricardo Energy & Environment et al, 2016), using more recent expectations for future battery cost projections and BEV electric ranges. Cost curves for xEVs are available for 2015, 2020, 2025, 2030, but also for 2040 and 2050 (unlike for conventional drivetrains where no post-2030 curves were available). In this case, the additional costs are referenced against the equivalent ICE vehicle in the baseline year. In the case of BEVs and FCEVs, the target is expressed in improvements in energy efficiency as opposed to reductions in CO_2 emissions. As there is no specific target for energy improvement of xEVs, the minimum additional cost that could be obtained from the curve for each year was selected. The curves assume cost reductions over time, with each subsequent curve including assumptions on the savings made through learning effects since the previous curve.

Pollutant emissions regulations

Changes in costs associated with air pollutant emissions regulation were defined based on the specific emission control technologies required to meet different Euro standards and other relevant vehicle-related air pollutant emissions regulations. It was generally possible to define specific technologies which would allow a jump from one Euro level to the next, thereby facilitating this analysis. Overlapping technologies between different regulatory strength levels were subtracted, to obtain only incremental costs for moving from one regulatory strength level to the next.

Where relevant, data was adjusted to account for the different engine sizes between the entry-level, mid-range and luxury passenger car variants and subsequent changes to the

[4] https://ec.europa.eu/clima/policies/transport/vehicles_en#tab-0-2

costs required to reduce emissions sufficiently to comply with the legal limit, whilst the very different technologies required to control pollutant emissions from petrol vs. diesel engines were also accounted for. For PHEVs, costs were assumed to be the same as for petrol vehicles, whilst for ZEVs, no costs were included.

The main technologies associated with the different regulatory levels and sources of data used to derive these are included in Table 2.5 below.

Table 2.5: Pollutant emission regulatory levels and sources for their costs

Level	Standards	Sources
0	Euro 3 and below	Petrol: (Posada, et al., 2013) Diesel: (Posada, et al., 2013)
1	Euro 4	
2	Euro 5	
3	Euro 6	
4	Euro 6 RDE	(TNO and AVL, 2014)
5	China 6b & US Tier 3	China 6b: (ICCT, 2017) US Tier 3: (US EPA, 2014)
6	Euro 7	Estimation

Note that for the highest illustrative "Euro 7" level, given the high degree of uncertainty as to how this regulation will be defined in the future, the cost of the technology to achieve this future regulatory standard were assumed to the same as the incremental cost of moving from Euro 5/Euro 6[5] to Euro 6 RDE in the case of petrol vehicles, and from Euro 6 to Euro 6 RDE in the case of diesel vehicles.

Safety regulations

Costs associated with changes in safety regulations were defined based on specific safety technologies associated with moving from one regulatory strength level to the next. Technologies included both traditional passive safety features such as seat belt reminders and ABS, to more active measures associated with increasing levels of automation. Overlapping technologies between different regulatory strength levels (e.g. between different levels of automation) were subtracted, to obtain only incremental costs for moving from one regulatory strength level to the next.

The main technologies associated with the different regulatory levels and sources of data used to derive these are included in Table 2.6 below.

Table 2.6: Safety technologies and sources

	Level	Technologies	Sources
0	Low	Seat belts	N/A
1	Very Basic	Air bag; Anti-lock Braking System (ABS)	(The Telegraph, 2001) (Business Standard, 2014) (NHTSA, 2009)
2	Basic	Electronic Stability Control (ESC), Tyre Pressure Monitoring System (TPMS); Isofix; Seat Belt Reminder (SBR) for driver	(NHTSA, 2007) (Steelmate Automotive, 2017) (Association for the Advancement of Automotive Medicine, 2003)
3	Intermediate	SBR; eCall; Rearview Cameras; Emergency Braking light Display	(Frost & Sullivan, 2015) (NHTSA (2), 2009)

[5] For petrol vehicles, the limits established by Euro 5 are the same as the limits mandated by Euro 6, which implies no additional cost between the two regulatory levels for this powertrain

Level		Technologies	Sources
		(EBD), Protection of far-side occupants in side impact collisions (SFS)	(European Commission, 2015)
4	Level 1	Forward Collision Warning (FCW); Speed Limit Detection (SLD); Lane Departure Warning (LDW); Blind Spot Detection and Rear Cross Traffic Alert (BSD+RCTA); Driver Distraction and Drowsiness recognition (DDR)	(CR , 2015) (Fleet News, 2016) (European Commission, 2015)
5	Level 1B	Intelligent Speed Advice (ISA); Lane Keep Assist (LKA); Automatic Emergency Braking (AEB); Adaptive Cruise Control (ACC); Alcohol Interlock; Event Data Recorder (EDR); Pedestrian and cyclist protection systems; Adult head to windscreen protection	(ETSC, 2017) (NHTSA (2), 2007) (ETSC, 2015) (TRL, 2014) (Autoevolution, 2013) (European Commission, 2015)
6	Level 2	Autopark (inc. BSD+RCTA); Traffic Jam Assist (TJA) (inc. LKA & ACC); Single-lane highway autopilot (inc. TJA); Highway autopilot with lane changing (inc. Single-lane highway autopilot)	(bcg perspectives, 2015)
7	Level 3	Urban autopilot (inc. TJA & Auto-park)	(bcg perspectives, 2015)
8	Level 4	Fully autonomous (inc. Auto-park, TJA, Highway autopilot with lane changing & urban autopilot)	(bcg perspectives, 2015)

Note that given the high costs associated with the higher levels of autonomy, the highest levels of automation were restricted to the larger vehicle sizes, with the highest regulatory level (level 8) mandating Level 4 autonomy in luxury vehicles, Level 2 autonomy in mid-range vehicles and Level 1 autonomy in entry-level vehicles.

2.4.4.2 Cost breakdown

Step 2 of the micro-economic modelling approach also includes an estimation of the cost breakdown for the incremental costs for moving between different regulatory levels, based initially on EU costs and subsequently converted to the other markets of interest.

Production costs determined for each step change described above are initially based on EU costs (or US costs in the case of safety technologies), in order to provide a level playing field for modelling changes in regulation through time in all markets.

The costs are then split into direct and indirect costs based on the EU percentage breakdown for the different vehicle segments:

- Direct costs: labour and material costs
- Indirect costs: production overheads, corporate overheads, selling and dealership costs

The cost breakdowns are then converted to the other markets following a similar approach as used for developing the detailed direct and indirect cost break-downs for the different vehicles (see Appendix A.2 for further details), with the costs in the other markets calculated for each cost category based on the ratios between the EU and the relevant market for that cost category (for example the labour cost ratios between the EU and other markets and how this varies through time). Note that for the US, costs are based directly on the US cost percentage breakdown for the different vehicle segments, given the availability of primary cost breakdown data for this market.

Finally, cost reductions are applied where relevant, driven by learning effects and economies of scale in production. Fully depreciated costs are assumed from the start for all technologies, based on the assumption that economies of scale in production have been achieved by the time technologies are mandated. This reflects the rationale that these are mature technologies or mass market adoption will allow manufacturers to quickly achieve cost reductions when regulation is mandated. The exception to this rule is on the costs associated with the CO_2 emission regulations since the cost curves intrinsically model cost reductions over time, hence applying any further learning effects would not be appropriate. The learning rates applied to the various technologies associated to pollutant emission and safety regulations are presented in Table 2.7 below, as derived from the US EPA (2014).

Table 2.7: Learning effects applied to technology costs in micro-economic model

Type of learning effect	Factor	Notes
No learning	1	
Steep learning	0.59	Applied to more recent technologies which are expected to benefit from cost reductions derived from learning *Note that the factor includes both steep and flat learning effects*
Flat learning	0.74	Applied to more mature technologies which will only benefit from small learning effects

Source: (US EPA, 2014)

Note that the fully depreciated costs applied in the modelling for pollutant emissions control and safety technologies do not account for any potential R&D expenditure that may be incurred in developing the technologies required to meet the regulatory strength levels considered. In some cases, such costs could be large and OEMs may need support in covering these costs, for example from existing R&D-related funding sources, such as Horizon 2020. These additional R&D costs are nevertheless indirectly accounted for in the analysis, through the use of overhead multipliers to determine production overheads. Regarding the production of xEVs, R&D costs were taken into account in the development of the CO_2 cost curves.

2.4.4.3 Profit margin analysis

The pricing response of OEMs to production cost changes is also estimated in the micro-economic model, in order to evaluate the likely impact on profit margins. Historically, the response of OEMs to cost changes has generally been to keep base prices stable, whilst maintaining margins through other means such as increasing the price of optional extras. For example, the cost of cloth seat trim increased by more than 100% between 2003 and 2015 (CAP HPI Consulting, 2016). To reflect this, a simple rule has been applied in the modelling which keeps profit margin to a minimum level of 2% in all markets, for all vehicle types. This means that if the margin prior to an increase in regulatory strength is higher than 2%, some of the cost increase will be absorbed by reduced margin, but once the margin is depleted to a minimum level of 2%, price increases will be required to model the response of OEMs to maintaining minimum profitability levels.

The model only considers profit margins on the vehicle itself ('product line' margins) and not on the whole business thereby excluding other sources of revenue such as post-sales insurance, financial services, parts and repair services, among others, which OEMs typically use to achieve higher profit margins. This could lead to an underestimation of overall profit margins and may also explain the higher margins described in the literature for luxury cars than predicted by model.

We also do not consider the impact of changes in prices on consumers' elasticity of demand in relation to purchasing vehicles. Rather, it is assumed that consumers continue to purchase the same number of vehicles, with the impact of this being modelled in the macro-economic model as a reduction in spending in other sectors.

2.4.5 Step 3: Estimation of the additional material use in vehicles

Step 3 of the micro-economic modelling approach described above is aimed at estimating the changes in material composition for vehicles associated with changes in regulation. For this purpose, the link between specific technologies and material use associated with different regulatory strength levels for both safety and pollutant emission control is assumed to be minimal, given that these technologies tend to be relatively simple technologies that are unlikely to have a significant impact on the overall material composition of the vehicles.

The impact of CO_2 emissions/fuel efficiency regulations however is largely associated with increased hybridisation and lightweighting, as well as changing market shares for different powertrains. These impacts were considered for the material composition analysis, given the significant impact of these measures on the material composition of vehicles. These were modelled as follows:

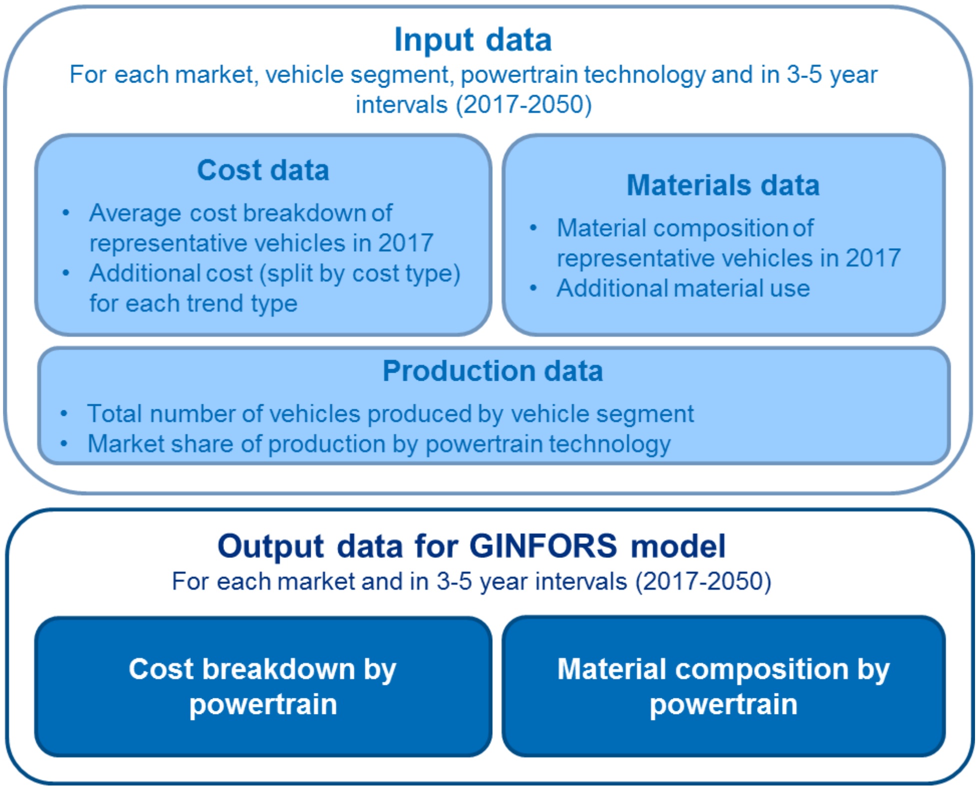
- The most significant impact from changes in material composition through time is driven by changes in market shares of different powertrain technologies, given the significant differences between the composition of e.g. a BEV vs. a traditional diesel ICE vehicle. The material composition of each drivetrain type is based on the GREET2 database last updated in 2016 (Argonne National Laboratory, 2007), which provides detailed information on the material use in vehicles for different drivetrains. Total mass for each powertrain and vehicle segment in 2017 is based on information for the representative vehicles.
- Changes through time related to lightweighting for all vehicle types, as well as battery efficiency improvements for the xEVs, are incorporated based on data identified in the IFEU database (Zimmer, et al., 2016). Note however that these are not directly linked to the specific technologies used to calculate regulatory costs but are instead covered through the timewise use of evolving materials compositions (e.g. greater use of composites and aluminium) from the IFEU database.
- Changes through time associated with battery efficiency improvements are based on estimates of total battery mass over time computed as part of recently updated in-house analysis building on the work conducted to develop the CO_2 costs curves produced by Ricardo for DG CLIMA (Ricardo Energy & Environment et al, 2016), using more recent expectations for future battery cost projections and BEV electric ranges. The share of materials applied to the battery mass in order to obtain the specific material composition of the lithium-ion battery is based on GREET2 database.

2.4.6 Step 4: Preparation of inputs for GINFORS macroeconomic model

Step 4 of the micro-economic modelling approach described above is aimed at aggregating the vehicle cost and materials breakdowns described above and preparing the input data for each market and powertrain to 2050, in order to in put this into the GINFORS-E macroeconomic model. Figure 2.6 summarises the input data for the micro-economic model and specifies the output data that is fed into the GINFORS-E model.

For each market, powertrain technology and 5 year interval, vehicle production costs were aggregated considering the strength of regulations in place in the market in each year (3 trends combined) and relative market share of different vehicle segments. The same procedure is followed to determine total material demand.

Figure 2.6: Input and output data of the microeconomic model



2.5 *GINFORS-E macroeconomic model*

The GINFORS-E macroeconomic model is used as the final step in the impact estimation modelling, whereby the inputs from the micro-economic model are fed into GINFORS-E, in order to estimate the overall macro-economic impacts on GDP, employment, trade flows, etc. for the various scenarios described below, as well as the relative importance of these impacts on the specific industries covered by GINFORS-E. The GINFORS-E baseline is aligned to the EU Reference Scenario regarding GDP development and energy price assumptions (European Commission, DGs for Energy, for Climate Action and for Mobility and Transport , 2016). Additional automotive sector specific information from the micro model has also been considered for the baseline and the other scenarios (see section 4.2.1).

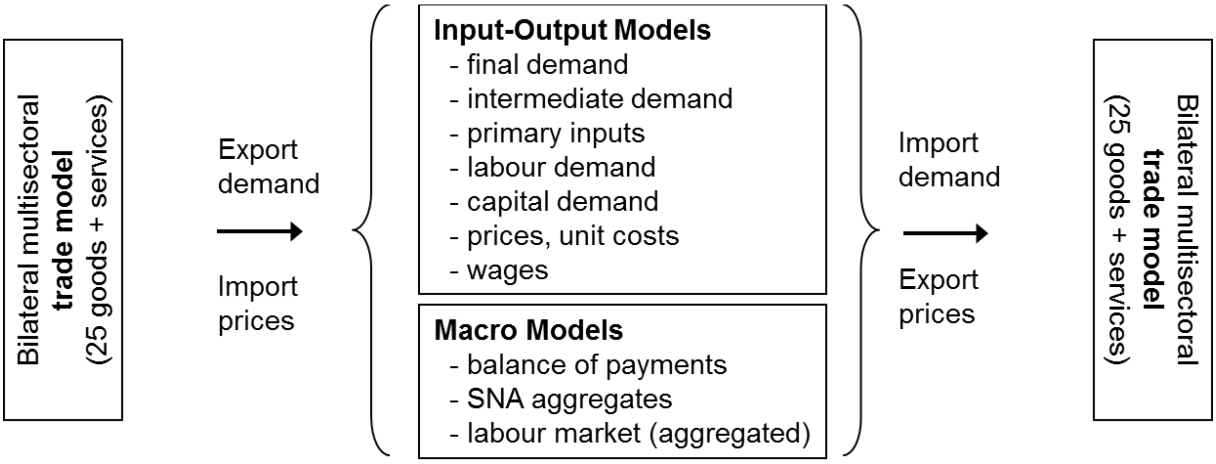
The **GINFORS-E** (global inter-industry forecasting system – energy) model is a bilateral world trade model based on OECD data, which consistently and coherently models exports and imports of 25 goods groups for 62 countries and one 'rest of the world' region (Figure 2.7). GINFORS-E includes IEA energy balances and CO_2 data to a high level of detail. It incorporates a macro-economic model, consisting of exports and imports, other core components of final demand (private and public sector consumption and investment), markets for goods and the labour market, for each country. For more than 50 countries, the models are also divided into 48 categories of goods in accordance with the OECD (2015) internationally harmonised input-output (IO) tables (Table 2.9)[6]. For every country OECD bilateral trade data at industry level is linked to the IO tables (Figure 2.7). In Lutz et al. (2010) the model is described in detail, although some of the relations have changed since then (e.g. OECD has adjusted the sector classification several times).

Each national model is linked to an energy model, which determines energy conversion, energy generation and final demand for energy for 19 energy sources disaggregated by

[6] Additional to the published version with 34 industries we have received more detailed data for 48 industries.

economic sector. The model takes into account technological trends and price dependencies. It comprehensively models international trade in energy sources.

Figure 2.7: Country model of GINFORS-E



GINFORS-E can be used to analyse the macroeconomic effects of a variety of price changes and policies in individual countries and enables users to drill down into individual sectors. It flexibly models trade structures, labour markets, energy intensities and energy source structures, taking into account price dependencies and the situation in specific countries. The parameters used in the model equations are econometrically estimated (OLS) on the basis of time-series data.

For all scenarios, results from the micro-economic model have been included in GINFORS-E. This input covers six markets (EU, China, USA, Japan, Korea, and India) and different powertrains in 5 year intervals and covers:

- Total cost breakdowns and profits for car light commercial vehicle sales, broken down by:
    - Direct and indirect cost category, as described in Section 2.4.4.2 above
    - Vehicle drivetrain, i.e. petrol, diesel, PHEV, BEV and FCEV
- Total material composition, broken down by drivetrain
- Market share of the different drivetrains considered in each market.

This has been transformed to be used as input in GINFORS-E as follows:

- The cost breakdown for car sales is used to adjust the input structure of industry 21, motor vehicles, trailers and semi-trailers. Table 2.8 shows in more detail how inputs from the micro-economic model have been used in the macro-economic model. The input structure, which is based on input-output tables from the OECD, describes in monetary terms for 48 industries according to Table 2.9, how much input is needed to produce one unit of output (input coefficient). It separates domestically produced and imported inputs.
- If regulation increases the cost of vehicle production in the EU, producers will have to adjust prices. As importers have to meet the same regulation, they will also have to raise prices. No change in the import ratio of vehicles is expected. In the internal market sensitivities, however, this assumption is partly altered, in order to represent the situation in which some OEMs from third countries may no longer be able to meet the more stringent requirements for selling vehicles in the EU. For vehicle exports from the EU, vehicle manufacturers do not have to meet more stringent domestic regulation. Costs for vehicles exported from the EU are not supposed to change due to stricter EU regulation. Prices of vehicles exported from the EU are not affected by EU regulation. (Smaller) Changes in EU exports and imports of motor vehicles in the scenarios can be assigned to suppliers. Nevertheless, EU OEMs may decide to produce more expensive cars for exports

because of the economies of scale, as their vehicles for the domestic market are already complying with the more stringent EU regulation. This potential comparative advantage in foreign markets is quantified for the Chinese market in the China case scenarios. The comparative advantage of less stringent regulation in the domestic market is analysed in scenario 5, which assumes freezing of EU regulation and in the internal market sensitivity analysis. In both scenarios EU import shares are increased exogenously according to the micro model analysis to account for easier access of foreign low-cost producers.

- To show the macroeconomic impacts of higher regulatory standards in the EU, it is assumed that the number of vehicles sold in EU is not affected by regulation. Consumers may either buy a cheaper vehicle (e.g. acquire an entry class car instead of a medium class car due to more stringent regulation) or reduce consumption of other products. Stronger regulation in the EU may then even be positive for the regulated automotive industry, but negative for most other industries. Industries that are supplying the motor vehicle industry may be able to increase their production, if their share in car production is increased.
- Changes in material composition will change the input structure of the EU motor vehicle industry accordingly. If, for example, 5% less iron and steel is needed for cars, the input coefficient for the 'iron and steel' industry sector that is applied in the model to the 'motor vehicles' industry category is reduced accordingly. Similarly, a higher share of batteries in car production due to more electric vehicles will increase the share of electrical machinery, where the batteries are produced.
- Growing market shares of electric vehicles increase the share of battery suppliers and powertrain electronics suppliers, while other part suppliers, mainly classified as motor vehicle industry, and OEMs lose shares in direct costs and therefore demand for their products. In the input-output classification electrical machinery (battery, powertrain electronics) and chemicals (battery) increase production. The change is mainly dependent on the increase in battery electric vehicles (BEV), while plug-in-hybrids (PHEV) still need the ICE powertrain.
- An increase in the share of electric vehicles will reduce the consumption of diesel and gasoline and increase the use of electricity. While a large proportion of mineral oil products consumed in the EU are imported, electricity is almost completely produced domestically. Overall CO_2 emissions will be reduced as the reduction in emissions from road transport is much higher than the increase in emissions from electricity production (if most of the additional electricity is produced carbon free). For the additional electricity supply in the scenarios it is assumed that the power generation mix will not change compared to the baseline. Renewable energy sources will reach about 43% of gross electricity generation in 2030 (55% in 2050) according to the EU Reference Scenario 2016. Investment needs for the higher generation capacities are included in the modelling. Their macroeconomic impact is not expected to be large, as the share of xEVs already increases strongly in the baseline.
- GINFORS is solved annually. Inputs from the micro-economic model for the intervening years between the five year intervals have been interpolated.

Table 2.8: Transformation from micro model and technical information into cost structure of GINFORS-E

Inputs from micro model	Translate into changes in the car industry	GINFORS structure (21 motor vehicles, trailers…)
		1-8…
Total direct costs (€), broken down as:		9 Chemicals excluding pharmaceuticals
Labour	employees	10 Pharmaceuticals
Materials	1 - 30	11 Rubber & plastics products
Total indirect costs (€), broken down as:		12 Other non-metallic mineral products (incl. glass)
Production overhead	32 - 48, consumption of fixed capital	13 Iron & steel
Corporate overhead	32 - 48	14 Non-ferrous metals
Selling costs Dealership costs	31 wholesale and retail trade	15 Fabricated metal products, except machinery & equipment
Profit (€)	operating surplus	16 Machinery & equipment, nec
		17 Office, accounting & computing machinery
Input material demand (Kg)		18 Electrical machinery & apparatus, nec
Ferrous metals	13	19 Radio, television & communication equipment
Light alloys	15	20 Medical, precision & optical instruments
Non-ferrous metals	14	21 Motor vehicles, trailers & semi-trailers
'Special' metals	15	22-30…
Polymers	11	31 Wholesale & retail trade, repairs
Glass	12	32 Hotels & restaurants
		33-47…
Vehicle market shares (total number of vehicles sold/manufacturered)		48 Private households with employed persons & extra-territorial organisations & bodies
ICE petrol	changes due to vehicle type shares (more BEV): 9, 18 +; 15, 21 -	CIF_FOB_Adjustment
ICE diesel		Taxes less subsidies on products
BEV		Compensation of employees
FCEV		Other net taxes on production
PHEV		Consumption of fixed capital
		Operating surplus, gross
		Value added at basic prices
Total number of manufactured vehicles	output	Output at basic prices

Table 2.9: Industry classification of OECD Input-Output Tables

Industries 1-24	Industries 25-48
1 Agriculture, hunting, forestry and fishing	25 Manufacturing nec.; recycling (include Furniture)
2 Mining and quarrying (energy)	26 Production, collection and distribution of electricity
3 Mining and quarrying (non-energy)	27 Manufacture of gas; distribution of gaseous fuels through mains
4 Food products, beverages and tobacco	28 Steam and hot water supply
5 Textiles, textile products, leather and footwear	29 Collection, purification and distribution of water
6 Wood and products of wood and cork	30 Construction
7 Pulp, paper, paper products, printing and publishing	31 Wholesale & retail trade; repairs
8 Coke, refined petroleum products and nuclear fuel	32 Hotels & restaurants
9 Chemicals excluding pharmaceuticals	33 Land transport; transport via pipelines
10 Pharmaceuticals	34 Water transport
11 Rubber & plastics products	35 Air transport

Industries 1-24	Industries 25-48
12 Other non-metallic mineral products	36 Supporting and auxiliary transport activities; activities of travel agencies
13 Iron & steel	37 Post & telecommunications
14 Non-ferrous metals	38 Finance & insurance
15 Fabricated metal products, except machinery & equipment	39 Real estate activities
16 Machinery & equipment, nec	40 Renting of machinery & equipment
17 Office, accounting & computing machinery	41 Computer & related activities
18 Electrical machinery & apparatus, nec	42 Research & development
19 Radio, television & communication equipment	43 Other Business Activities
20 Medical, precision & optical instruments	44 Public admin. & defence; compulsory social security
21 Motor vehicles, trailers & semi-trailers	45 Education
22 Building & repairing of ships & boats	46 Health & social work
23 Aircraft & spacecraft	47 Other community, social & personal services
24 Railroad equipment & transport equip nec.	48 Private households with employed persons & extra-territorial organisations & bodies

Source: (OECD, 2015)

3 BASELINE AND SCENARIO DEFINITION

This section includes a description of the micro-economic modelling baseline used to estimate the impact of future regulatory changes in different markets on the production costs, margins and materials composition of different vehicle types in the various markets of interest. It also includes definitions for the modelling scenarios used to estimate the likely impact of changes in EU and Chinese ambition, with regards to environmental and safety regulations through time.

3.1 Baseline definition

It is important to note that the baseline definition for this study does not represent the situation in which no further action is taken by the EC or other national Governments. The baseline is defined in this study as representing the most likely scenario for future progression of market, regulatory and technology trends between now and 2050, as defined by the research described in detail in Appendices A.1 and A.4.

The baseline assumes a gradual ramping up of regulations from one strength 'level' to the next at varying rates in the six markets of interest, with changes implemented over five year intervals. In reality, changes in regulation may be implemented over longer timescales, for example at ten year intervals, to allow manufacturers sufficient time to adapt. Nevertheless, it is assumed that even if this was the case, manufacturers would be adapting their product portfolios gradually to meet future regulations and as such it is appropriate to model a more gradual transition with changes occurring every five years where appropriate.

3.1.1 CO_2 emission regulations

Some of the key environmental regulations analysed in this study are aimed at reducing CO_2 emissions/improving fuel efficiency. The strength levels defined for these regulations are linked to CO_2 standards (expressed as a limit of gCO_2/km), but for the purposes of the modelling, these also include a target for the market share of the different powertrain options in production (this allows for more ambitious decarbonisation targets to be achieved in the future), as described in Section 2.4.3.1. Figure 3.1 and Figure 3.2 show expectations regarding the future development of these regulations, as applied to passenger cars and LCVs, respectively, in the different markets.

Figure 3.1: CO_2 emission regulations for passenger cars in the baseline

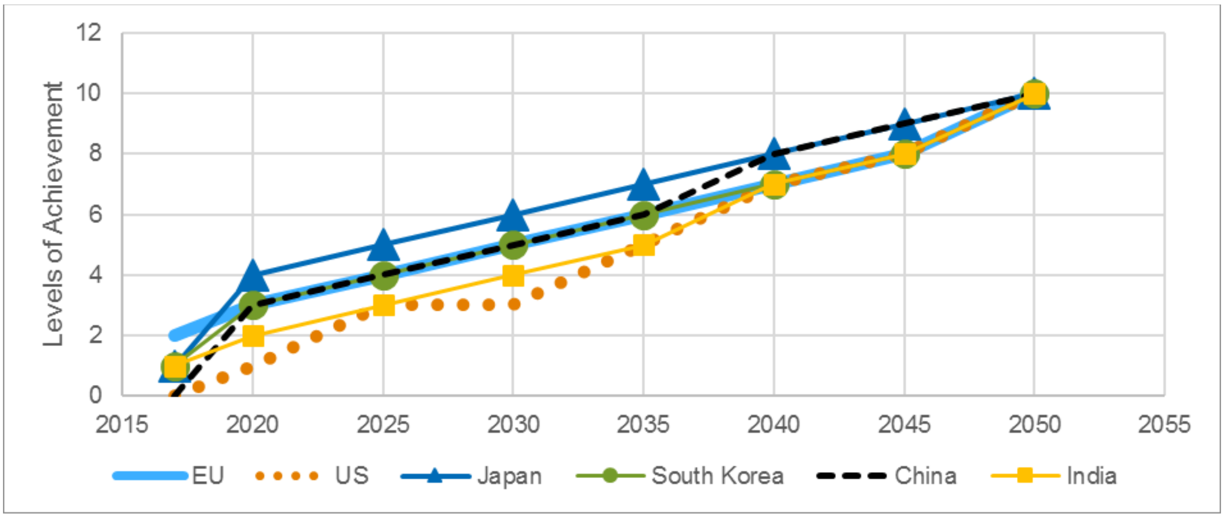
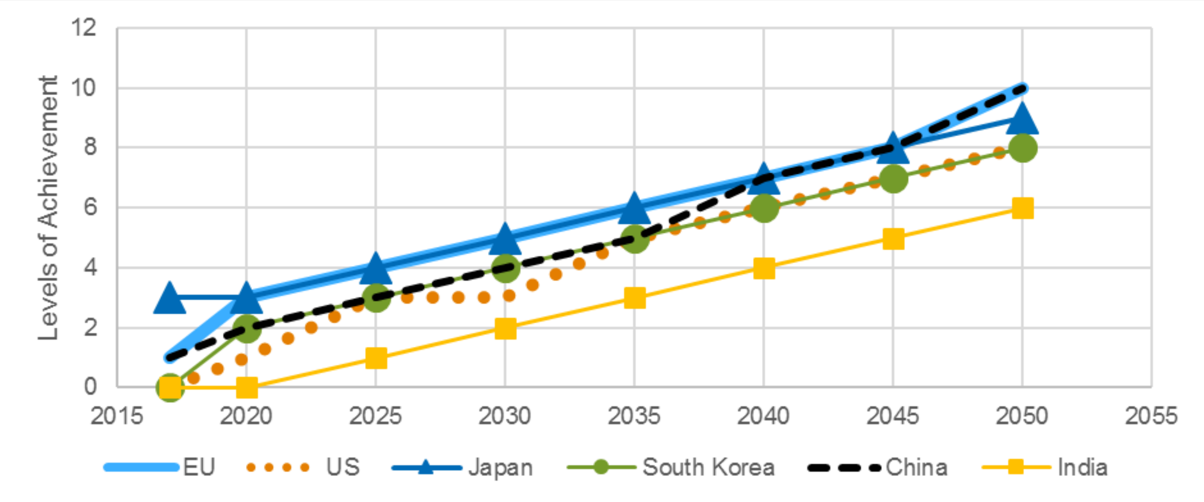


Figure 3.2: CO_2 emission regulations for LCVs in the baseline



In line with the research conducted to develop roadmaps representing the likely regulatory, policy, market and technology trends expected in the various markets of interest, the EU is anticipated to have one of the strictest regulatory frameworks for controlling CO_2 emissions over the time period out to 2050. China, and to some extent India, have shown a strong intent to become leaders in the field of e-mobility and as such both countries are expected to catch up in terms of their regulatory ambition in this area, in the near future. This is particularly observed in certain regions of China which have already started to implement stricter regulations than those implemented in the rest of country.

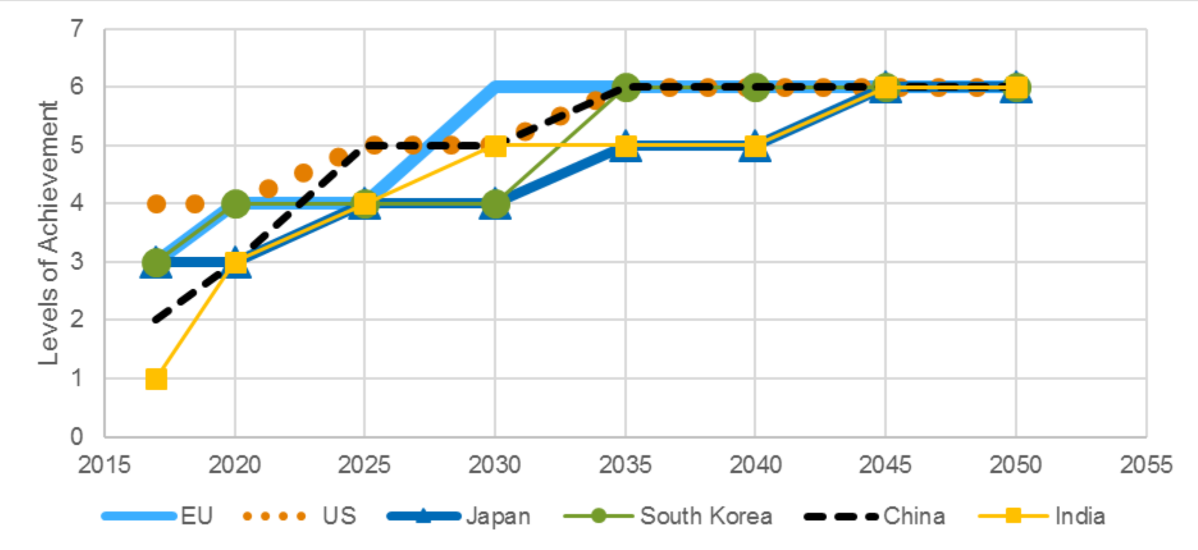
Regarding passenger cars in particular, Japan is currently in the lead on environmental regulation, as the country has one of the most ambitious environmental regulation frameworks in place but also a relatively high penetration of conventional hybrid-electric vehicles in its vehicle fleet – and it intends to maintain this high ambition going forward. The EU and South Korea are expected to follow closely behind and only fully catch up by 2050. On the other hand, the US is expected to stagnate for a period of five years and lag behind the other countries. This reflects the current political situation in the country as the Federal Administration is likely to put a halt to the historical trend of progressively more ambitious environmental regulations and the country might observe a period of stagnation, after which it is expected to increase efforts to catch up with the other countries.

With respect to LCVs, the EU is leading the implementation of the strictest regulation in this area, followed closely by Japan. Unlike for passenger cars, South Korea is expected to lag behind as the country has only recently set its first CO_2 standards specifically targeting LCVs, and this will not enter into force until 2020. The trend for the US is similar to the one observed for passenger cars as it is expected to be equally influenced by the political situation described above. India has yet to set standards for LCVs and therefore the country is anticipated to remain behind all other markets for the whole period analysed.

3.1.2 Pollutant emission regulations

The other key environmental regulation trend analysed concerns air pollutant emissions. Section 2.4.3.2 describes in detail the levels of achievement which are mainly linked to Euro standards. Figure 3.3 presents the baseline assumptions on the future progression of the regulations in the different markets.

Figure 3.3: Pollutant emission regulations in the baseline



According to the research conducted to support the development of the regulatory/policy/technology/market roadmaps, the US is the world leader in setting the most ambitious air pollutant emission regulations. By 2025, the country will have fully implemented its Tier 3 standard (level 5 on the y-axis) which is the most ambitious legal framework in the world for reducing pollutant emissions from road vehicles. Nevertheless, the current Federal Administration is likely to have an impact on the overall environmental regulatory environment in the US and regulations targeting pollutant emissions are also expected to stall between 2025 and 2030 after which the country is assumed to return to its historical trend.

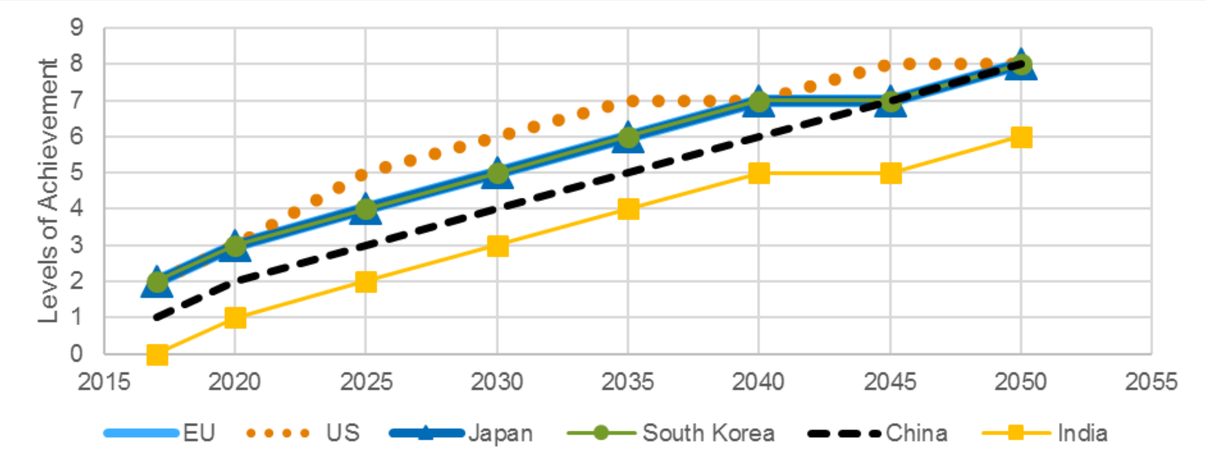
In the EU, Euro 6 RDE (level 4 in the figure) is currently being implemented. A new standard, Euro 7 (level 6 in the figure), is expected to be defined but a significant lag between the current and next level is expected. Indeed, based on stakeholder input, it is not expected that Euro 7 will be implemented before 2030 as it is yet unclear exactly what the new standard will entail. In the meantime, China is anticipated to catch up and even overtake the EU. China has developed its own "China 6" standard and in particular the planned China 6b standard (level 5 in the figure) improves on Euro 6 RDE and mandates stricter limits. South Korea and Japan follow the EU's regulations, albeit with some delay, adopting the Euro standards as the main regulatory instrument to control pollutant emissions from vehicles. India's trend line reflects its ambition to skip a level and move from Bharat Stage IV (equivalent to Euro 4 – level 1 in the figure) to Bharat Stage VI (equivalent to Euro 6 – level 3 in the figure) for all models from 2020. The country then follows a similar path as China, albeit delayed by 5-10 years.

All countries are expected to converge to the same level by 2050, in line with the future Euro 7 standard. Before 2030, the US and China (from 2025) are expected to be in the lead with respect to the most stringent air pollutant emissions standards. In 2030, if the EU implements Euro 7 it could take the lead in setting the most ambitious regulation. For modelling purposes, it is assumed that Euro 7 is implemented in 2030 in the EU. After this year, all other countries are anticipated to converge, albeit at different paces. The US, China and South Korea reach Euro 7 level in 2035, whilst Japan lags behind as the regulatory process is seen as more complex and lengthy in this country and reaches the highest level in 2045, together with India. It is possible that Japan implements the Euro 7 level before 2045, however the impact on the modelling results of this alternative path is not expected to be significant.

3.1.3 Safety regulations

Safety regulations are linked to both passive and active safety features, as described in Section 2.4.3.3. The highest levels (levels 4-8) are associated to the levels of automation defined in Appendix A.4. Figure 3.4 illustrates the future developments in regulation expected for this field in all the markets considered in this study.

Figure 3.4: Safety regulations in the baseline



Currently, the EU is a leader in safety regulations, together with the US, Japan and Korea. All these countries except the US are heavily involved in the harmonisation of ambitious safety regulations and the sharing of best practices at the UN level through the work of the World Forum for Harmonization of Vehicle Regulations (WP.29). The US, despite being less involved at the UN level, also has one of the strictest safety regulatory frameworks currently in place and on par with the other countries.

After 2020, the US is expected to take the lead transitioning first towards regulations mandating different levels of automation. The country is likely to be better prepared to mandate higher levels of automation given the enabling regulation for the testing of CAVs which is already in force in the country. The highest levels (7 and 8 – equivalent to autonomy Levels 3 and 4 respectively) entail more complex technology and thereby their regulation is also expected to take longer to be put in place.

The EU is expected to closely follow the US, but we expect it to be one level behind the US for most years after 2020 until it catches in 2050. Japan and South Korea are expected to follow a similar path to the EU's since the two countries have been leading discussions on automation at the UN level and have announced plans for automation (e.g. for the 2020 Olympic Games in Tokyo).

China and India start from a lower level as these countries have yet to mandate some of the basic and intermediate safety features that are already common in some of the other countries. Nevertheless, China is expected to catch up rapidly and is anticipated to play an important role in developing autonomous vehicle technology. India, on the other hand, is expected to lag behind over the full time period to 2050 and fail to catch up with the other countries. The trend reveals the expectation that higher levels of safety regulation will be difficult to be achieved in this country since unresolved traffic management issues are anticipated to prevent higher levels of automation.

3.2 Scenario definitions

In addition to the baseline, five scenarios have also been modelled. The scenarios are intended to reflect potential alternatives to the EU's baseline path regarding the future development of regulation in the three key areas (CO_2 emissions, air pollutant emissions and safety) considered in this study. The five core scenarios represent the following situations:

- Scenario 1: Levelling the technological and regulatory standards gradually till 2030
- Scenario 2: One-off levelling of the technological and regulatory standards by 2030
- Scenario 3: Overshooting the technological and regulatory standards gradually till 2030

- Scenario 4: One-off overshooting of the technological and regulatory standards by 2030
- Scenario 5: Freezing of EU regulations

The scenarios differ in the levels of ambition but also the pace at which regulation is set. Scenarios 1 and 2, the levelling scenarios, represent a situation in which the EU implements regulation to match the highest level of ambition in place in 2030. On the other hand, scenarios 3 and 4, the overshooting scenarios, reflect the situation in which the EU decides to take the lead and sets highly ambitious regulatory standards, above the level in place in all other markets by 2030. Note that no further levelling and overshooting of EU regulation is modelled after 2030. This is a model construct; in reality, further regulatory changes are expected across different markets at different points in time and the EU may need to adjust its position in order to maintain or extend its lead. Nevertheless, the scenarios that are modelled, provide a good indication of the value of matching or exceeding the global regulatory ambition.

The levelling and overshooting scenarios can be achieved at different paces. In scenarios 1 and 3, the increase in the stringency of regulation is implemented gradually whilst in scenarios 2 and 4 this occurs in one go. The difference in pace is intended to reflect two different approaches to the regulatory process. In the one-off approach, regulation is announced to be implemented by a certain date so as to give time for OEMs to adapt. In the gradual approach, regulation is implemented step-by-step. An example of this is the gradual implementation of the RDE requirements in four packages.

Finally, scenario 5 is very different from the other scenarios as it is aimed at representing a situation in which the EU does not continue strengthening its regulatory framework but instead maintains the regulations already announced to take effect up until 2020 for the whole period.

In practice, the five core scenarios have been modelled by adjusting the EU's trend line accordingly. In the levelling scenarios, the EU's level of achievements for each of the three key regulatory trends matches the highest level in place elsewhere, whilst the overshooting scenarios have been set one level ahead of the other markets. Regarding timeframes, it was assumed that all regulation entering into force by 2020 has already been announced. As such, changes in regulation only take place in 2025, to be fully implemented by 2030 in the gradual approach, whilst in the one-off approach changes only occur in 2030. In scenario 5, the EU's trend line is kept constant at the same level as observed in 2020 for the whole period.

The impacts of regulation defined at different levels of ambition and with different timelines have then been analysed. For each scenario, the model assesses the impacts on costs / prices of vehicles made by EU OEMs, industry trade flows and macro-economic impacts. The outputs from this analysis are covered in Section 4.

In addition to the five core scenarios, another case study scenario was built to represent the situation in which a foreign market takes unilateral action to become the most ambitious market in the future, in terms of its regulatory requirements. China has been used as the representative foreign market in this case, given the size of its market, the political system in place which allows rapid, unilateral changes to be implemented, and its known ambition to become a global leader in the environmental regulation of vehicles. In practice, this scenario implies that China's trend line will be adjusted to reflect the global-leadership standards in each of the key three regulatory trends.

The China case scenario aims to evaluate the opportunities from this change for EU OEMs operating in this country. Similarly, the model assesses the impacts on total costs, revenues and profits in China but also analyses the potential market share and revenues that could be taken by EU OEMs, at the expense of other non-compliant foreign OEMs (given the EU's existing leadership position, which would allow it to gain market share in this instance). In the China case scenario, the EU's regulatory environment is based on scenario 2 in which regulation is levelled to the global standards and achieved in one go. This scenario was chosen as it demonstrated an overall positive impact on EU GDP when combined with the China case scenario, as explained in more detailed in Section 4.2.

The following sub-sections present in detail the changes to the regulatory environment in each scenario.

3.2.1 Scenario 1: EU levelling gradually

In scenario 1, the EU is assumed to gradually ramp up its regulations to the overall highest levels in place by 2030. Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8 below represent the new situation for each of the three key regulatory areas. It is worth noting that only the EU's trend line changes and the charts show both the baseline path and the new path.

Figure 3.5: CO_2 emission regulations for passenger cars in scenario 1

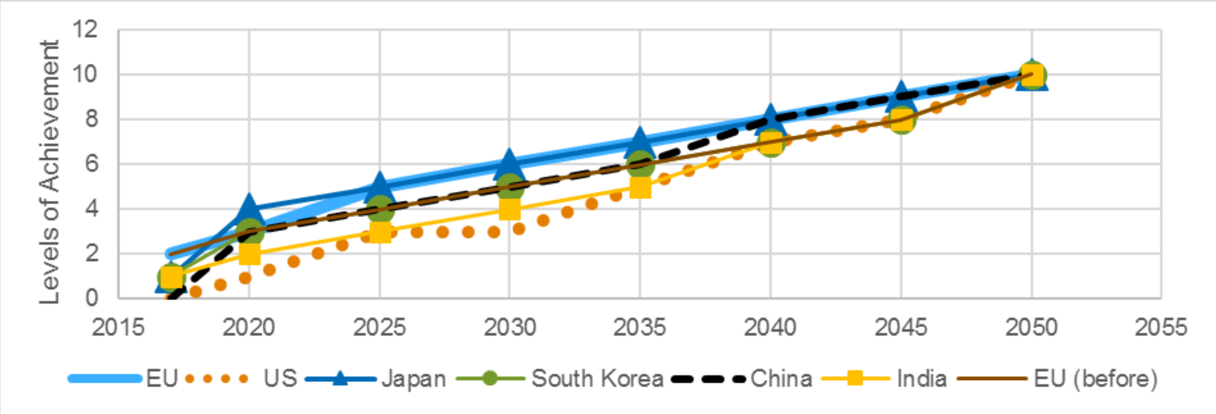


Figure 3.6: CO_2 emission regulations for LCVs in scenario 1

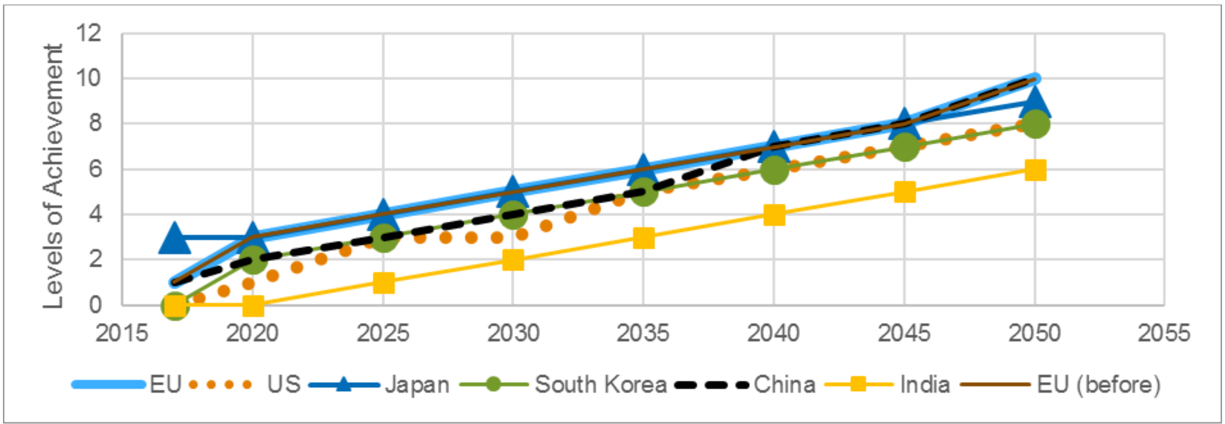
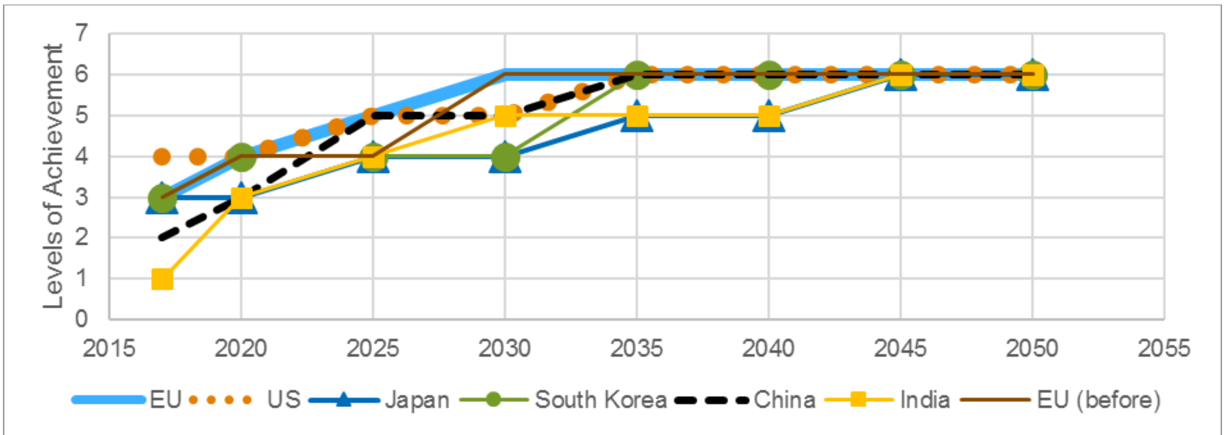


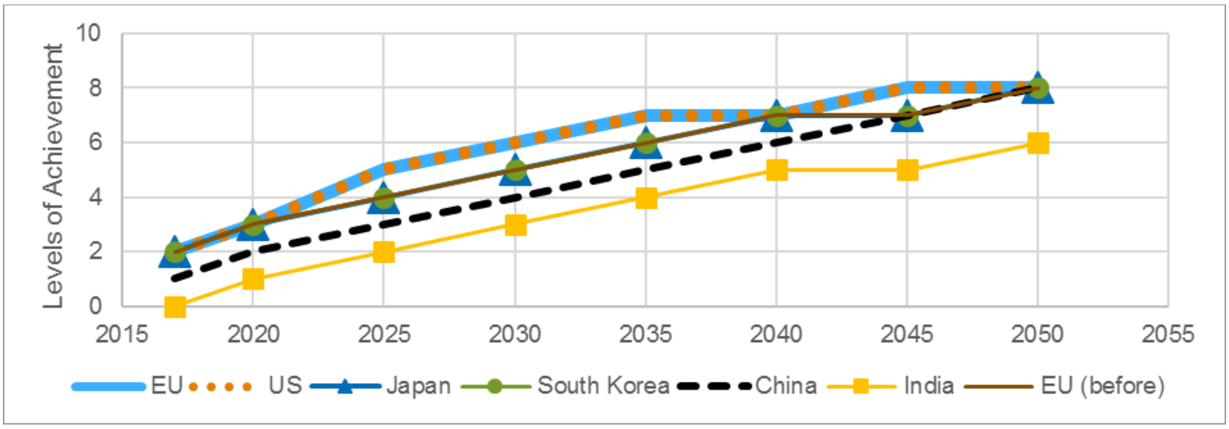
Figure 3.5 and Figure 3.6 show that the EU would implement stricter CO_2 emission regulation from 2025 for passenger cars in scenario 1, being always one level ahead until 2050 when compared to its situation in the baseline. The situation does not change regarding the regulation for LCVs as the EU is already in a leading position in the baseline.

Figure 3.7: Air pollutant emission regulations in scenario 1



Regarding air pollutant emissions regulations, the EU also strengthens its ambition from 2025 in scenario 1, in order to more gradually achieve the highest level in 2030. From 2030, the EU is at the same level as in the baseline.

Figure 3.8: Safety regulations in scenario 1



Finally, safety regulations in scenario 1 in the EU entail a higher level of ambition from 2025. This essentially means the EU will match the level already observed in the US in the baseline until 2050.

3.2.2 Scenario 2: EU one-off levelling

In scenario 2, the regulatory environment in the EU also matches the highest level of ambition observed in the baseline as in scenario 1, but it achieves this by 2030 in one go. Effectively, Figure 3.9, Figure 3.10, Figure 3.11 and Figure 3.12 below tend to show a larger 'jump' between the baseline in 2025 and scenario 2's levels in 2030, albeit still achieving the same level as in scenario 1, as there is no gradual adjustment in this scenario (i.e. no change before 2030). Beyond 2030, scenario 2 follows the same trajectory as in scenario 1 for all regulations.

Figure 3.9: CO_2 emission regulations for passenger cars in scenario 2

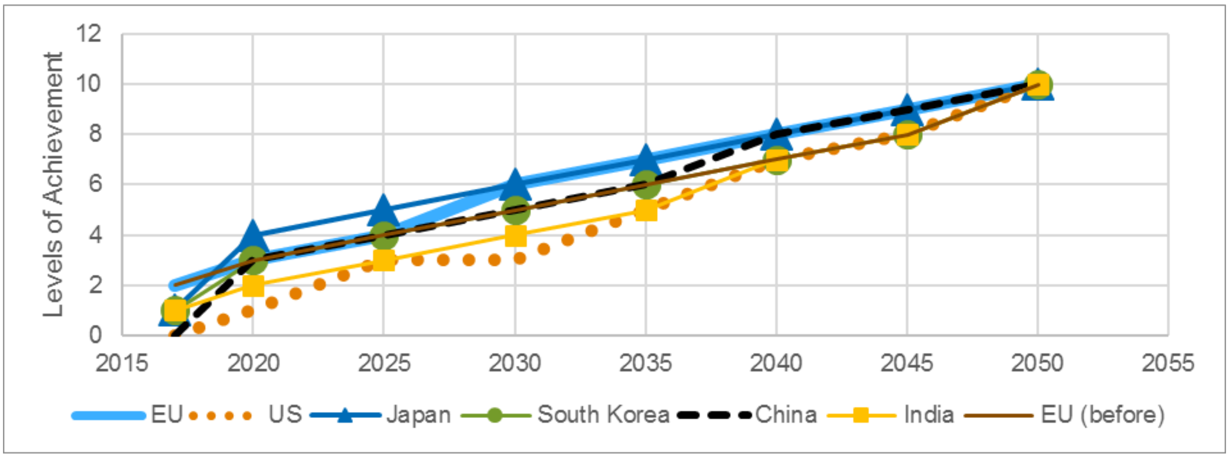


Figure 3.10: CO2 emission regulations for LCVs in scenario 2

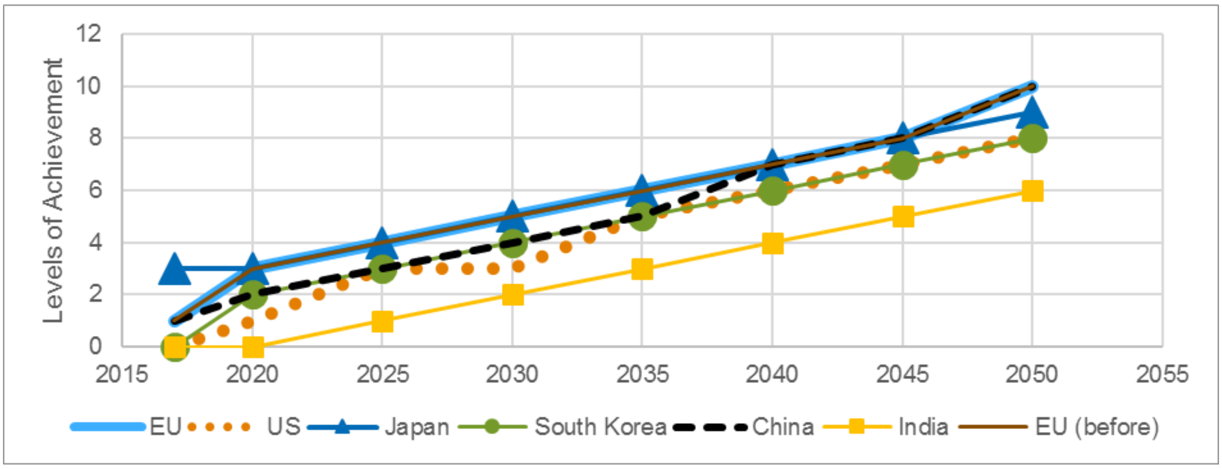


Figure 3.11: Air pollutant emissions regulations in scenario 2

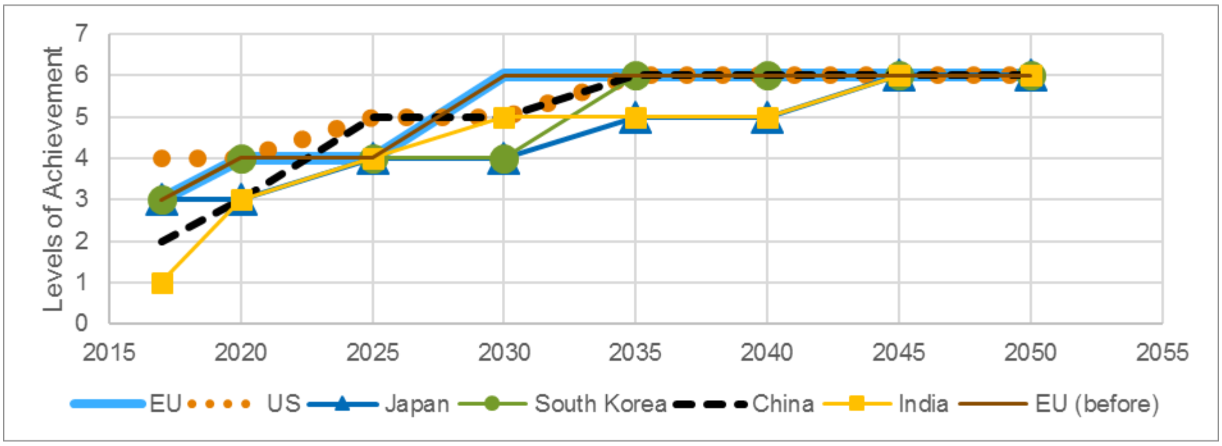
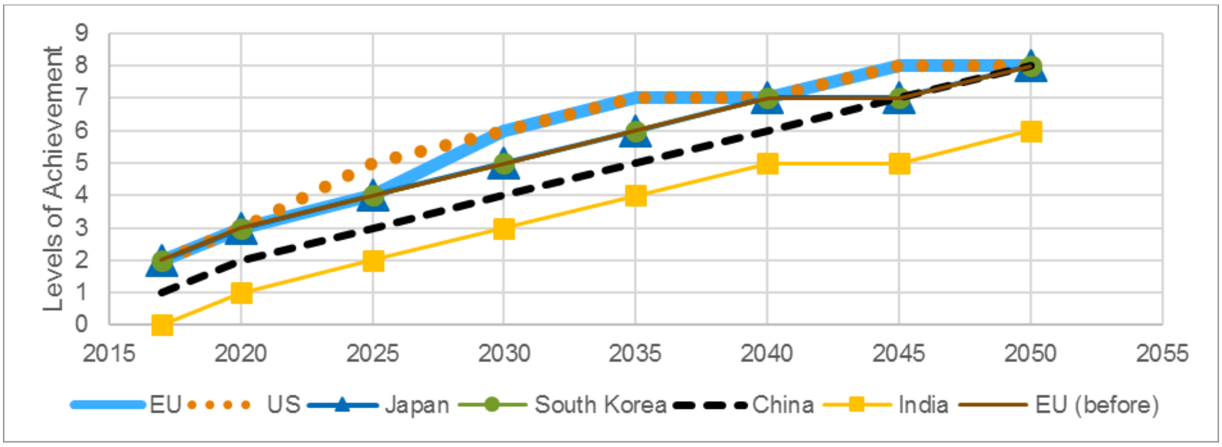


Figure 3.12: Safety regulations in scenario 2



3.2.3 Scenario 3: EU overshooting gradually

In scenario 3, the EU is expected to strengthen its regulations to a global-leadership level, surpassing the highest level of ambition observed in the baseline by 2030. Figure 3.13. Figure 3.14, Figure 3.15 and Figure 3.16 below show the gradual tightening of regulation from 2025 that characterises this scenario. Again, adjustments have only been made to the EU's trend line.

Figure 3.13: CO_2 emission regulations for passenger cars in scenario 3

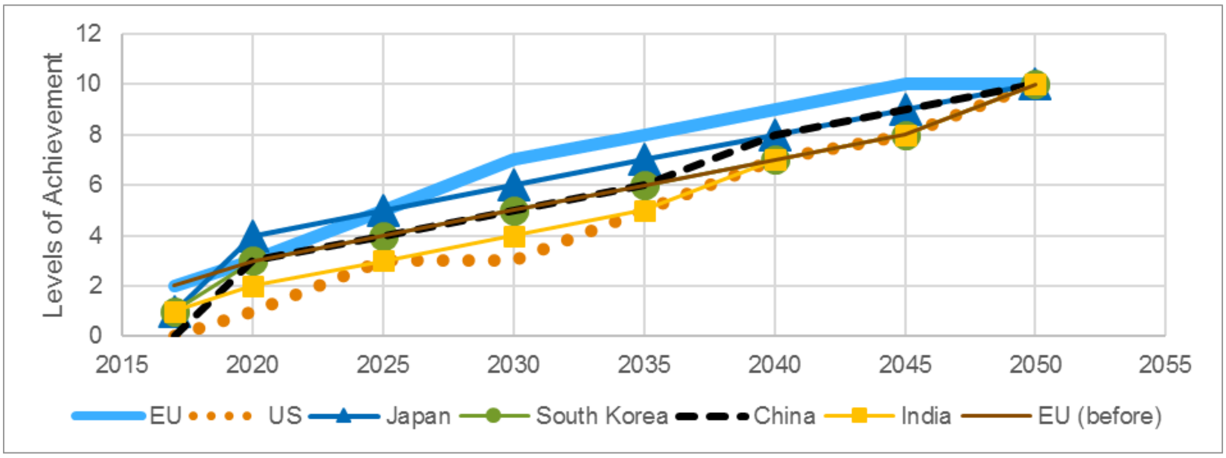
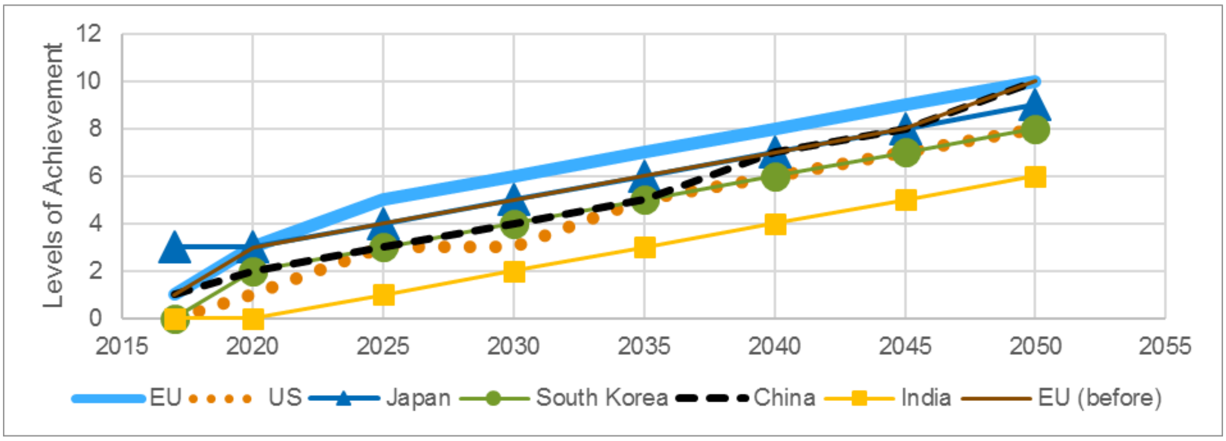


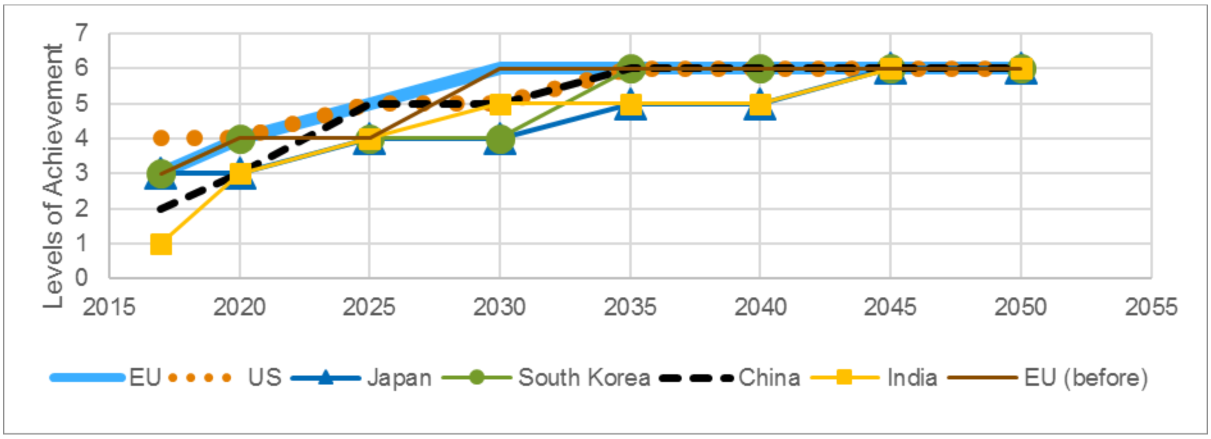
Figure 3.14: CO_2 emission regulations for LCVs in scenario 3



For scenario 3, we assume the EU implements stricter CO_2 emission regulations for passenger cars in 2025, to the same level as in scenario 1. However, in 2030, the EU further strengthens its standards and achieves a level above the highest in the baseline and in scenarios 1 and 2, in line with the definition of this scenario. Specifically, the EU overshoots by about 50% and 22% compared to the baseline in 2030 for passenger cars and LCVs, respectively, and 33% and 22% compared to the foreign market with next highest regulatory strength level (calculated based on the differences between the CO_2 standards defined for each level). It maintains its leadership position throughout the period to 2050.

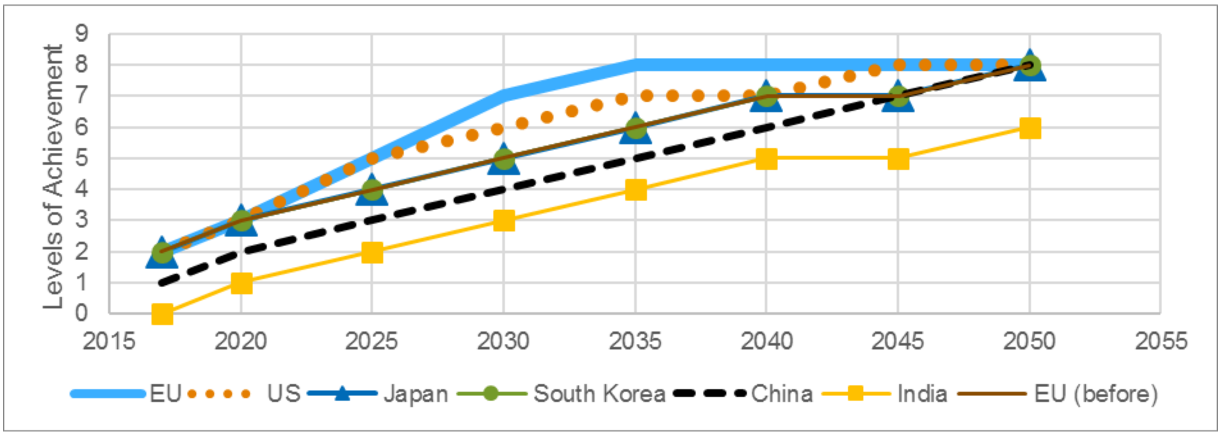
Regarding the regulation targeting LCVs, in this scenario, and unlike in the previous scenarios, the EU's trend line shifts as the EU moves to a stringency level above the baseline, in order to become the absolute leader in this regulatory area.

Figure 3.15: Air pollutant emission regulations in scenario 3



In the case of pollutant emission regulations in scenario 3, the EU is also expected to start strengthening its stringency level in 2025 to the same level as observed in scenario 1, in order to achieve the highest level by 2030. This is the same level as in the baseline and in scenario 1 and therefore scenario 1 and 3 represent exactly the same pathway for the EU's pollutant emissions regulations. Due to the limited number of strength levels available, it was not possible to distinguish between the scenarios in this case.

Figure 3.16: Safety regulations in scenario 3



Regarding safety regulations, the EU also implements stricter regulation in 2025, in order to gradually overshoot the regulatory level by 2030. This requires one level being skipped, as the EU moves directly from level 5 to level 7 between 2025 and 2030.

3.2.4 Scenario 4: EU one-off overshooting

Scenario 4 reflects the situation in which the EU also overshoots the current regulatory level by 2030, but it achieves this in one go. Figure 3.17, Figure 3.18, Figure 3.19 and Figure 3.20 illustrate the changes that this scenario entails. Similarly to the difference between scenarios 1 and 2, scenario 4 tends to represent a larger change in the level of ambition in 2030 relative to the baseline, compared to scenario 3 as there is no adjustment in 2025 and there is a requirement for a larger 'jump' across multiple regulatory levels to achieve the highest level of ambition in 2030.

Figure 3.17: CO_2 emission regulations for passenger cars in scenario 4

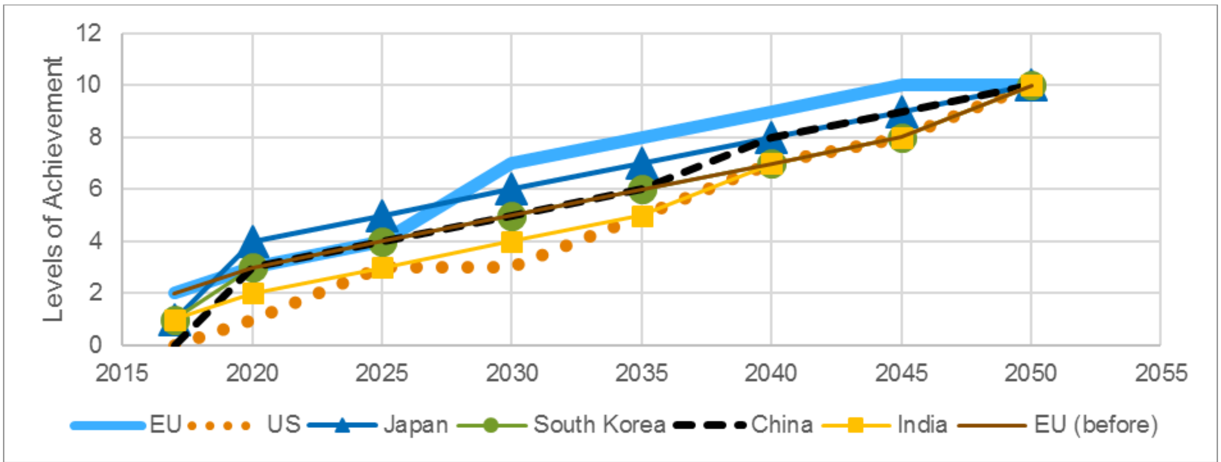


Figure 3.18: CO_2 emission regulations for LCVs in scenario 4

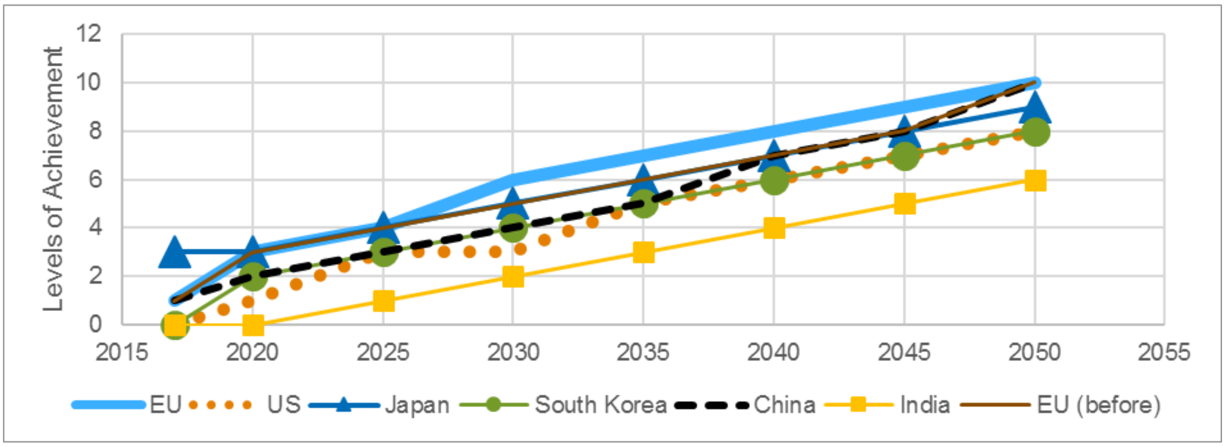


Figure 3.19: Pollutant emission regulations in scenario 4

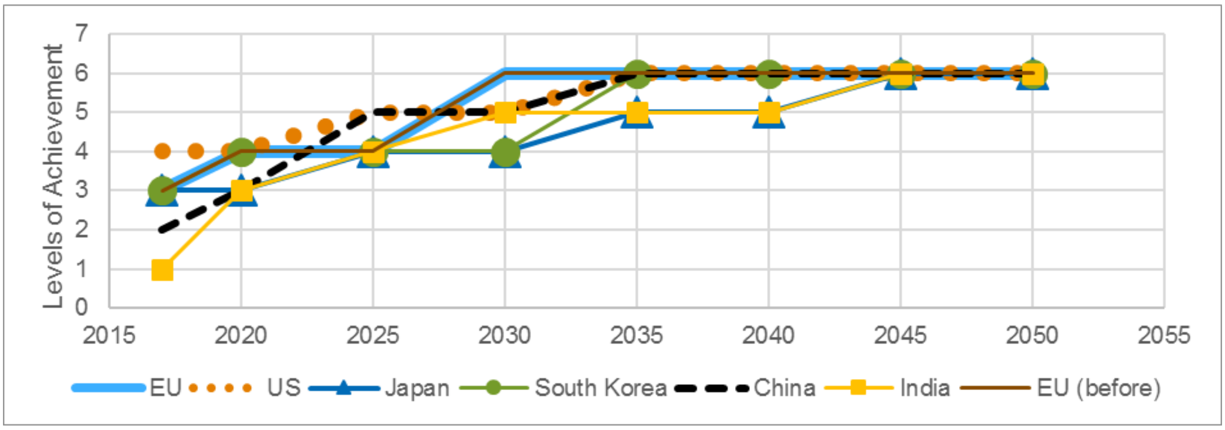
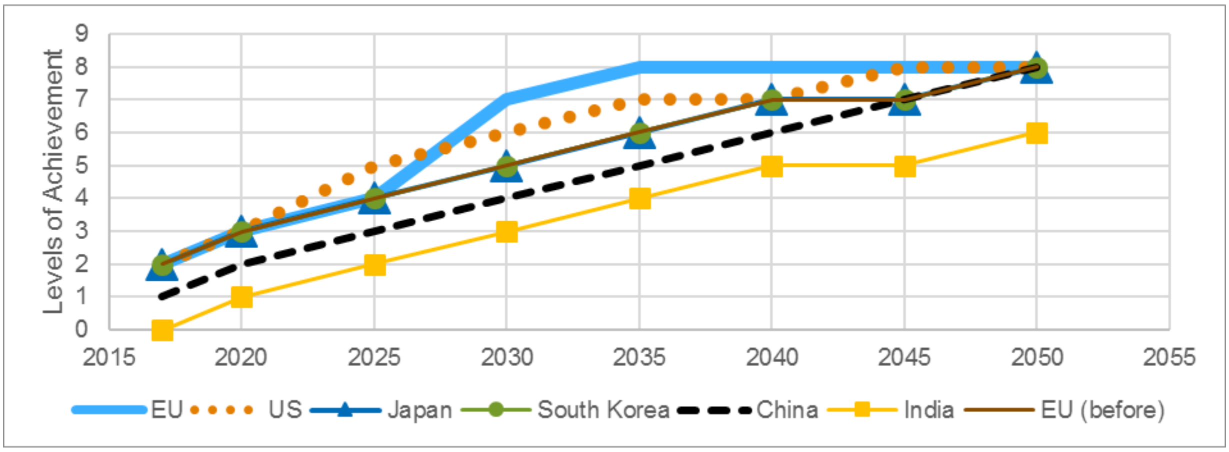


Figure 3.20: Safety regulations in scenario 4



3.2.5 Scenario 5: Freezing of EU regulations

Scenario 5 represents the situation in which the EU essentially does not make any changes to its regulatory framework besides those already announced to 2020. Figure 3.21, Figure 3.22, Figure 3.23 and Figure 3.24 illustrate this scenario for each of the three key trends. As the figures show, in practice this scenario is represented by a straight line for the EU after 2020.

Figure 3.21: CO_2 emission regulations for passenger cars in scenario 5

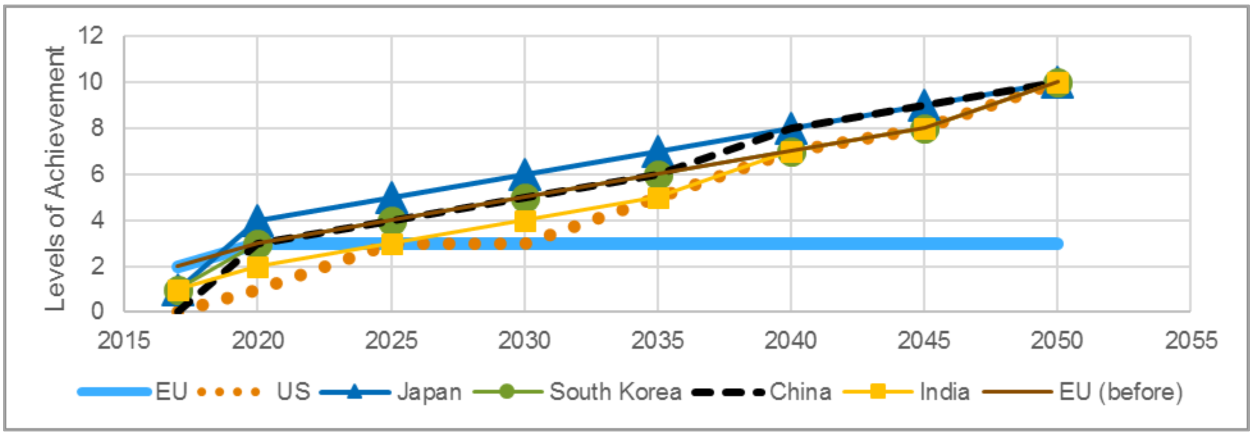


Figure 3.22: CO_2 emission regulations for LCVs in scenario 5

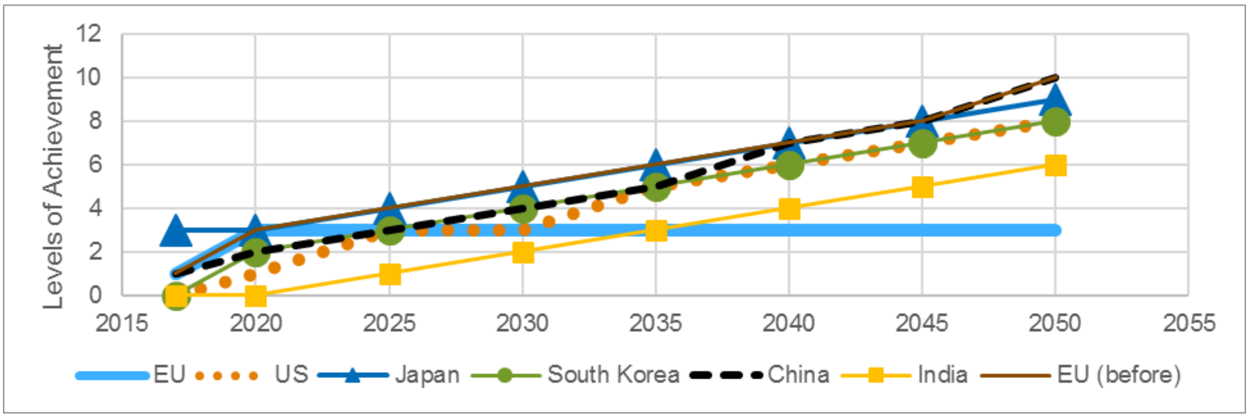


Figure 3.23: Pollutant emission regulations in scenario 5

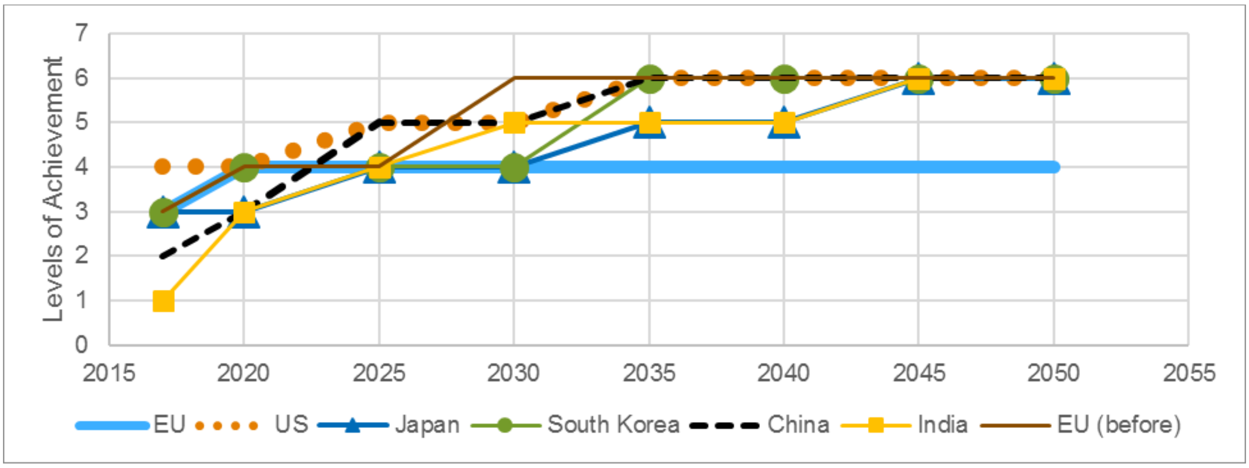
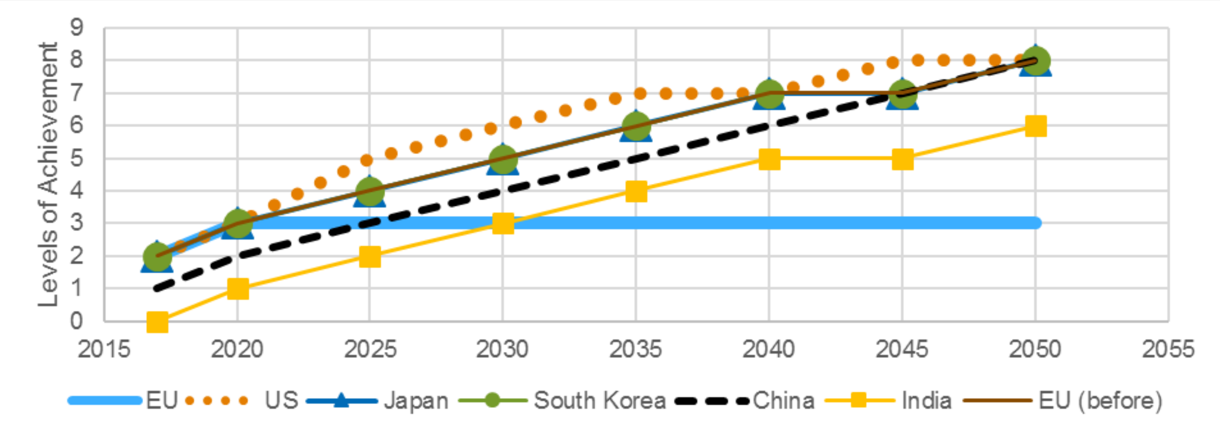


Figure 3.24: Safety regulations in scenario 5



3.2.6 China case scenario

The China case scenario entails strengthening of the regulatory environment in China combined with changes in the regulatory framework in the EU based on scenario 2. It essentially represents the unilateral tightening of regulations in China to the global-leadership level whilst the EU is levelling its regulatory level in one go. With the EU and China at the same regulatory level from 2030 (and with both markets ahead of their other global competitors on some regulations), the EU is well-placed to increase its market share in China, as discussed further in Section 4.2 below.

Figure 3.25, Figure 3.26, Figure 3.27 and Figure 3.28 below illustrate this situation. These figures focus on the changes to China's trend line as the EU's path under scenario 2 is already assessed in Section 3.2.2.

Figure 3.25: CO_2 emission regulations for passenger cars in the China case scenario

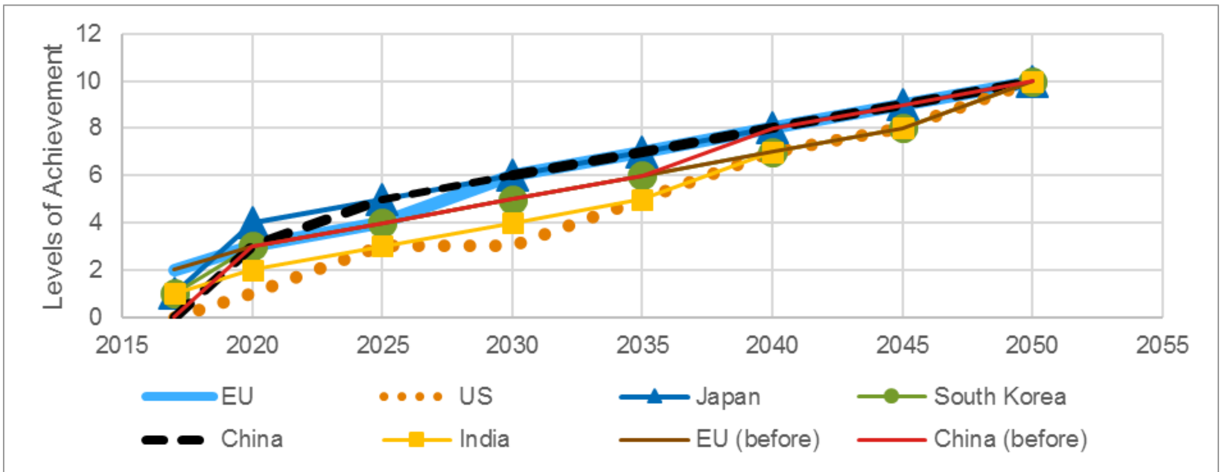
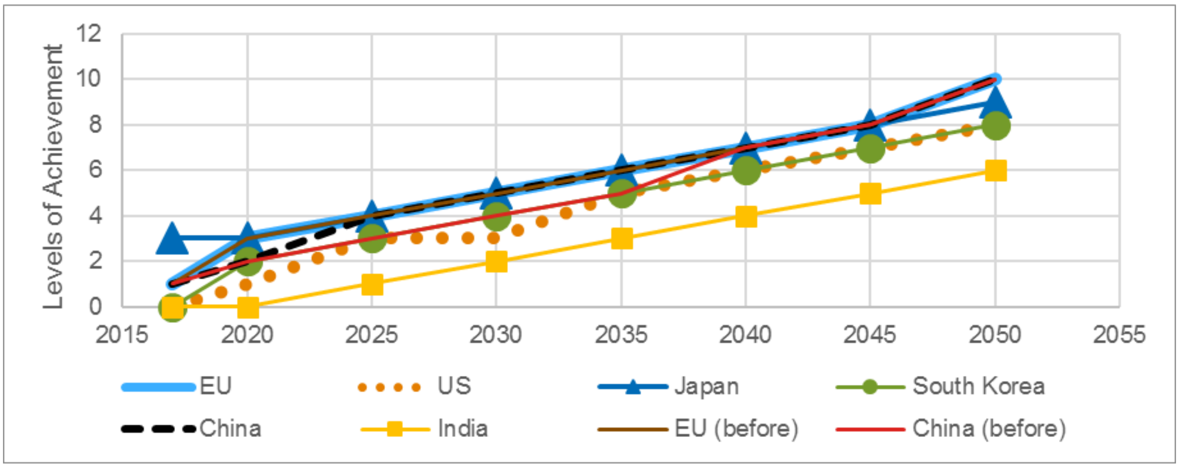
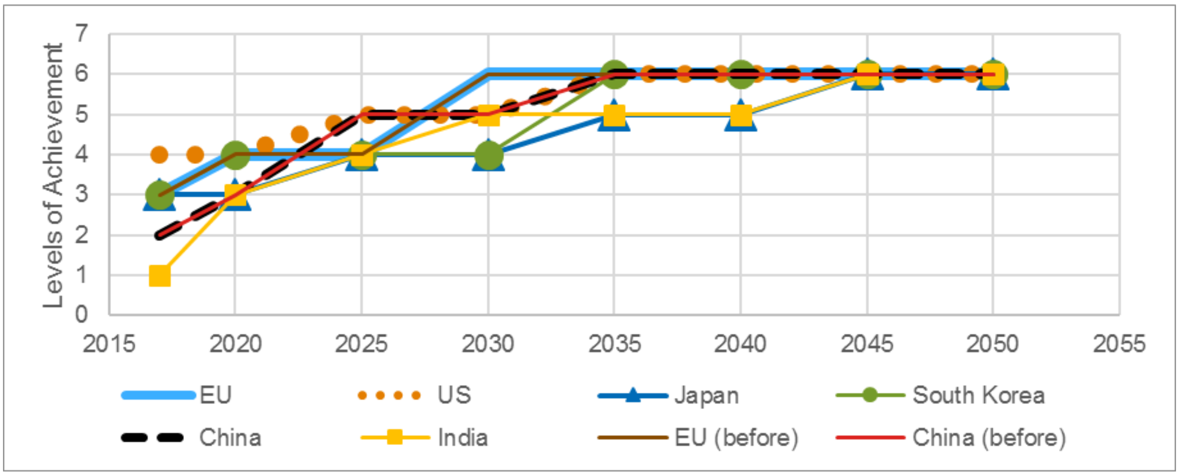


Figure 3.26: CO_2 emission regulations for LCVs in the China case scenario



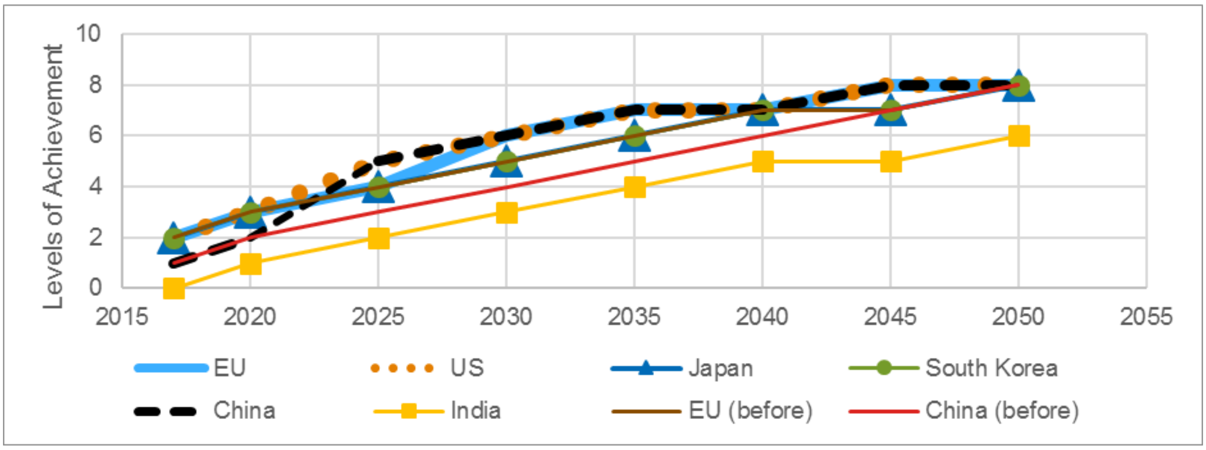
As Figure 3.25 and Figure 3.26 show, the strengthening of CO_2 emission regulations in China takes place after 2020 and it entails essentially following Japan's path in the case of passenger cars and the EU's path in the case of LCVs, as these represent the stricter regulations in place on CO_2 emissions.

Figure 3.27: Pollutant emission regulations in the China case scenario



For pollutant emission regulations, the China case scenario represents no change from the baseline for China as the country is already implementing very ambitious regulations in this field from 2025.

Figure 3.28: Safety regulations in the China case scenario



Finally, safety regulations in the China case scenario result in a situation in which China follows the US's path as the US is ahead of all other markets from 2025 in the baseline.

4 ASSESSMENT OF IMPACTS

This section presents the outputs of the modelling analysis, including the outputs from the micro-economic model (Section 4.1), the macroeconomic model (Section 4.2), and from the qualitative assessment of the impact on Tier 1 suppliers (Section 4.3).

The aim here is to present an overview of the key changes in production costs, profitability and material composition observed in the baseline as a result of the regulatory changes expected in the six markets of interest to 2050, and to contrast this with the additional changes resulting from the unilateral tightening of regulations in the EU and China respectively in the various scenarios.

Broadly, the EU-based scenarios (in which the EU unilaterally tightens regulations at varying rates) are aimed at understanding how increased regulation applied at different rates affects the costs and profitability of the EU automotive sector. The China case scenarios (in which China unilaterally tightens regulations, presenting the EU with an opportunity to gain market share) are aimed at understanding the opportunity associated with the EU maintaining a regulatory leadership position in the future.

Whilst the micro-economic model outputs focus on the likely cost, profitability and material composition impacts for the production specific vehicle types in specific markets, the GINFORS-E macroeconomic model outputs cover the wider impacts on GDP, consumption, employment and trade flows of the changes observed.

4.1 Micro-economic modelling outputs

4.1.1 Baseline scenario

The baseline scenario as defined in Section 3 is characterised by an overall increase in regulatory stringency over time for each of the three trends analysed. This is expected to have a significant impact on costs, prices and profits of EU OEMs in their home market but also in the five foreign markets considered in this study, and will thus impact on the future competitiveness of EU OEMs in these markets.

To gain a better understanding of their combined impacts on costs, prices and profits in each market, Figure 4.1 below provides a comparison of stringency of regulation over time among the different markets, aggregating all the regulatory trends, i.e. CO_2 emissions/fuel efficiency, air pollution and safety. By providing a qualitative scoring of the stringency levels, the figure is useful to assess the relative position of each market through time.

Figure 4.1: Comparison of stringency of regulation over time

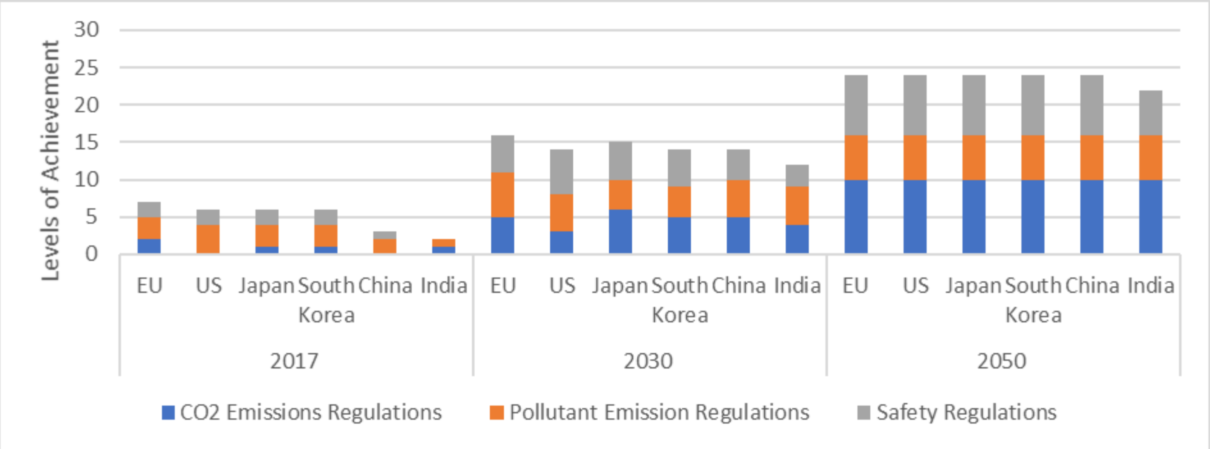


Figure 4.1 shows that in 2017 the EU has the highest overall stringency level (although not for each trend individually), followed by the US, Japan and South Korea which present the same overall stringency level in 2017 as each other, despite differences in the level corresponding to individual regulatory trends.

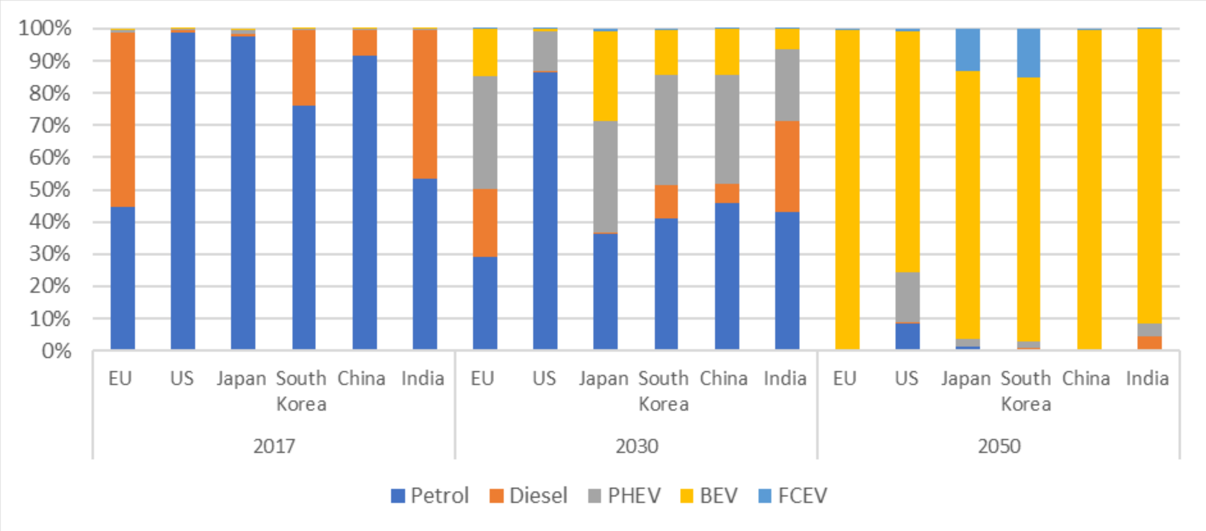
By 2030, the overall stringency level in all markets is anticipated to increase. It is worth highlighting the significant increase in regulatory stringency that is expected in China and India which put these two countries on a par with the developed countries.

In 2050, the overall stringency level in all markets is again anticipated to be higher for all countries. The EU, the US, Japan, South Korea and China are all at the same and higher level, followed closely by India.

The varying levels of stringency and changes in the relative position between countries have an impact on the costs, prices and profits observed for each market over time. Please note however that a proportional link between these outputs and the overall stringency levels cannot be established because the impact of each trend on vehicle costs differs widely.

These changes in regulatory stringency over time, in particular environmental regulation, are also associated with changes in the market share of the different powertrains considered for this study. Figure 4.2 provides an overview of the market shares of different powertrains for each market in 2017, 2030 and 2050.

Figure 4.2: Powertrain market shares



The figure illustrates the almost absolute dominance of ICE vehicles (petrol and diesel vehicles) in all markets in 2017. It is worth highlighting the significant importance of diesel vehicles in the EU and India where this powertrain represents about half of ICE vehicles produced.

The penetration of xEVs[7] is expected to increase in all markets over time, as environmental regulations tighten. By 2030, PHEVs and BEVs represent about half of the market in the EU, South Korea and China. In Japan, the share of xEVs is anticipated to be even higher at about 63%. On the other hand, the penetration of xEVs in the US is considerably lower, at only about 13%. Note that the powertrain shares in 2030 demonstrate that Japan (and to some extent South Korea and China) are expected to outpace the EU in terms of the production of xEVs in the near-term – this could have important competitiveness implications.

In 2050, ICE vehicles are expected to disappear from the EU and Chinese markets as BEVs and a small share of FCEVs are expected to become the dominant drivetrain produced in these locations. The picture is similar for the US, Japan, South Korea and India, although a small number of ICE vans is still anticipated to be produced. Japan and South Korea in particular are expected to produce a higher number of FCEVs due these countries' support for this technology, whilst the US catches up somewhat from its lagging position on xEV production expected in 2030.

These changes in policy stringency and powertrain market shares influence the costs, prices and profits observed in each market over time, which are analysed in the sub-sections below.

[7] Include PHEVs, BEVs and FCEVs

4.1.1.1 Vehicle costs

Vehicle production costs are key to assessing the future competitiveness of EU OEMs in the different markets. As described in section 2.4, changes in regulation are expected to have an impact on the costs of producing vehicles in each market. This sub-section provides an overview of the changes in vehicle costs for each vehicle segment in particular, and the average production cost of a vehicle over time. The analysis in this sub-section presents the results for the mid-range passenger car (as this is the most representative car segment in the EU) and the light commercial vehicle. Conclusions are made for all vehicle segments but the charts for the remaining passenger car segments are provided in Appendix A.8.

It is worth mentioning that the costs of the petrol vehicles (i.e. representative vehicles) in each market are the same as those presented and analysed in Appendix A.2. The diesel vehicle costs are based on the price for the diesel version of the representative vehicles in each market and the cost breakdown also described in Appendix A.2. Please note that not all markets present the cost for diesel vehicles since this powertrain option does not exist in some markets for the representative vehicle. The xEV costs are calculated based on the petrol base vehicle (or diesel vehicle in the case of LCVs) and information from the CO_2 cost curves (described in Section 2.4.4.1) for the additional cost of producing each of these alternative powertrains.

Passenger car

To assess the impact on production costs due to regulatory changes for passenger cars, Figure 4.3 below shows the costs of producing a mid-range vehicle in the different markets over time. It is worth noting that the US, Japan and China do not produce the diesel option of the mid-range car.

Figure 4.3: Mid-range per vehicle production costs in 2017, 2030 and 2050

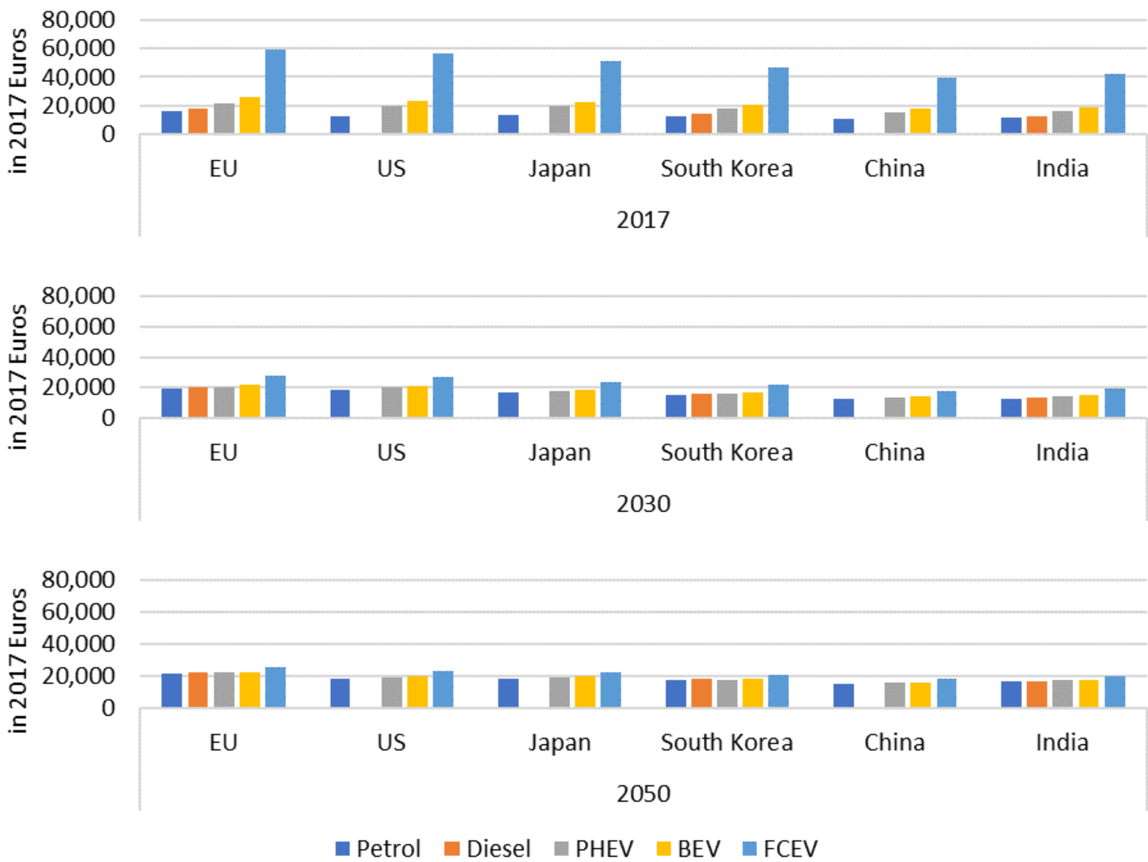


Figure 4.3 shows that over time the cost of producing the different powertrains is expected to converge as the costs of ICE vehicles increase and the costs of xEVs tend to decrease.

The production of the petrol version of the mid-range car always incurs the lowest costs of all powertrain options for all markets, although only by a small margin by 2050, highlighting the need to maximise cost savings in order to support the widespread deployment of xEVs. The xEVs are more costly to produce than the ICE vehicles in 2017 in all markets but this gap is expected to shrink over time. Indeed, by 2050 the diesel vehicle is in fact more costly to produce than a petrol PHEV and incurs about the same production cost as a BEV in the EU. The costs of producing the FCEV remain the highest until 2050.

In general terms, from 2017 to 2030, costs increase for the ICE options but decrease for the xEV options in all markets. This is due to stricter regulation in all markets regarding CO_2 and pollutant emissions which require new technologies that add to the costs of producing ICE vehicles. Reductions in the costs of producing EVs are explained by technological developments which allow the production of more efficient vehicles at lower costs, including expected advances in battery technology. Note that the total costs of xEVs decrease between 2017 and 2030 in all markets, despite the increased costs associated with more stringent safety regulations and the increased labour costs expected through time, implying that the cost reductions from mass-production and lower cost batteries are substantial[8].

Between 2030 and 2050, costs tend to increase for both the ICE and xEV options (excluding FCEVs) compared to 2030 (except for PHEVs and BEVs in the US), due to stricter safety and pollutant emissions regulations (the latter applies only to PHEVs over this time period), as well as further increases in labour costs, particularly in China and India. Nevertheless, costs of producing xEVs in 2050 tend to be below the 2017 level, again highlighting the significant cost reductions achieved in battery technology and through mass production learning effects. The exceptions to this trend include PHEVs produced in the EU, South Korea, China and India as the substantial safety costs combined with the cost associated to the reduction in pollutant emissions and the increasing labour costs are likely to outweigh the cost reductions achieved in battery production. The costs of producing BEVs and FCEVs are always lower in 2050 compared to 2017.

As well as showing a convergence of costs between powertrains over time, Figure 4.3 also illustrates that production costs are expected to converge over time between markets. Vehicle costs are always higher in the EU for all powertrain options. Nonetheless, the gap between costs in the EU and all markets tends to decrease, particularly from 2030 (with few exceptions) as regulation in the different markets is expected to converge to the same stringency level and their labour costs relative to the EU also increase.

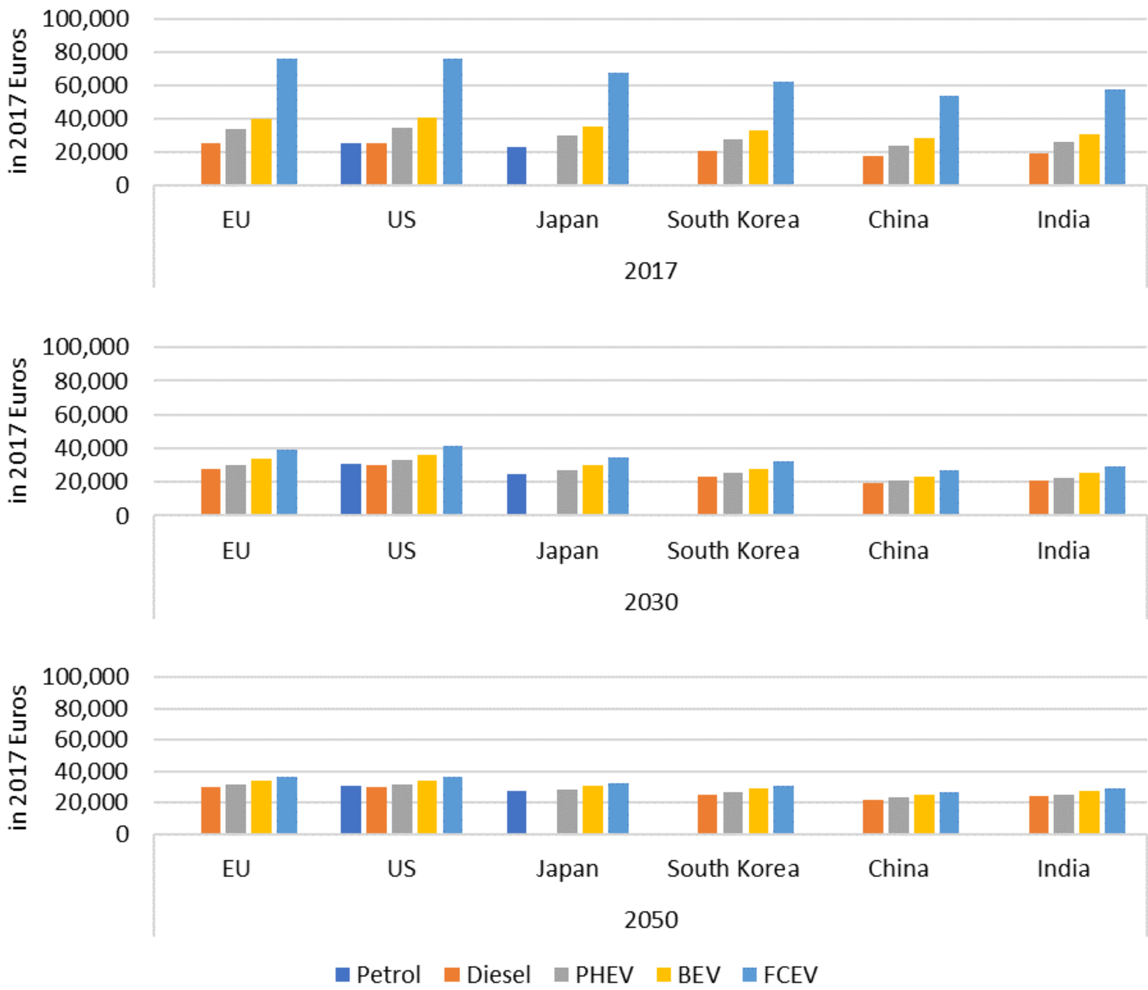
Regarding the entry-level and luxury car (charts provided in Appendix A.8), costs of producing ICE vehicles increase continuously until 2050, whilst the production costs of xEVs decrease between 2017 and 2030 as observed for the mid-range car. Costs are also the highest in the EU, although costs in the other markets tend to converge to the EU level by 2050. A number of differences do exist for these vehicle types however, as summarised below under the key observations section and described in detail in Appendix A.8.

Light commercial vehicles

Figure 4.4 provides a similar overview of changes in costs over time for light commercial vehicles. It is worth noting that there it is assumed that there are no petrol LCVs except in the US and Japan.

[8] Please note that whilst safety regulations affect all powertrains equally by increasing costs by the same amount, the impact of CO_2 and pollutant emissions regulations on costs depends on the powertrain. In the case of pollutant emissions regulation, they have no impact on BEVs and FCEVs.

Figure 4.4: Light commercial vehicle production costs in 2017, 2030 and 2050



Similarly to what was observed for the passenger car segment, the production costs of the different powertrains tend to converge to a similar level through time. Comparing between 2017 and 2050, the costs of producing ICE vehicles increases as expected but the production costs of xEVs decreases. Any increase through time for ICE vehicles and xEVs is accounted for by the increased safety regulatory costs, as well as increasing labour costs, particularly in the developing markets such as China and India.

Regarding the relative costs between markets, the costs of producing the diesel option tend to be highest in the EU given the cost structures in the EU (and despite the more stringent pollutant emissions regulations currently in place in the US), however for all other alternative powertrains these costs are slightly higher in the US. Over time, costs between markets tend to converge to similar values, again due to converging regulatory levels and labour costs.

Average vehicle production costs

The above analysis also has important implications regarding differences between markets, which are reflected in the average production costs illustrated in Figure 4.5.

Figure 4.5: Weighted average passenger car production costs by market shares over time

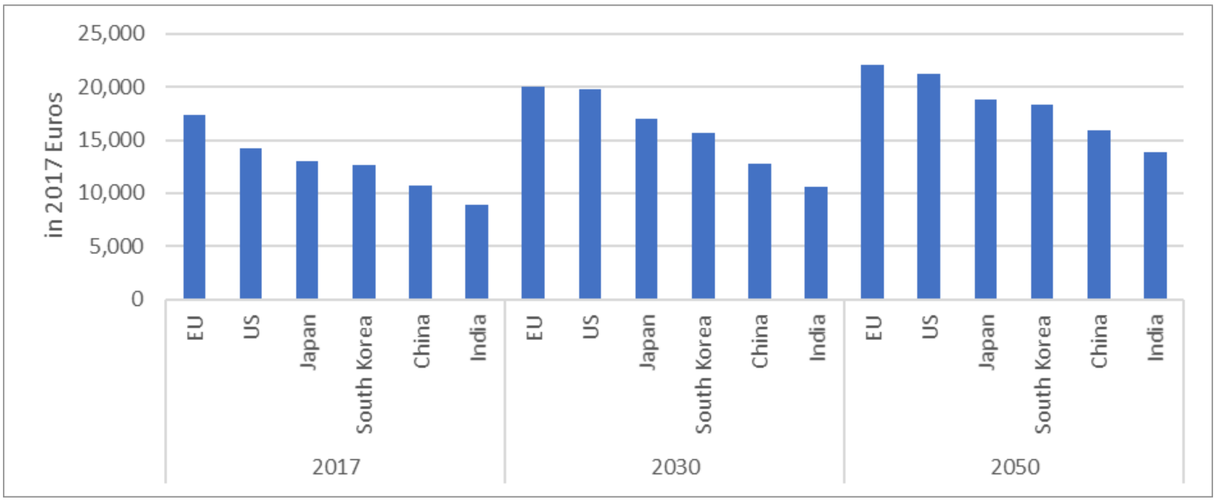


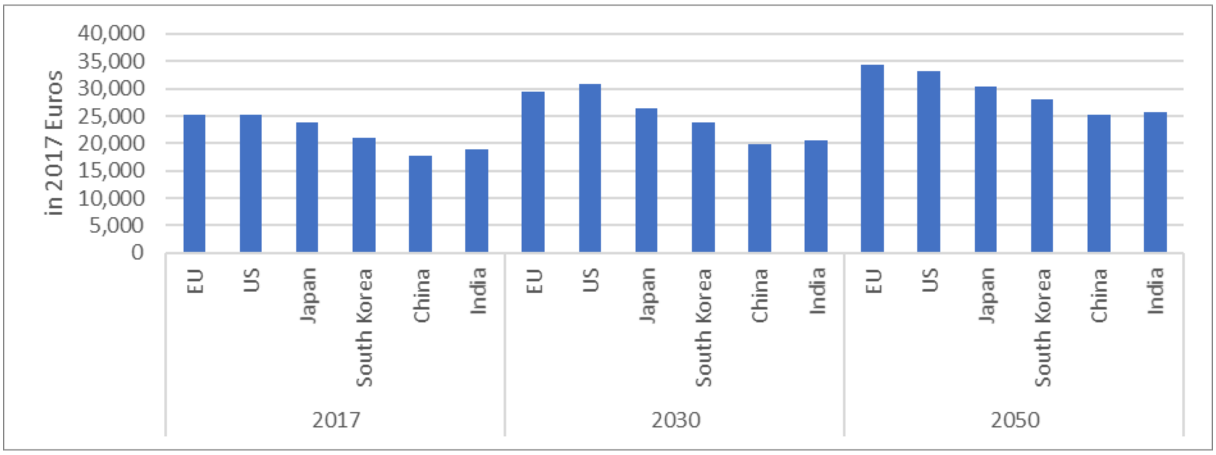
Figure 4.5 demonstrates that the average cost of producing a passenger car in all markets is expected to increase substantially over time. As concluded previously, the production in the EU always incurs higher costs than in other markets (although there are exceptions as discussed above) but the costs in these markets are anticipated to converge closer to EU levels as regulation also converges to the same level of stringency and labour costs in the other countries relative to the EU are expected to increase over time.

Indeed, the gap between EU and the Chinese and Indian costs shrinks over time as expected and the average cost in China and India represents 72% and 63% of EU costs respectively, compared to 62% and 51% of EU costs in 2017. On the other hand, the gap between average cost in the US and the EU increases between 2030 and 2050 reflecting the initial gap in vehicle costs, as in 2050 both countries converge to the same regulatory level (i.e. incremental costs are the same).

Nevertheless the gap between the EU and other developed countries is still considerable in 2050 which indicates other issues at play. This is likely to be related to the high level of indirect costs (as reported in Appendix A.2) in the EU compared to other markets, reflecting structural issues in the EU automotive industry, such as over-capacity, high employment costs, R&D costs, etc.

Figure 4.6 below illustrates similar results for LCVs. The average production costs tend to be higher in the EU, except in 2030 where the cost is marginally higher in the US. In the case of LCVs, the gap between EU and the other markets' average costs tends to increase between 2017 and 2050, except for China, as the other markets tend to lag behind the EU and China by 2050 regarding CO_2 emission regulations targeting LCVs in particular. In 2050, the average production cost in China represents 74% of the EU cost.

Figure 4.6: Average LCV production costs over time



Key observations for all vehicle segments

There are a number of key points from this analysis regarding the production costs of each powertrain:

- The EU tends to have the highest production costs of all markets analysed, across all vehicle segments, with the exception of some vehicle categories which are more expensive to produce in the US (in particular in the LCV segment). Nevertheless the gap between the EU and other markets tends to narrow through time, as regulations converge and labour costs increase at a faster rate in the non-EU markets, particularly China and India.
- Between 2017 and 2030, the increase in stringency of regulations leads to higher production costs of ICE vehicles. Conversely, costs of xEVs decrease due to learning effects and improvements in technologies such as batteries.
- Between 2030 and 2050, the production costs of ICE vehicles increase but, whilst significant learning effects are expected to lead to lower battery and xEV drivetrain costs, the change in overall costs of xEVs is also dependent on cost increases related to safety features and therefore depends on the segment and powertrain. In the entry-level segment for example, xEV costs tend to decrease (except for PHEVs and BEVs in China and India) as the level of vehicle autonomy mandated for this segment is lowest, which also translates into affordable increases in overall safety costs. For larger, more expensive vehicles, PHEV and BEV costs tend to increase as the safety costs associated with increased safety regulations and the advent of greater levels of autonomy offset any cost reductions from the learning effects associated with alternative powertrains. In the case of the luxury segment, substantial battery efficiency improvements are expected such that production cost decreases for BEV powertrains in all markets except China and India and are thus sufficient to outweigh the increase in safety costs. FCEV costs tend to decrease in all markets with few exceptions.
- Overall, the production costs of ICE vehicles increase continuously to 2050, whilst the costs of BEVs and FCEVs decrease between 2017 and 2050. Regarding PHEVs, the change in production costs over time varies by vehicle segment but production tends to become more costly between 2017 and 2050, particularly for the larger mid-range and luxury passenger cars where on-board safety technology combined with emission control technologies is expected to offset the cost savings from improvements in battery efficiency.
- The production costs of PHEVs[9] and BEVs becomes close or lower to the cost of ICE vehicles by 2050 in all cases, showing that cost parity between ICE vehicles and xEVs is likely to occur in the long-run[10]. Further regulatory support to encourage the take-up of xEVs will be crucial to achieve this. Between ICE vehicles, production costs tend to be lower for the petrol option, compared to the diesel option.

The impacts of the production cost changes described in this sub-section for EU OEMs and the EU economy are analysed through the GINFORS-E model in Section 4.2.

4.1.1.2 Price and profitability analysis

The profitability of the EU OEMs in the different markets has been assessed to understand the impacts of regulation on the economic viability of the automotive industry. As described in section 2.4.4.3, OEMs tend to keep prices stable and maintain margins in response to cost changes. A minimum profit margin was therefore assumed to be equal to 2% and prices were only raised for those vehicles whose profit margin fell below this threshold, once the additional costs of regulation were taken into account. Price increases are not

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[9] Although the costs of PHEVs in 2050 are higher compared to 2017, the cost increase was greater for ICE vehicles and thereby the costs between ICE vehicles and PHEVs are closer in 2050 than in 2017

[10] Note that this is not the same as lifecycle ownership costs for xEVs, which are expected to compete with ICE vehicles much earlier, given the significantly lower xEV running costs

modelled to have an impact on vehicle demand. Similarly to the analysis of vehicle costs, this sub-section only presents the results for the mid-range car and the LCV, although conclusions are provided for all vehicle segments and the charts for the remaining segments are provided in Appendix A.9 and A.10.

The base price consists of the price of the (petrol) representative vehicle as indicated in Appendix A.2. This is in effect the price of the petrol option, except for LCVs which have a diesel engine. The prices of xEVs are calculated based on the representative vehicle's price and taking into account the additional costs of producing these alternative powertrains. On the other hand, the prices of the diesel vehicles were obtained from the manufacturers' websites for the relevant representative vehicle. For time periods after 2017, prices are calculated based on the additional costs generated by the regulatory changes, whilst ensuring the minimum profit margin is respected.

Table 4.1 and Table 4.2 below show how the prices used in the model compare with the initial price of the representative vehicle for the mid-range passenger cars and the LCV. A colour scaling is used, where grey represents no change from the initial price, whilst the gradient moving from green to red represents an increase in the price (i.e. red is the largest price in the group).

Table 4.1: Prices of the mid-range passenger car over time (in 2017 Euros)

Year	Powertrain/Market	EU	US	Japan	South Korea	China	India
2017	Representative Vehicle	17,096	14,652	18,974	20,873	14,227	18,198
	Petrol	17,096	14,652	18,974	20,873	14,227	18,198
	Diesel	19,184	NA	NA	23,782	NA	19,642
	PHEV	22,254	20,090	20,023	20,873	15,591	18,198
	BEV	26,150	23,986	23,318	20,997	18,156	19,372
	FCEV	60,374	58,210	52,255	47,398	40,692	43,407
2030	Petrol	19,447	18,507	18,974	20,873	14,227	18,198
	Diesel	20,648	NA	NA	23,782	NA	19,642
	PHEV	20,865	20,168	18,974	20,873	14,227	18,198
	BEV	22,105	21,502	19,180	20,873	14,297	18,198
	FCEV	28,143	27,539	24,284	22,265	18,381	19,802
2050	Petrol	22,082	19,128	19,028	20,873	15,545	18,198
	Diesel	23,125	NA	NA	23,782	NA	19,642
	PHEV	22,555	19,502	19,539	20,873	15,920	18,198
	BEV	23,192	20,178	20,075	20,873	16,396	18,198
	FCEV	26,294	23,280	22,687	21,363	18,717	20,576

Table 4.2: Prices of the light commercial vehicle over time (in 2017 Euros)

Year	Powertrain/Market	EU	US	Japan	South Korea	China	India
2017	Representative Vehicle	25,933	29,865	12,148	14,982	13,923	8,000
	Petrol	NA	29,865	23,260	NA	NA	NA
	Diesel	25,933	29,865	NA	21,290	18,182	19,347
	PHEV	34,652	35,152	30,608	28,311	24,691	26,498
	BEV	41,088	41,588	36,417	33,633	29,231	31,327
	FCEV	77,578	78,078	69,348	63,805	54,972	58,704
2030	Petrol	NA	31,267	25,370	NA	NA	NA
	Diesel	28,241	30,444	NA	23,335	19,436	21,023
	PHEV	30,985	33,429	27,717	25,556	21,207	22,934
	BEV	34,500	37,055	30,970	28,620	23,800	25,672
	FCEV	39,597	42,153	35,571	32,952	27,495	29,595

Year	Powertrain/Market	EU	US	Japan	South Korea	China	India
2050	Petrol	NA	31,361	27,850	NA	NA	NA
	Diesel	30,719	30,551	NA	25,769	22,561	24,969
	PHEV	32,390	32,494	29,043	27,219	23,698	26,059
	BEV	34,952	35,104	31,347	29,551	25,755	28,213
	FCEV	37,066	37,218	33,247	31,475	27,452	30,005

The tables above and provided in Appendix A.9 (for the entry-level and luxury vehicles) illustrate a number of key points relevant to the profitability analysis, as follows:

- Prices of the petrol vehicles (diesel in the case of LCVs) in 2017 match the price of the representative vehicle for the majority of the vehicle segments in the different markets which implies that profit margins are at least equal to 2%. The exceptions are the entry-level car in India where competition with low-cost alternatives is very strong, and LCVs in Japan, South Korea, China and India which have a negative profit margin as demonstrated in the analysis provided in Appendix A.2 (and are therefore not available in those markets).
- The prices of xEVs tend to be higher than (or equal to) the ICE option. The only exception occurs when the costs of the PHEV and BEV in the EU are lower than the diesel option and thereby the price of these xEV is also lower than the price of the diesel vehicle.
- If profit margin was already low and close to 2% in 2017 – as is the case in the EU and US in particular - prices of ICE vehicles tend to increase over time as costs increase. Indeed, in the EU and the US, manufacturers are not able to maintain the initial price for the ICE or the xEV options in the majority of cases. This indicates that profit margins are already low in 2017 for the representative vehicle.
- Prices of xEVs tend to decrease between 2017 and 2030 in line with the decline in costs due to learning effects and improvements in xEV technologies (e.g. batteries) as observed in the previous sub-section. Only the price of the mid-range PHEV in the US marginally increases during this period.
- Between 2030 and 2050, prices of xEVs are expected to either increase or decrease depending on the cost changes analysed in the previous sub-sections and the aim of maintaining at least a 2% profit margin. This is linked to higher levels of automation that raise safety costs. All in all, the cost and price change depends on whether the higher safety costs offset the cost reductions from the production of xEVs. Note that prices of FCEVs always decrease in line with costs.
- Overall, prices of BEVs and FCEVs are anticipated to fall between 2017 and 2050. This does not always hold true for PHEVs however, where the price changes depend on the market and vehicle segment (for larger vehicle segments prices tend to marginally increase).
- To sell the FCEV in all vehicle segments with a 2% profit margin in 2017, manufacturers in all markets require a very high price compared to alternatives.
- Except in the EU and US, manufacturers are able to sell the majority of the powertrain options (including EVs) at the same price as the representative vehicle in the luxury vehicle market which reflects the fact that this segment usually commands higher profit margins. This is also the case for most powertrain options in the entry-level segment in China, Japan and Korea, where margins are sufficient, and production costs low enough, to enable prices to be maintained through time.
- In all markets, the price of the LCV is raised for the alternative powertrain options which indicates low profit margins on the representative vehicle.

The points above already generate important conclusions on the profit margins modelled over time. The sections below discuss this aspect for the mid-range car (representing the passenger car segment – the remaining charts are provided in Appendix A.10) and the

LCV. A comparison with the average profit is also made to understand how profit margins affect the absolute profitability of EU OEMs in the different markets, taking into account the powertrain market shares over time.

Passenger car

To assess the impacts of the regulatory changes on profit margins for the passenger car, Figure 4.7 on profit margins and average profit for mid-range car in 2017, 2030 and 2050 is presented below.

Figure 4.7: Profit margin and average profit on mid-range passenger cars in 2017, 2030 and 2050

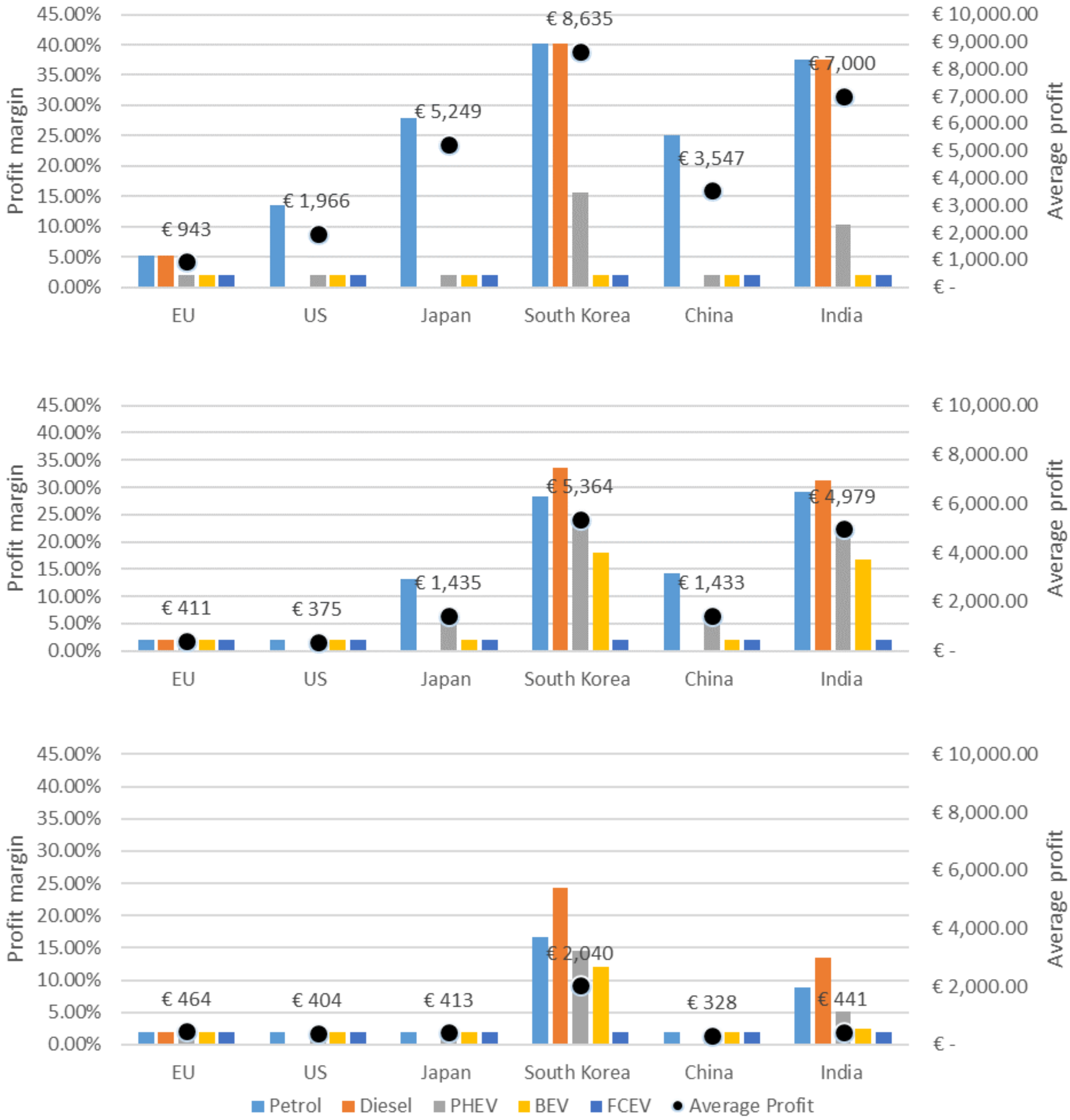


Figure 4.7 shows that the mid-range car in the EU has very low profit margins today. In fact, only the ICE vehicles have a profit margin above the minimum level of 2% in 2017. By 2030, mid-range cars in all powertrain options in the EU can only sustain the minimum profit margin, given the additional costs of meeting the more stringent regulation. As a result, average profit per vehicle decreases to 2030. They are nevertheless expected to increase subsequently as OEMs in the EU are expected to produce a higher share of xEVs which have a higher price than their ICE counterparts and thereby ensure a higher absolute profit (in spite of sustaining the same minimum profit margin). This is an important point

as it indicates that increasing regulation can have a positive effect on absolute profit levels, despite a possible negative impact on percentage margins.

All other markets have a higher profit margin on the petrol vehicle. However the majority cannot produce vehicles profitably for the other powertrain options in 2017, relying as they do on increasing the price to achieve the minimum profit level of 2%. The only exceptions are South Korea and India, where it is possible to incur higher costs and maintain profitability for some alternative powertrains at the same original pricing level. As a result, these countries show the highest average profit for this segment. Only FCEVs incur such high costs that all markets can only sustain the minimum profit margin.

By 2030, profit margins for petrol vehicles in all markets decrease as their costs increase due to regulatory changes. As the costs of xEVs decrease between 2017 and 2030, some markets are able to sustain higher profit margins for these powertrain technologies. Indeed, South Korea, India, Japan and China now show a higher profitability on the BEVs and PHEVs. This means they are able to sell these vehicle options at the same price as their petrol counterparts and still make a sizeable profit as Table 4.1 also illustrates. Nevertheless, the average profit for all markets decreases by 2030 as the increase in the profit margins on xEVs does not offset the decrease in the high profit margins of ICE vehicles and the declining market share of ICEs, both of which contribute to lower average profitability levels.

In 2050, profit margins decrease further for petrol vehicles in line with the changes in costs observed previously. Costs of xEVs also increase between 2030 and 2050 (primarily due to increased safety features and labour costs – as discussed in Section 4.1.1.1 above – these costs also affect ICE vehicles) and therefore profit margins decrease. As a result, profit margins reduce to the minimum level for most markets and powertrains. This also means that average profit further decreases for these countries. Whilst South Korea and India's profit margins on these powertrains also decrease, the cost increases are not sufficient to erode profit to the minimum margin – meaning that xEVs in these markets can continue to be sold profitably at highly-competitive prices comparable to those of ICE vehicles in 2017.

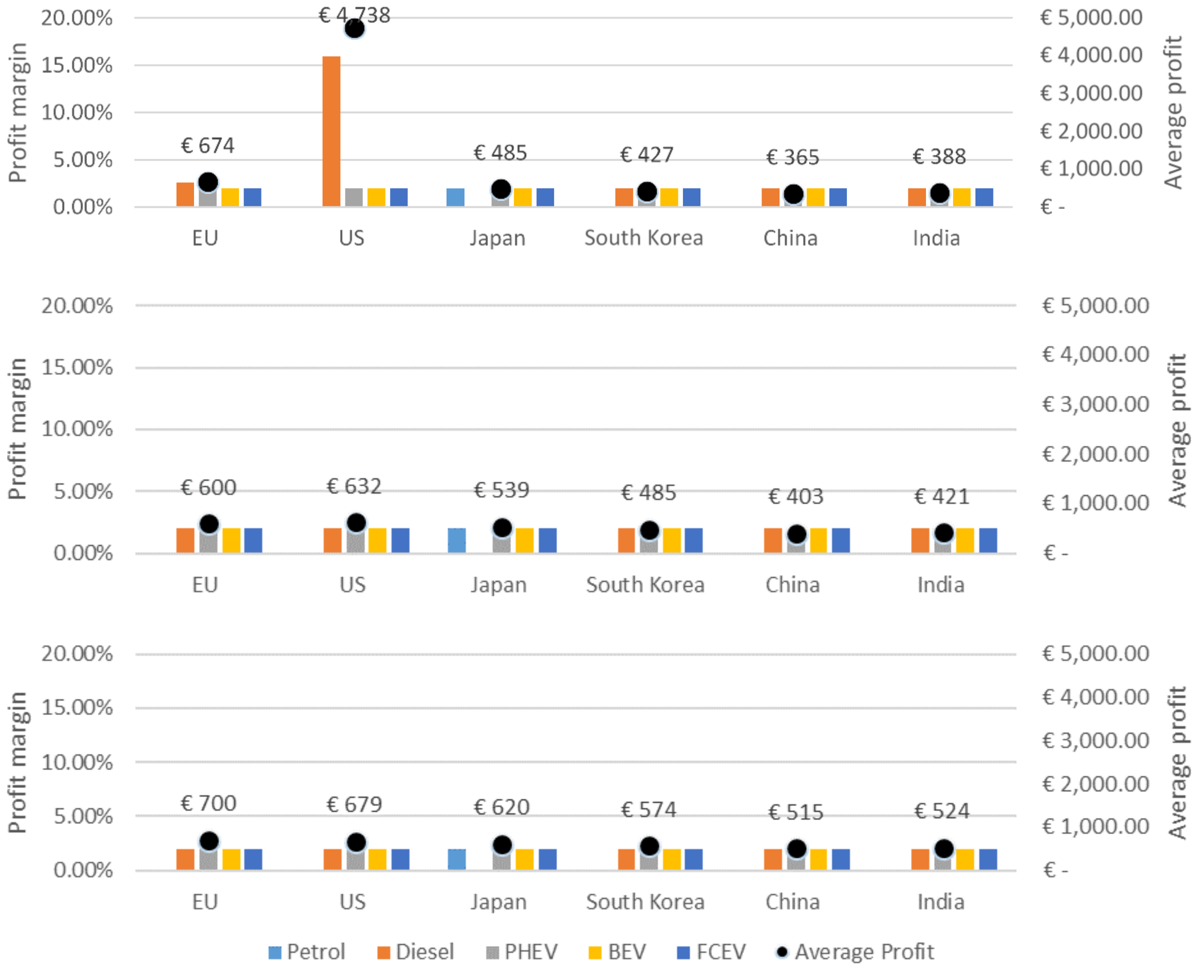
All in all, more ambitious regulations and the shift towards e-mobility contribute to eroding profit margins in most markets, which converge towards the levels seen in the EU. Indeed, by 2050, only South Korea shows a higher average profit than the EU's level. Whilst detrimental in most markets, this trend benefits production in the EU (and to some extent the US) as the prices of xEVs tend to be higher in this market and therefore average profit is also higher than in most other countries by 2050 – whilst at the same time, the EU is no longer at a disadvantage relative to foreign markets. South Korea is the exception to the rule, being the only country where higher profit margins on all powertrains except FCEVs can be sustained even to 2050, at competitive prices. This is possible due to the high price of the mid-range car in this country. The VW Golf, which represents the mid-range vehicle segment in the model, commands the highest price in South Korea (amongst all the markets analysed here), which allows Korean OEMs to better accommodate cost increases and still maintain relatively high profit margins – note that this effect may not be replicated for other locally-branded vehicles. This implies it can sell all powertrains at the same price as the petrol vehicle and the average profit per vehicle is significantly higher.

Compared to the entry-level and luxury cars (charts provided in Appendix A.10), profit margins of ICE vehicles are equally low in the entry-level segment but slightly higher (around 5%) in the luxury segment in 2017 in the EU. Similarly to the mid-range car, profit margins rapidly drop to the minimum level (at 2%) as costs with regulation increase. As a result, average profit in the EU decreases until 2030 after which it tends to recover to a higher level in 2050 (although not higher than in 2017) in the case of both the entry-level and luxury segment. All the other markets tend to sustain higher profit margins on the ICE vehicles, particularly in China, South Korea and Japan in the entry-level segment, and in the four Asian countries in the luxury segment. Similarly, the transition to e-mobility leads to lower profit margins and average profits in all non-EU markets for the whole period analysed. A number of differences do exist for the entry-level and luxury vehicle types however, as summarised below under the key observations section and described in detail in Appendix A.10.

Light commercial vehicles

For LCVs, Figure 4.8 presents the profit margin and average profit over time.

Figure 4.8: Profit margin and average profit on light commercial vehicles in 2017, 2030 and 2050

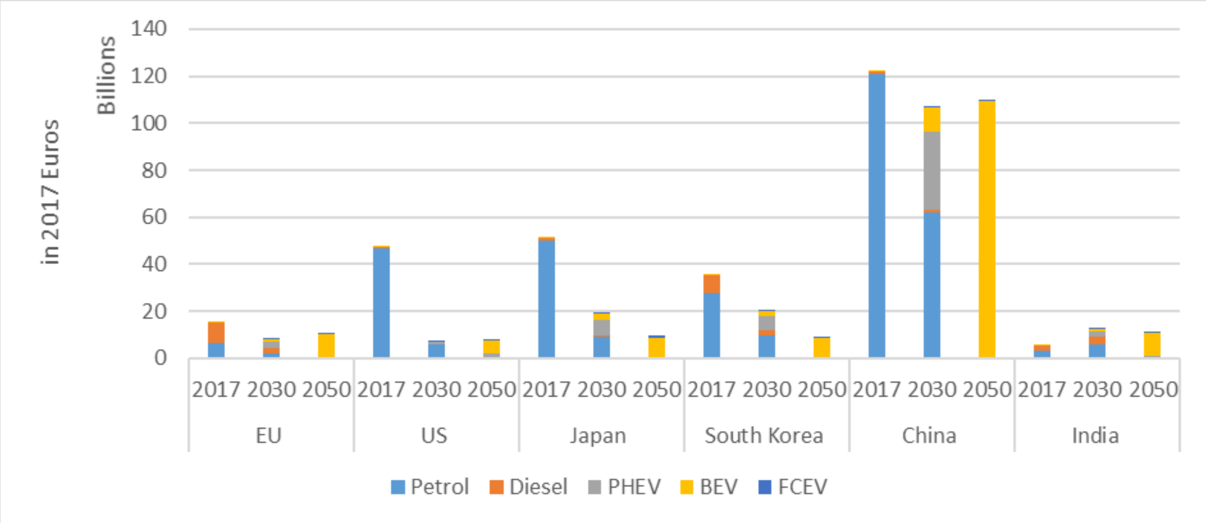


As concluded from Table 4.2, the market for LCVs entails relatively low profit margins in all markets, except for LCVs in the US in 2017 (the great majority representing pick-up trucks, which are known to have high profit margins). By 2030, all powertrains can only sustain the minimum profit margin level. Consequently, average profit is higher in the EU where LCV prices are also higher. It also follows that the e-mobility trend leads to higher average profits for all markets as the more expensive powertrain options are sold in higher proportions.

Total profitability

The above analysis has important implications for total profits accrued in the different markets as Figure 4.9 illustrates.

Figure 4.9: Total profits over time



In 2017, total profits are substantially higher in China (€122 bn), followed by Japan (€51 bn) and the US (€47 bn), compared to the EU (€18 bn). This is due to a combination of high profit margins per vehicle as well as the market size, especially in the case of China.

Profit is anticipated to decrease over time in almost all markets. By 2050, the picture is much changed from 2017, with China showing the highest total profits (€110 bn), followed by India (€11 bn) and the EU (€10 bn). The EU and India present approximately the same amount of total profits but due to different factors: the market is larger in India but the average profit per vehicle is higher in the EU. The decrease in profits over time can be explained by the increase in costs from regulatory changes, assuming constant prices unless profit margins go below the minimum level (set at 2%). In Japan and South Korea, this effect is reinforced by the shrinking market. In China, total profitability decreases between 2017 and 2030 mainly as the transition towards xEVs and higher labour costs eat into high margins but as the market size increases, total profits in the country rise in 2050. The EU shows only a relatively small decrease in profitability despite additional regulation, primarily as a result of the low initial margin in the EU and the higher absolute cost of vehicles in 2050, which makes up for the low minimum margin of 2% being applied across all models by that point in time.

Clearly the shift towards e-mobility makes a significant contribution towards reduced overall profitability in most markets, as these powertrains have lower profit margins when compared to ICE vehicles and, despite their higher price, this is not expected to be sufficient to offset the higher profit margins sustained by ICE vehicles.

Key observations

There are a number of key conclusions from this analysis:

- Profit margins of xEVs are never higher than for their ICE counterparts.
- Profit margins are generally low in the EU for all vehicle segments (although less-so for luxury vehicles), which implies that any increases in costs due to regulatory changes leads to higher prices but not always lower average profit margins over time.
- In other markets such as China, India, Japan and South Korea, OEMs are generally able to sustain higher profit margins. As a result, they have more scope to accommodate cost increases, maintain high profitability and keep prices stable as new regulations and powertrains enter the market over time.
    - This is particularly apparent in the luxury segment, where all four Asian markets are able to command significant (though reduced) margins at today’s ICE-equivalent prices, despite much higher regulatory standards. This supports EU OEMs’ desire to produce and sell vehicles in these markets.

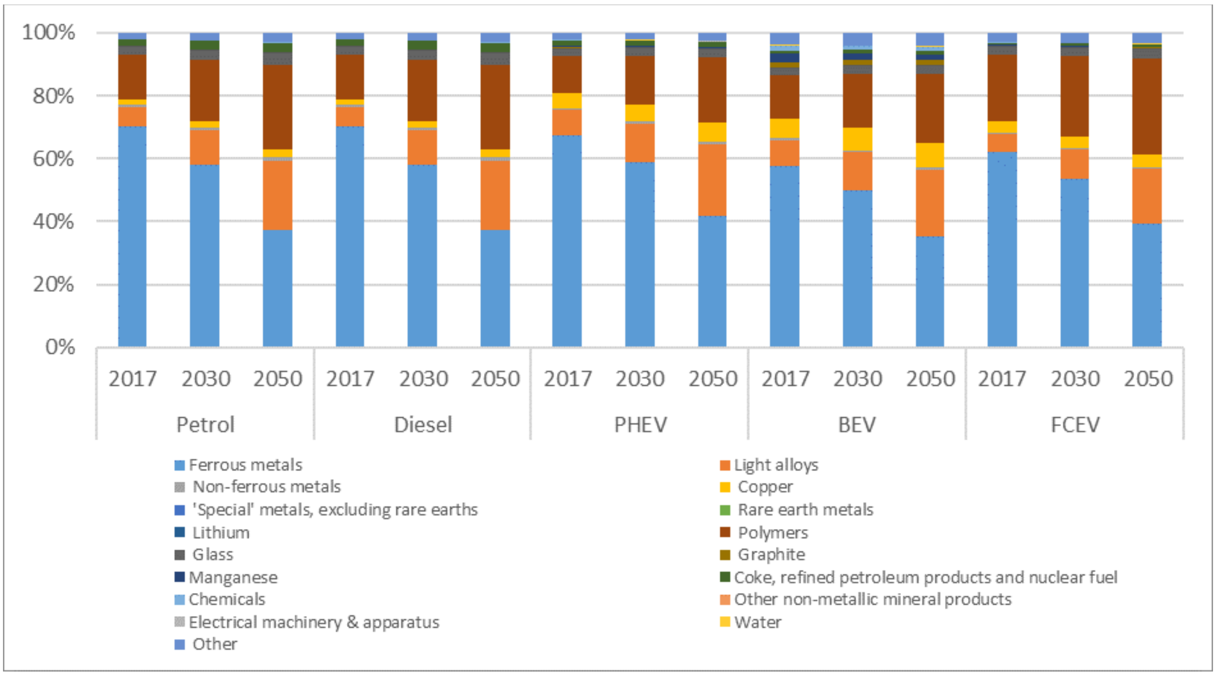
  - In the entry-level market, China stands out as being able to produce xEVs at highly-competitive ICE-equivalent prices, even in 2050.
- Regulatory convergence and labour cost increases in the emerging markets brings down profit margins as costs increase and erodes the average profit per vehicle in these markets.
- The shift towards e-mobility has two opposite effects depending on the level of the profit margins of the ICE vehicles. If low as in the EU, the higher penetration of xEVs actually contributes to increase average profit between 2030 and 2050 (average profit still tends to decrease between 2017 and 2050). If, on the other hand, they were high then average profit tends to go down.
  - It follows that the EU usually benefits from the e-mobility trend as the price of vehicles in this market are generally higher, provided vehicle demand remains constant.
  - When the market is more competitive, high profit margins are not sustained for all powertrains and therefore both profit margins and average profit goes down. In this case the EU holds an advantage as vehicle prices are higher in this market.

4.1.1.3 Material demand

More ambitious regulation together with the e-mobility trend are expected to significantly affect the material composition of vehicles produced, and in turn material demand. Ultimately, changes in the average material composition are expected to have substantial impacts for the EU economy and world trade. This will be covered in more detail in Section 4.2. This sub-section contributes to provide a first overview of the expected changes in material composition and overall demand over time.

Figure 4.10 illustrates the material composition of each powertrain option of the mid-range passenger car over time. The other vehicles segments (charts provided in Appendix A.11) show similar material proportions, apart from the luxury vehicles which already shows a relatively high degree of lightweighting in 2017. The material composition for individual vehicles is the same for all markets; differences between markets result from different powertrain market shares.

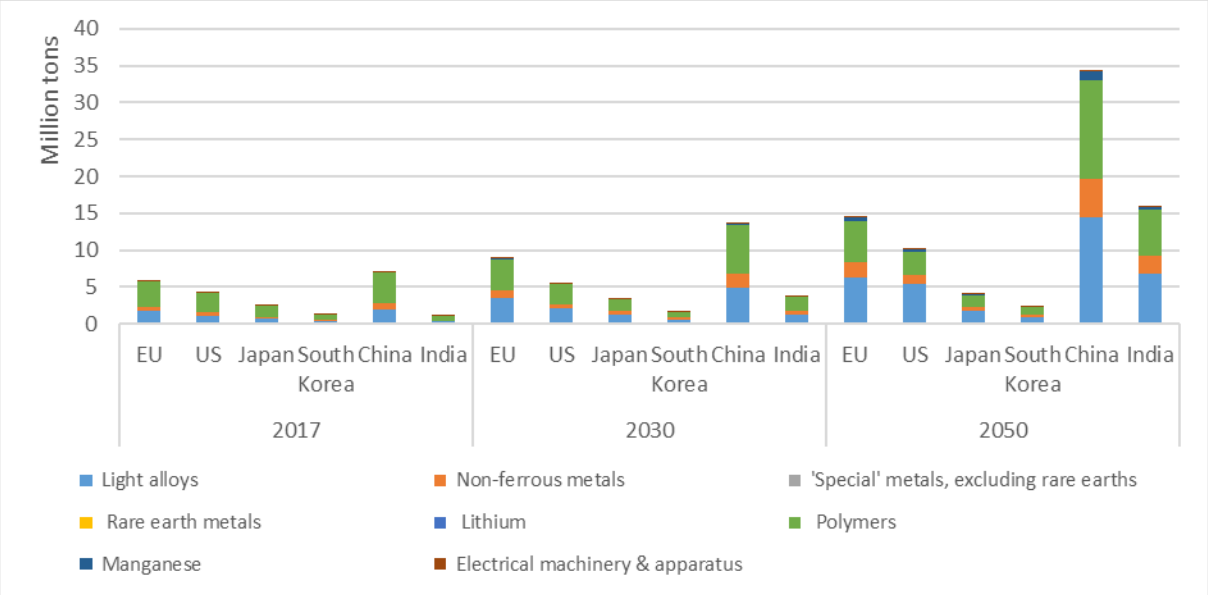
Figure 4.10: Material composition of powertrain options of the mid-range passenger car over time



The above analysis highlights the impacts of regulation, in particular policies targeting CO_2 emissions, to encourage the lightweighting of ICE vehicles[11]. Accordingly, ferrous metals such as steel are replaced by lighter materials such as the light alloys and polymers (where composites such as carbon fibre are included) through time. It is worth highlighting that xEVs have a higher share of lighter materials already in 2017 and this is expected to continue as manufacturers seek to increase efficiency and improve battery range.

These expected changes in material composition have important implications for total material demand through time, as Figure 4.11 illustrates.

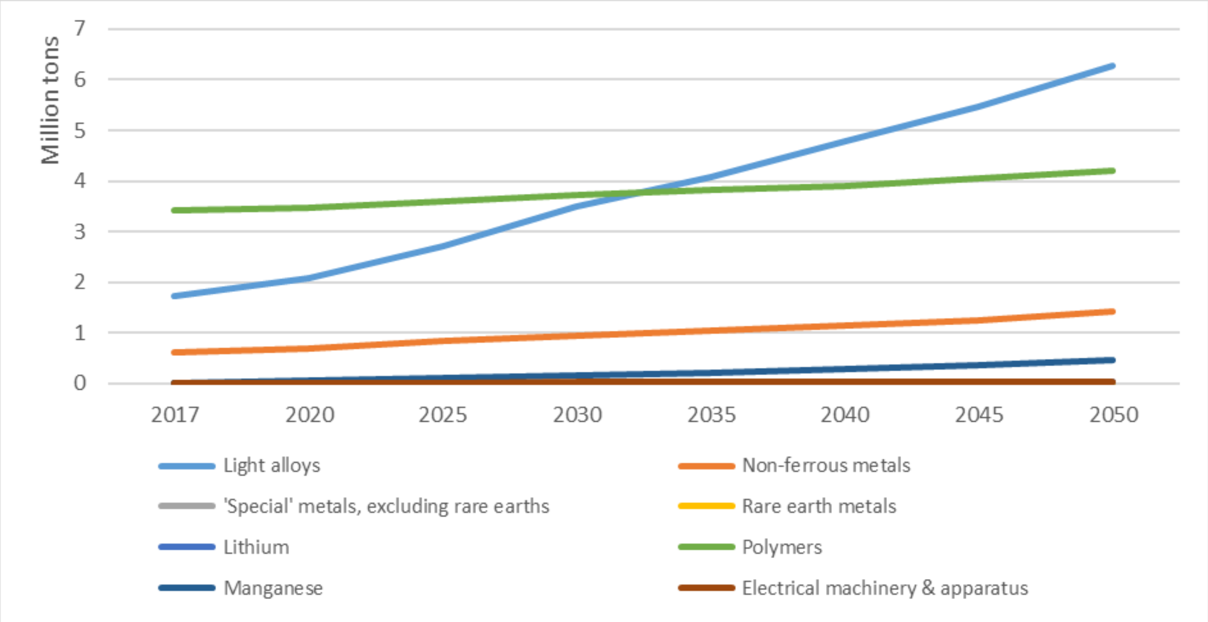
Figure 4.11: Material demand in the different markets over time



The figure shows material demand in each market over time, focusing on the materials used to achieved reductions in weight (light alloys, polymers) but also those which are characteristic to the alternative powertrains and are used in batteries such as lithium and manganese, among others. It shows the substantial increase in the use of these materials, in particular in China and India, where market growth reinforces this trend. Focusing on the EU, Figure 4.12 below provides a clearer overview of the growth in the use of these selected materials over time.

[11] In the case of the EU regulations, it should be noted that the mass balancing equation that can be applied to estimate the CO_2 target for different vehicle masses does not always encourage lightweighting. Nevertheless, this is a strategy that EU OEMs are pursuing for performance and cost reasons, whilst it is also a key element to enabling longer range xEVs in the future.

Figure 4.12: Changes in material demand in the EU



There is expected to be a considerable increase in demand for light alloys and polymers over time due to the lightweighting trend. The figure also shows the growth in the demand for the materials used in batteries which reflects the e-mobility trend. Where native production capacity for these materials is not strong, it will be important for the EU to secure sufficient reliable supply in order to meet this growing demand through time. These outputs from the micro-economic model have important implications for world trade flows, which were assessed through the GINFORS-E model and are discussed in Section 4.2.

4.1.2 EU at varying levels of leadership (scenarios 1 - 4)

In order to assess the impacts of regulation implemented in the EU at different stages and with varying levels of ambition, four scenarios were defined as described in section 3.2:

- Scenario 1: Levelling the technological and regulatory standards gradually till 2030
- Scenario 2: One-off levelling of the technological and regulatory standards by 2030
- Scenario 3: Overshooting the technological and regulatory standards gradually till 2030
- Scenario 4: One-off overshooting of the technological and regulatory standards by 2030

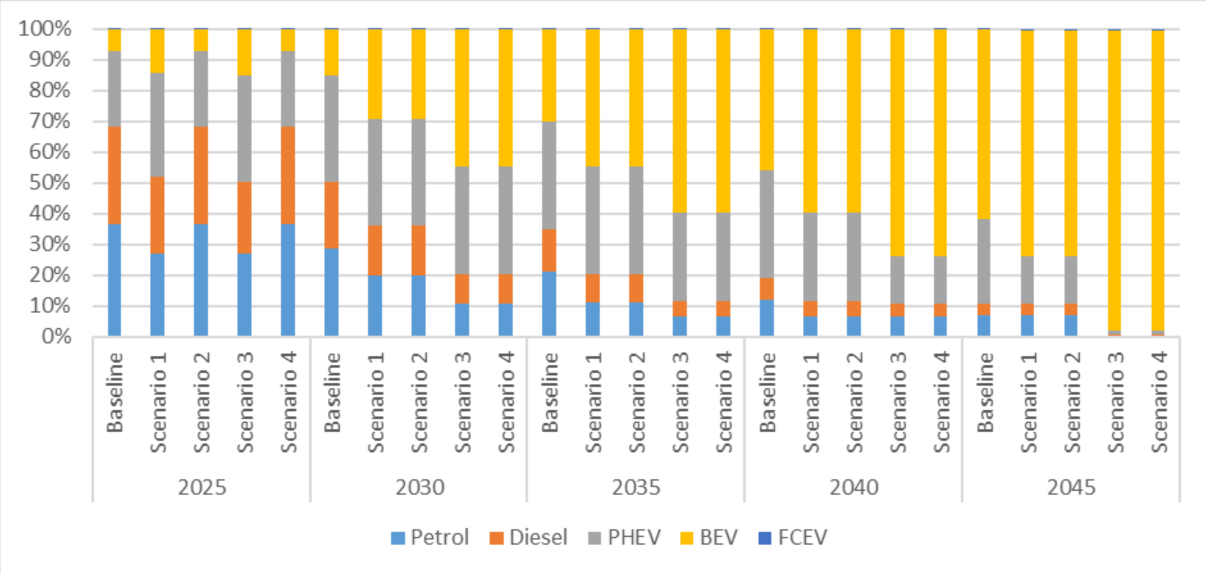
In effect, the four scenarios represent future potential situations where the EU is at varying levels of leadership. In scenarios 1 and 2, the EU implements regulation in the three key areas (CO_2 emissions, air pollutant emissions and safety) that match the highest regulatory level in place globally from 2030, while in scenarios 3 and 4 the EU aims to lead and sets more ambitious regulations than those in place in the other markets by 2030.

The difference between the gradual and one-off approaches is on the pace at which the regulation is set. In scenarios 1 and 3 the EU gradually ramps up its regulations, whilst in scenarios 2 and 4 the EU implements the tighter regulations in one go. As described in Section 3.2, this difference is intended to represent a situation in scenarios 2 and 4 where OEMs are informed of the change in regulation but can choose how to adapt to it whilst in scenarios 1 and 3 the gradual implementation of the regulation guides more closely OEMs' responses. In reality however, it is likely that the responses of OEMs sit somewhere in between the gradual and one-off approaches, as they are informed about future regulations well in advance, thereby allowing them time to adapt (but not necessarily compelling them to before the regulation is fully implemented).

4.1.2.1 Powertrain market shares

Section 3.2 describes in detail the changes between each scenario and the baseline for each of the three trends. Based on these changes, the market shares of the different powertrain options are also expected to vary according the pattern shown in Figure 4.13. Note that the figure only shows the years for which there are changes in market shares in the EU.

Figure 4.13: Powertrain market shares in the EU for the baseline and scenarios 1-4



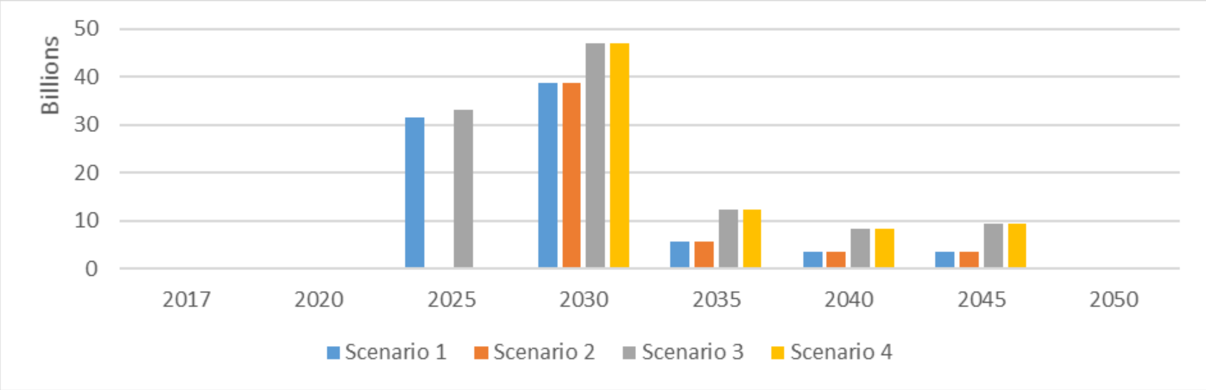
In 2025, only scenarios 1 and 3 show changes relative to the baseline as in these scenarios regulation is implemented gradually until 2030. Essentially, it means the shift towards e-mobility occurs sooner as more ambitious environmental regulation is anticipated from 2025. By 2030, scenarios 2 and 4 also change relative to the baseline, reaching the same level as scenarios 1 and 3 respectively – indicating a very sudden and significant shift in market shares for the 'one-off' scenarios. In this year, the overshooting scenarios (3 and 4) represent a situation where environmental regulations are tighter than in the levelling scenarios (1 and 2) and thereby the penetration of xEVs is higher for the former scenarios. Until 2045, the same picture is observed as the overshooting scenarios are ahead of the e-mobility trend in the levelling scenarios.

The changes in regulations and the associated variations in the powertrain market shares in the EU have important implications for the costs, pricing strategies and profits of EU OEMs, which are assessed in the following sub-sections.

4.1.2.2 Vehicle costs

Compared to the baseline, vehicle costs are expected to increase in all scenarios as the EU either tightens its regulations to the highest level of stringency, or surpasses it. Figure 4.14 shows in detail the magnitude and pace of these changes in costs.

Figure 4.14: Changes in total costs in the EU compared to the baseline



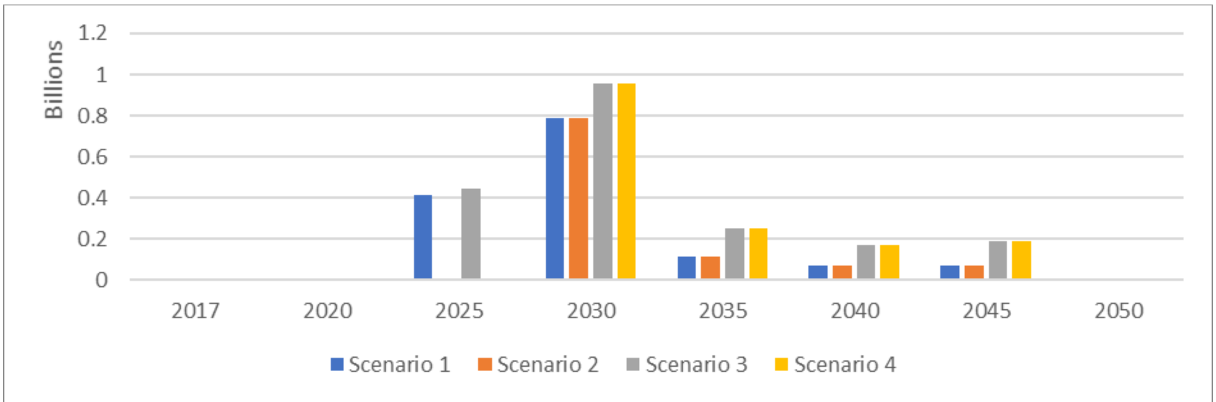
Changes occur as soon as 2025 for scenarios 1 and 3 as stricter regulation is implemented gradually. Costs increase slightly more in scenario 3 in 2025 (8.8% against 8.5% in scenario 1, both compared to the baseline) since this scenario entails the overshooting of regulations by 2030 and thus a faster ramping from 2025. From 2030, the levelling scenarios (1 and 2) entail the same cost increases (10% relative to the baseline) as regulation is at the same stringency level for both scenarios. The same occurs in the overshooting scenarios (3 and 4 at 12% increase relative to the baseline), although the increase is higher as the overall level of stringency is also higher.

Overall, all the scenarios incur additional vehicle costs for the OEMs. Cumulatively, the overshooting scenarios (3 and 4) entail the highest total costs, given the fact that they incur higher costs earlier. Scenario 3 is therefore the scenario in which OEMs incur the highest additional costs compared to the baseline (€467 bn cumulative approximately to 2050 representing €914 per vehicle), whilst scenario 2 involves the lowest costs (additional €159 bn euros cumulative approximately to 2050 representing €384 per vehicle).

4.1.2.3 Price and profitability analysis

Prices and profits also change in line with the cost changes analysed previously, as Figure 4.15 shows.

Figure 4.15: Changes in total profits in the EU compared to the baseline



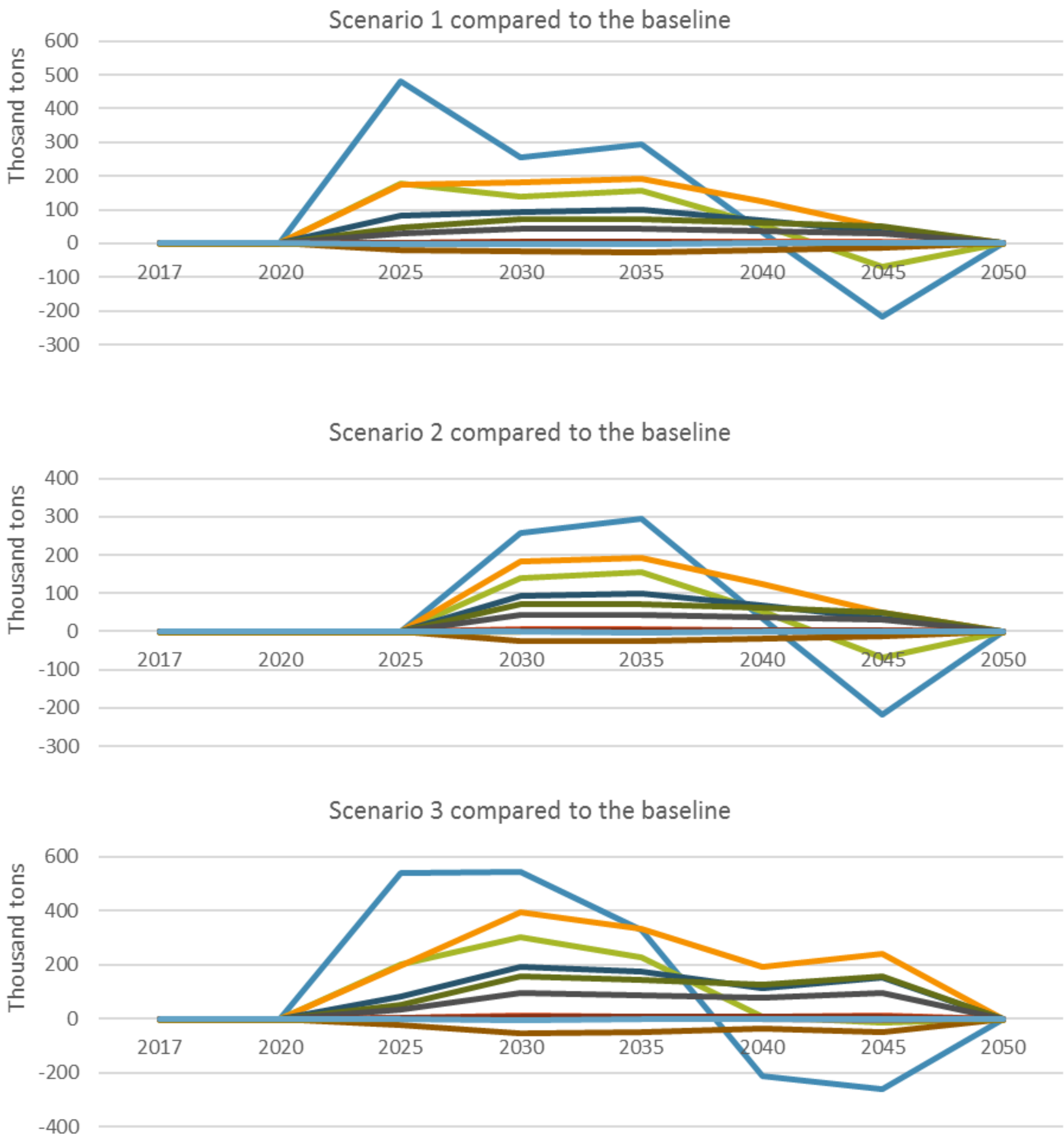
Total profits in all scenarios are expected to increase in the EU due to two effects. Firstly, the increase in costs is likely to lead to an increase in prices. Given that the modelling assumptions require a minimum 2% profit margin and that profit margins are relatively small in the baseline in the EU (close to 2% on average), average profits increase when prices increase. Indeed, profits in all scenarios increase by the same percentage as costs except in 2025 when profit margins for some vehicle segments are above the minimum, which allow the price to remain stable. Secondly, the early shift towards xEVs whose prices are generally higher also contributes to increased profits, despite their lower expected individual margins. Note that a key assumption here is that manufacturers increase prices to maintain profitability and that demand for vehicles is assumed to remain the same as in the baseline, despite the changes in price. This is likely to have knock-on effects on other sectors of the economy as discussed further in Section 4.2.

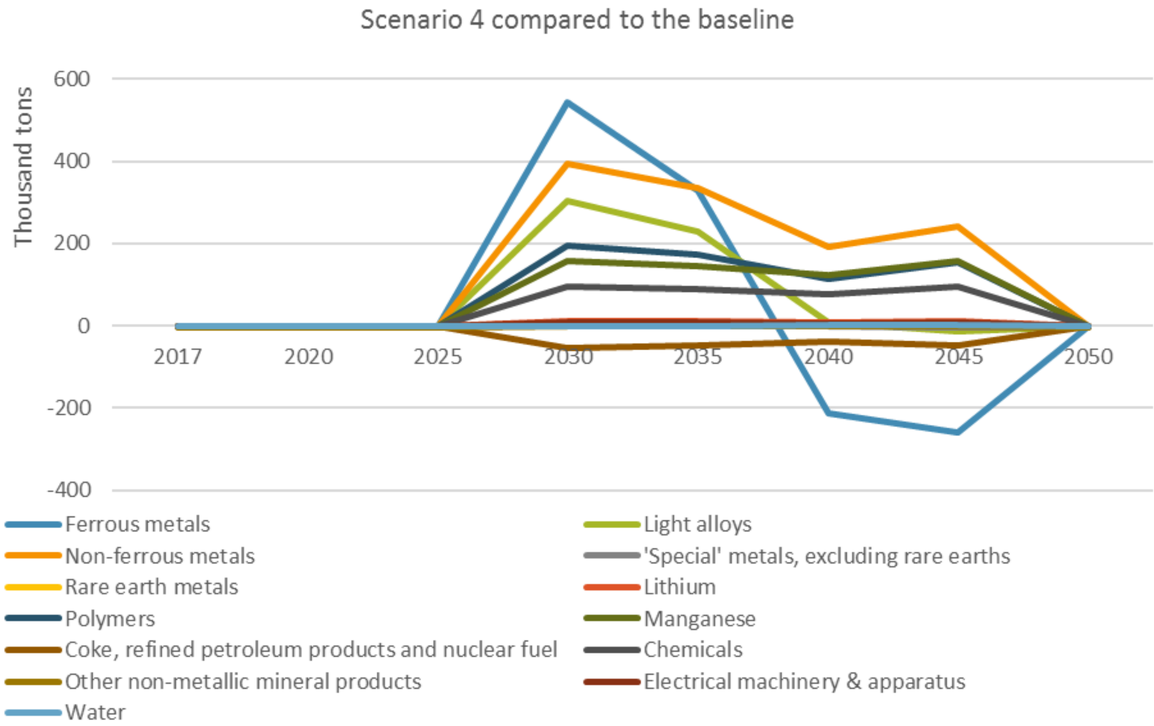
Overall, the situation such as the one represented by scenario 3 which entails the early implementation of regulation at a very high level of stringency (overshooting) is the most beneficial for the EU in terms of additional profits between 2017 and 2050, which are at the highest level (€9 bn cumulative approximately to 2050 representing €18 per vehicle).

4.1.2.4 Material demand

The strengthening of regulations modelled in the EU scenarios also influences demand for materials in the EU. As more ambitious environmental regulation is anticipated, both the effects of lightweighting and the early transition towards the electrification of powertrains lead to changes in the average material composition of vehicles in the EU. Figure 4.16 below shows the changes in material demand in the EU in each scenario compared to the baseline.

Figure 4.16: Changes in material demand in the EU in each scenario compared to the baseline





In line with the previous analysis, changes in material demand are observed for scenarios 1 and 3 already in 2025 as these scenarios entail the gradual implementation of stricter regulation. After 2030, material demand changes in all scenarios compared to the baseline, albeit with different magnitudes. Changes tend to be higher for the overshooting scenarios (3 and 4) as these entail the implementation of stricter regulation.

The main impact observed is from the increased use of materials used in lightweighting in ICE vehicles and for materials associated with xEVs (and a corresponding decrease in those materials used in more traditional ICE vehicles), as these two elements are closely linked to the strength of the environmental regulation in place. Indeed, the scenarios result in higher demand for light alloys and polymers since the lightweighting of all powertrains is anticipated to be more rapid and extensive than in the baseline. The demand for ferrous metals, however, also increases at first despite the lightweighting effect since xEVs also use these materials in more quantity (due to their overall higher mass compared to ICE vehicles) and thereby the transition to e-mobility results in more demand for these materials. After 2030/2035 (overshooting/levelling scenarios, respectively), the demand for ferrous metals declines as the lightweighting effect intensifies. The demand for non-ferrous metals such as copper and other rarer materials such as lithium, manganese, rare earth metals, etc. rises compared to the baseline due to the early shift towards xEVs and the demand for these materials in the production of batteries and electric motors.

The additional demand for light alloys starts decreasing in 2030 for the overshooting scenarios (3 and 4) and in 2035 for the levelling scenarios (1 and 2). Indeed, demand for these metals eventually becomes lower in the scenarios relative to the baseline due to the higher penetration of xEVs in the scenarios and the associated improvements in energy efficiency of batteries in these vehicles that require progressively lower quantities of these materials. This effect dominates over the lightweighting effect and total demand for this material declines.

Overall, the scenarios in which regulation is overshooting result in higher costs cumulatively but also higher cumulative profits due to the specificities of the EU market where profit margins are relatively low in the baseline. The increase in price required to keep the percentage profit margin at the minimum level combined with the shift to e-mobility results in a situation in which the early implementation of very ambitious regulation benefits the market – with the assumption that total demand for vehicles remains constant. The effects on material demand are also more extreme for this scenario.

Section 4.2 elaborates on the wider impacts on the EU automotive industry, market and economy.

4.1.2.5 Internal market sensitivity analysis

The EU's leadership ambition in the regulatory environment is also likely to have repercussions on the competitiveness of both EU and foreign OEMs within the internal market. In effect, the strengthening of EU regulations could present a barrier to foreign OEMs accessing the internal market provided they are not able to respond to the regulatory shock in the EU and comply with the stricter levels of regulation.

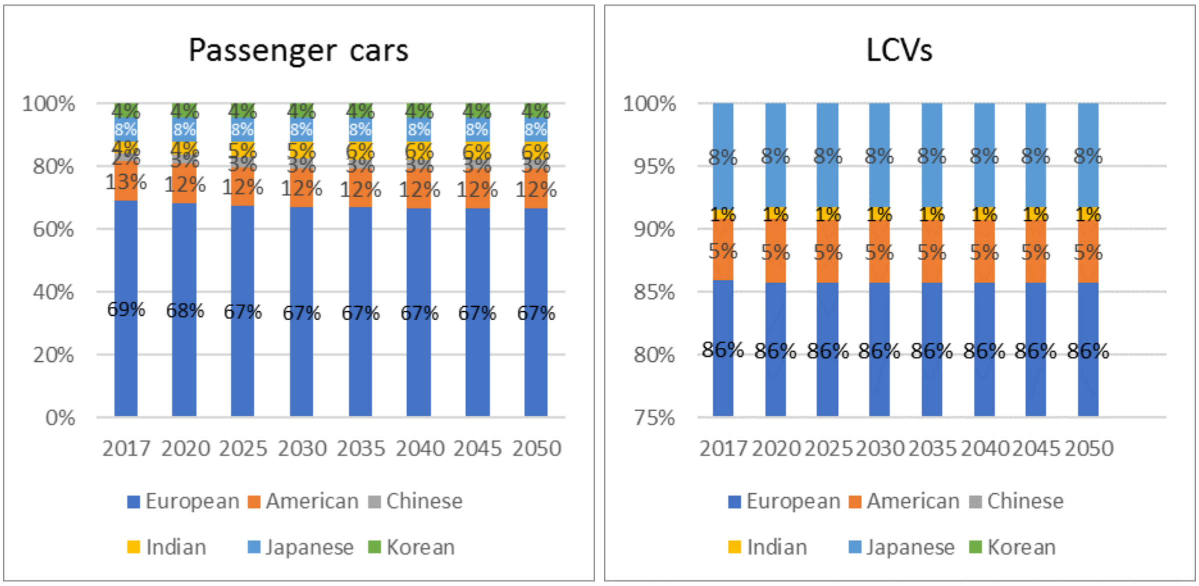
To fully understand the impacts of regulation on competitiveness of EU OEMs, a sensitivity analysis on the internal market was thus performed based on the analysis of expected changes to the market shares in production of the different OEMs. A similar analysis is undertaken to assess the impacts of the unilateral strengthening of regulations in China (China case scenarios), described in section 4.1.4.

The sensitivity analysis assesses the situation in which OEMs from markets where regulations are not as stringent as in the EU have limited access to the internal market. The following assumptions define the modelling of the analysis:

- The sensitivity is only performed to scenario 2 as this is also the reference scenario used to study the impacts of the China case scenarios
- In practice, OEMs from markets where regulatory ambition is lower have their market share in the EU market reduced significantly when the shock occurs in 2030
- The impact is only modelled for the entry-level and mid-range car segments since these are the vehicle segments which are less likely to be prepared for a regulatory shock. Due to the low vehicle production costs, these vehicles are not likely to be fitted with more advanced technology that would enable them to comply with stricter regulation
- Non-compliant OEMs take about ten years to adapt to the stricter regulation (i.e. by 2040), after which they are only able to regain half of their baseline market share. This is because they are likely to suffer from reputational issues and will find it hard to compete with the enlarged market power of the OEMs which gained a dominant position in the market for the ten years they were excluded from these segments

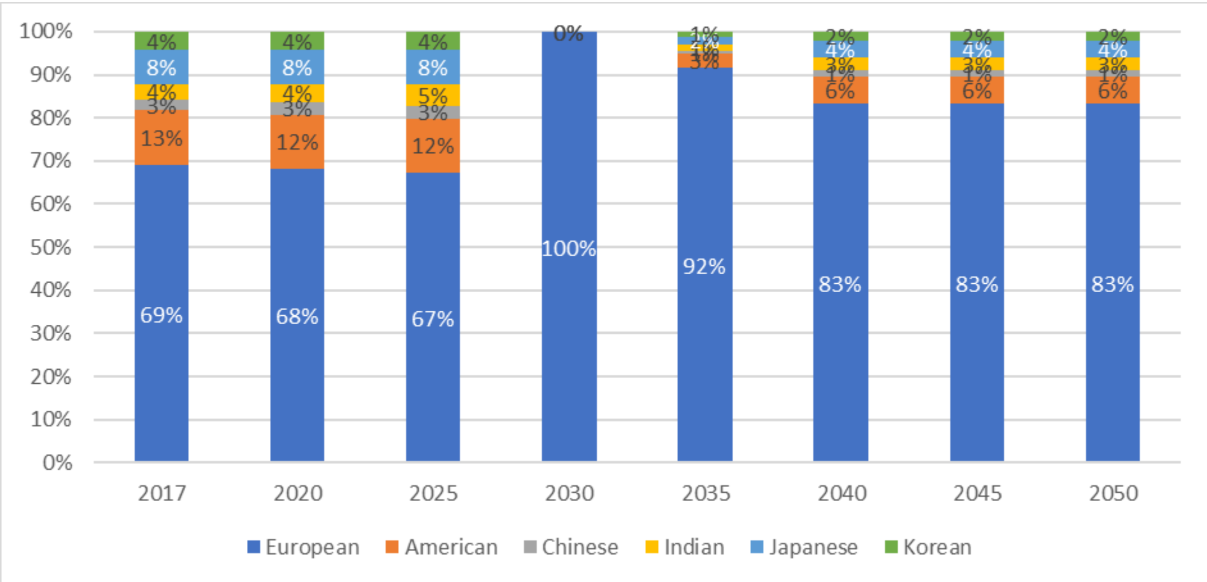
Figure 4.17 below shows the shares of the different OEMs grouped by nationality in the production of passenger cars (equal for all segments) and LCVs in the baseline. More information on the forecasted market shares is provided in Appendix A.1.

Figure 4.17: Production in the EU by manufacturer's nationality in the baseline



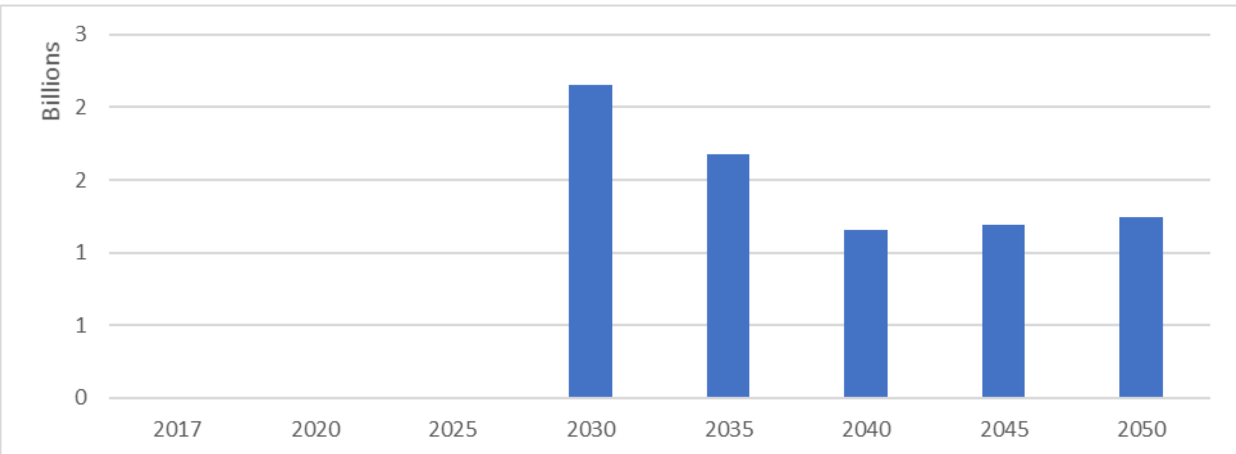
Under scenario 2, none of the markets considered match the overall regulatory level in the EU and, as a result, all foreign OEMs are excluded from the EU entry-level and mid-range car markets in the internal market sensitivity analysis. Note that this sensitivity analysis follows a similar approach to the China case scenario (section 4.1.4), in order to estimate the order of magnitude of the net benefits accrued to EU OEMs stemming from the higher regulatory ambition in the EU. In reality, some foreign OEMs with localised production in the EU are also expected to be able to comply with the stricter regulations; whilst their imports into the EU would likely still be affected, the overall impact would be less severe than that predicted by this scenario and as such the results reported here represent upper bound estimates. Figure 4.18 below shows the expected changes in the market shares of the EU and foreign manufacturers in both the entry-level and mid-range car segments.

Figure 4.18: Production in the EU by manufacturer's nationality in the internal market sensitivity analysis for entry-level and mid-range cars



In line with the assumptions described previously, foreign OEMs see their market share reduced to 0% in 2030. EU OEMs, on the other hand, gain complete control of the EU entry-level and mid-range markets in 2030 and are able to maintain a market share of 83% after 2040 (compared to 67% in the baseline) for these segments. This additional market power is anticipated to have a significant impact on the costs, revenues and thereby on profits of EU OEMs, as Figure 4.19 below illustrates.

Figure 4.19: Additional profits accrued to EU OEMs under the internal market sensitivity analysis



Dominating the entry-level and mid-range car market represents €2.2 bn in additional profits for EU OEMs in 2030 and €1.2 bn in 2040. After 2040, the additional profits accrued to EU OEMs are expected to increase, despite the constant market share, since the value of the market is growing. Cumulatively, the EU OEMs are expected to gain €29 bn in additional profits between 2030 and 2050 (or €69 per vehicle produced). The impacts of this sensitivity analysis on the wider economy are described in section 4.2.

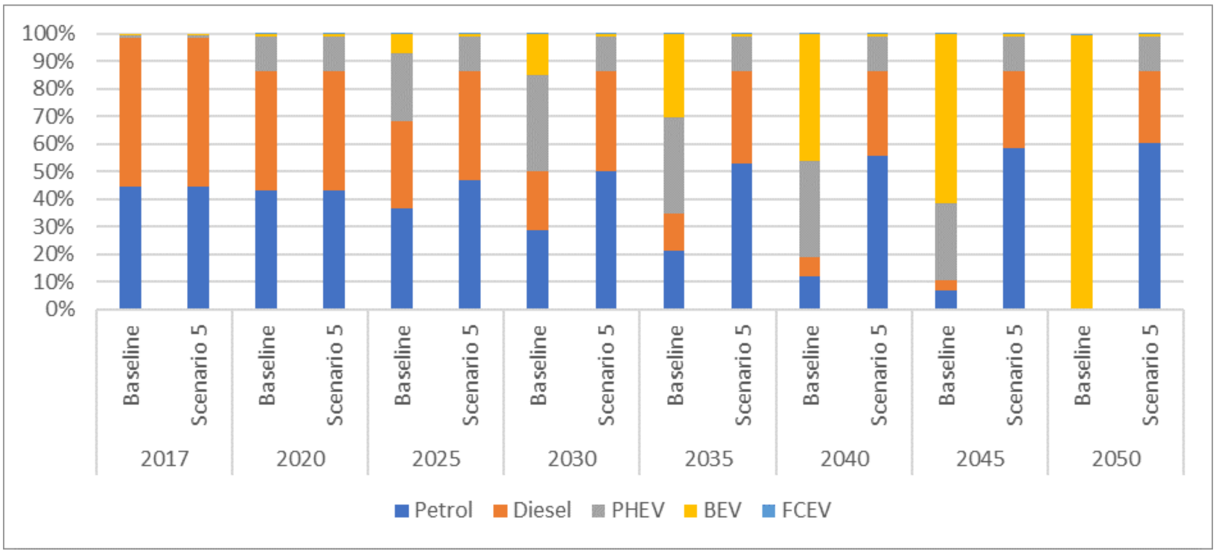
4.1.3 Freezing of EU regulations (scenario 5)

Scenario 5 models the situation in which the EU maintains the regulatory level already announced up to 2020 for the whole period until 2050. In effect, this implies the freezing of regulations in the EU as described in more detail in Section 3.2.

4.1.3.1 Powertrain market shares

For the powertrain market shares in the EU, the freezing of regulation also entails no changes in the market shares of different powertrains after 2020, as Figure 4.20 illustrates.

Figure 4.20: Powertrain market shares in the EU for the baseline and scenario 5



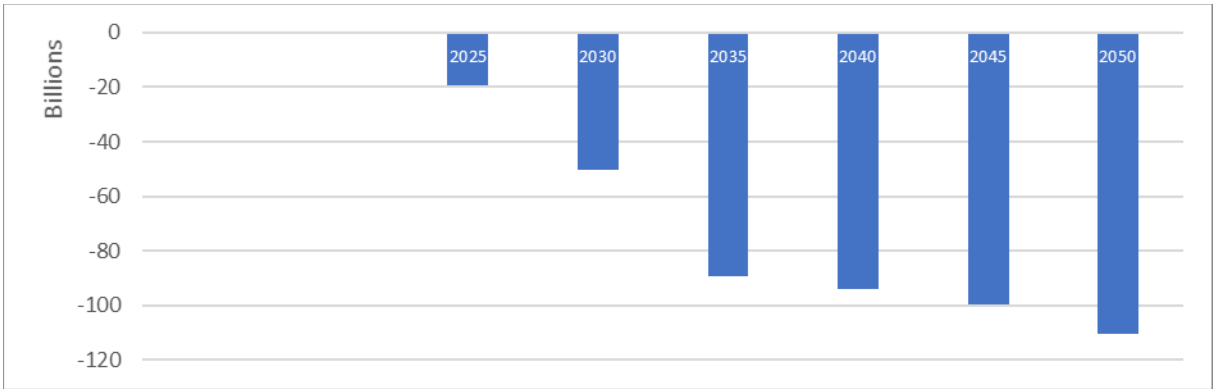
In this scenario, the shift towards e-mobility never fully occurs. By 2050, ICE vehicles still represent 87% of all vehicles produced in the EU in scenario 5.

This scenario entails significant impacts for the EU OEMs' costs, prices and profits as the following analysis shows.

4.1.3.2 Vehicle costs

Figure 4.21 below shows the changes in total costs for this scenario compared to the baseline. As expected, total costs are always lower after 2020 as regulation remains constant at the same level of stringency, whilst in the baseline progressively more ambitious regulation requires investment in new technologies. Cumulatively, scenario 5 is predicted to entail €1,991 bn lower costs in the EU representing €3,899 less per vehicle.

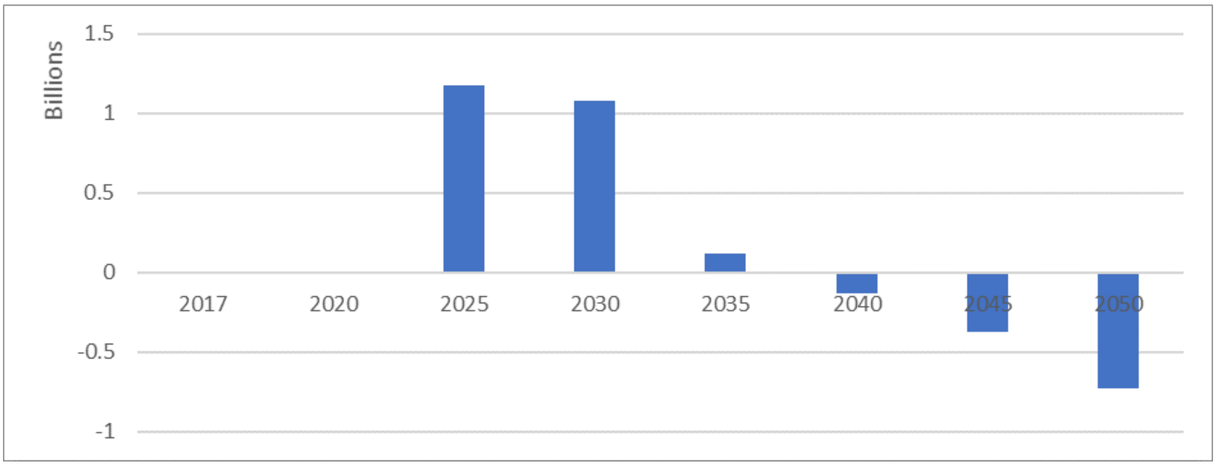
Figure 4.21: Changes in total costs in the EU in scenario 5 compared to the baseline



4.1.3.3 Price and profitability analysis

Accordingly, price and profits also change in scenario 5 as shown in Figure 4.22. Although profits start by increasing compared to the baseline in 2025, 2030 and 2035, they progressively decrease after 2035. Nevertheless, this represents a gain of €4.6 bn in profit in scenario 5 in the EU to 2050 cumulatively (and €9 per vehicle).

Figure 4.22: Changes in total profits in the EU in scenario 5 compared to the baseline

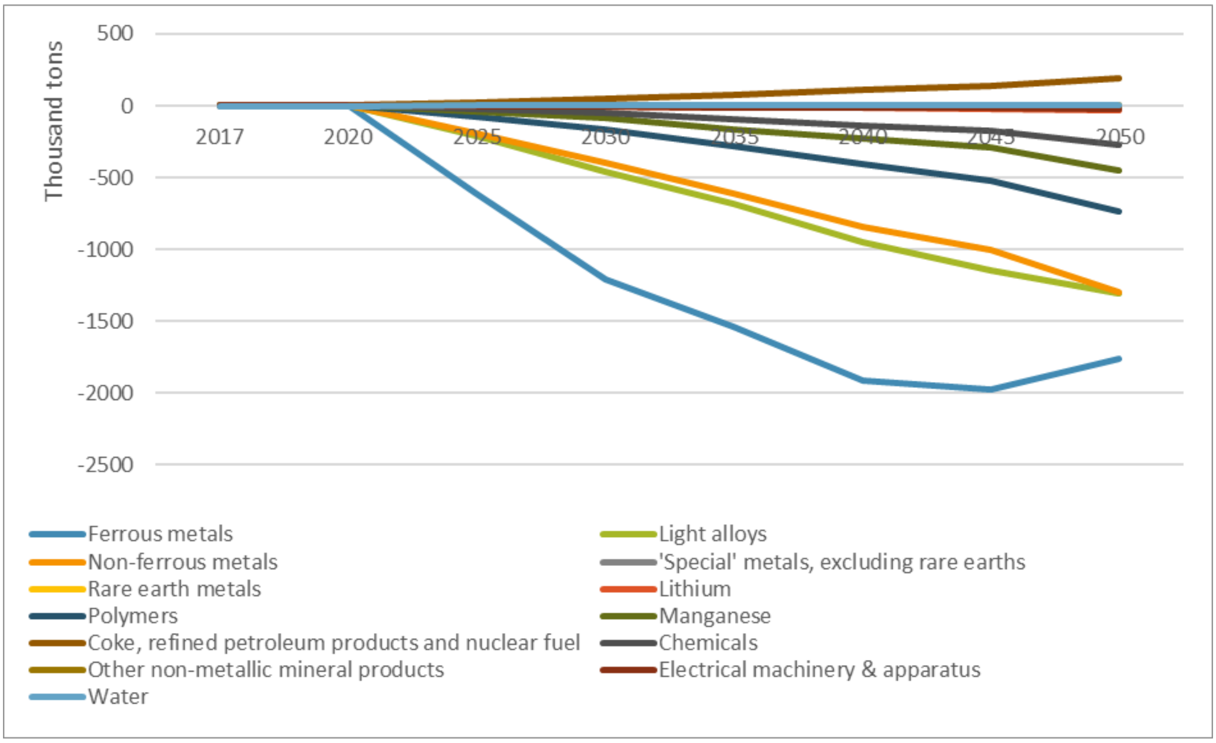


This impact in scenario 5 can be explained by the fixed nature of the powertrain market shares after 2020 and the low penetration of xEVs compared to the baseline. In the initial period to 2030 when the share of ICE vehicles is still high in the baseline, the lower costs observed in scenario 5 result in higher average profit margins. However, as ICE vehicles are progressively replaced by the production of xEVs in the baseline, the cost advantage of scenario 5 is no longer sufficient to offset the gains in the baseline from the sale of vehicles which command higher prices and thereby higher average profits. This is a particular effect occurring in the EU, since profit margins are relatively low for both ICE vehicles and xEVs in the baseline and are assumed to be maintained close to the minimum level of 2% going forward. Whilst the gains made in the first years are sufficient to offset the losses between 2040 and 2050, the analysis does not take into account the the significant negative impacts likely to be seen under this scenario from foreign OEMs gaining a much stronger foothold in the EU due to the lower regulatory barriers. In reality, this could significantly hinder EU OEM’s capacity to compete in their home market and losses would be expected to be much more significant.

4.1.3.4 Material demand

Material demand is also affected by the freezing of EU regulations after 2020 as Figure 4.23 illustrates.

Figure 4.23: Changes in material demand in the EU in scenario 5 compared to the baseline



The major changes in material demand can be explained mainly by the low penetration of xEVs in this scenario. The ICE vehicles have a lower overall mass and accordingly the figure shows the decrease in use of most materials, except for instances refined petroleum products which are used in higher proportion in ICE vehicles. In particular, non-ferrous metals and other materials specific to e-mobility are more predominant in the alternative powertrains and thereby their demand declines significantly in scenario 5 compared to the baseline.

All in all, in spite of the cost reductions achieved in scenario 5, freezing EU regulations at 2020 levels does not seem to be favourable for OEMs in the EU as cumulative profits would actually decline in the future – assuming that demand remains constant. Note however that it is the specificities of the market characterised by low profit margins that contribute to this result. Material demand also changes significantly in this scenario, which has impacts for the wider EU economy and trade with other countries. These topics are explored in more detail in Section 4.2.

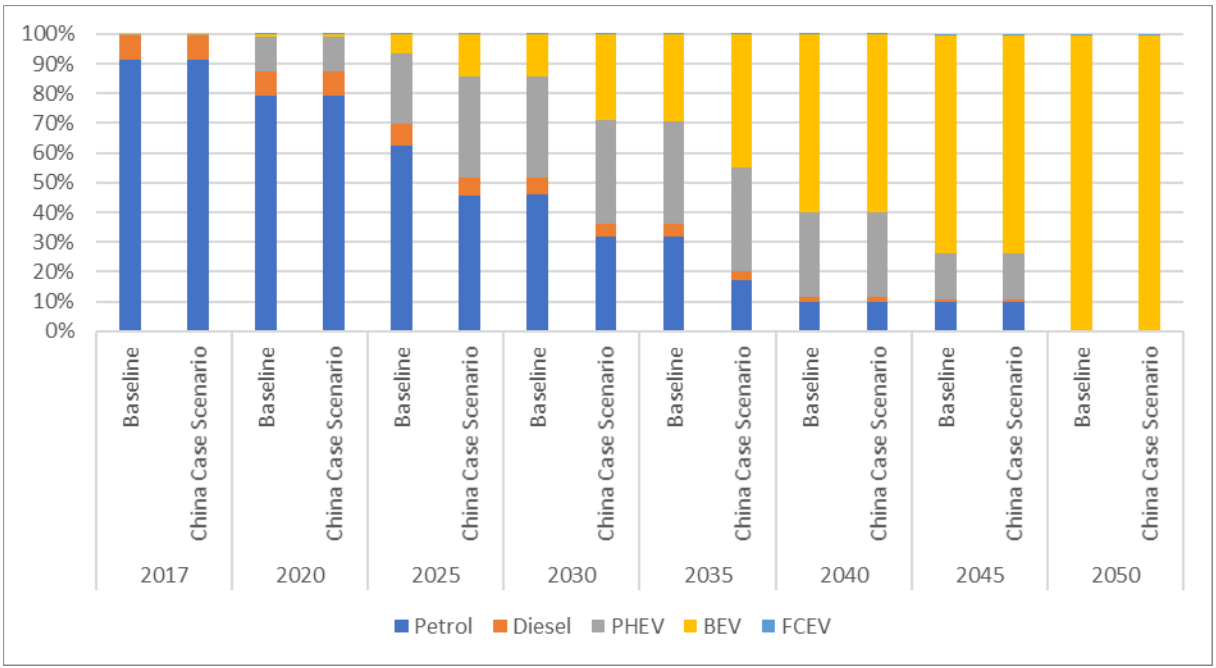
4.1.4 Strengthening of Chinese regulations to global-leadership standards (China case scenarios)

The China case scenario represents the unilateral strengthening of regulations in China to the highest levels of stringency in place in the different markets. It aims to demonstrate the impacts for EU OEMs of how EU regulatory leadership could impact the ability of EU OEMs to access major foreign markets in the event that they suddenly take a regulatory leadership position.

4.1.4.1 Powertrain market shares

Section 3.2 defines the specific changes in regulation in the three key trends which have an impact on the powertrain market shares illustrated in Figure 4.24 below.

Figure 4.24: Powertrain market shares in China for the baseline and the China case scenario

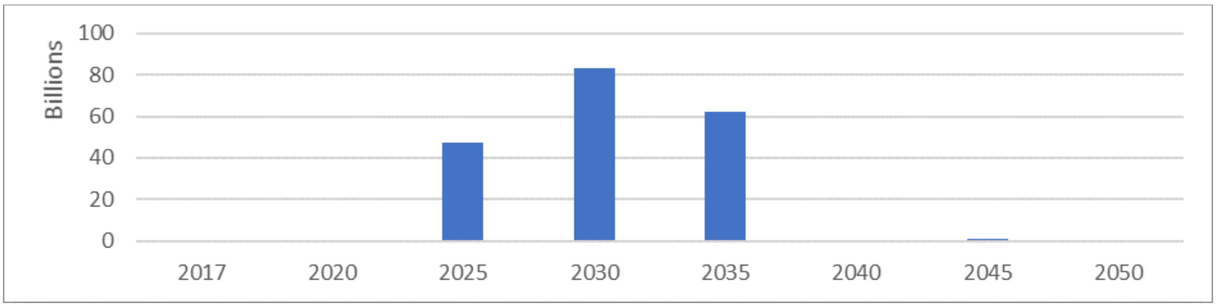


As environmental regulation targeting CO_2 emissions is tightened in China specifically for the years 2025 to 2040 in this scenario, the changes in market shares are also observed for this period. As a result, an early move towards the electrification of powertrains occurs in the China case scenario and the share of xEVs increases substantially over this time period.

4.1.4.2 Vehicle costs

As in the EU scenarios, the ramping up of regulation leads to higher costs occurring earlier as shown in Figure 4.25.

Figure 4.25: Changes in total costs in China in the China case scenario compared to the baseline

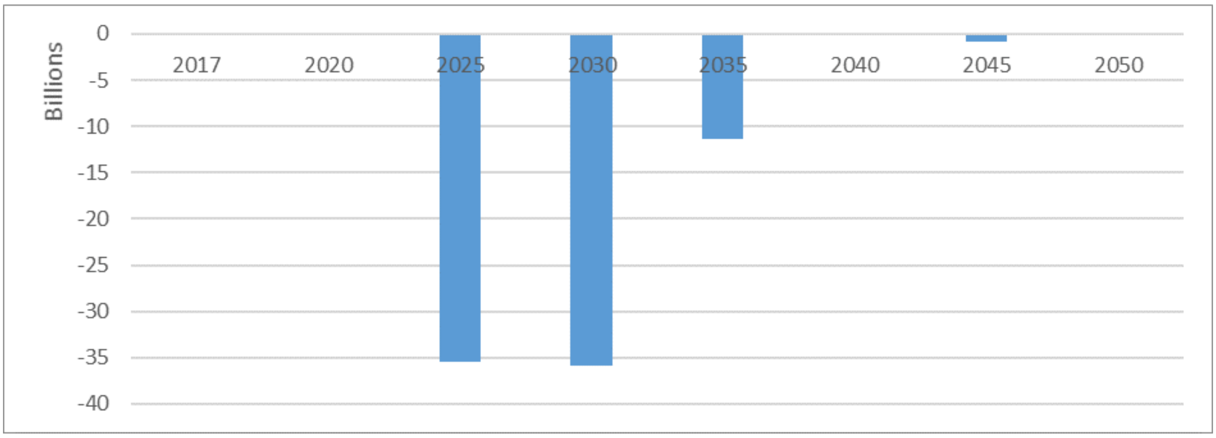


The cost increase is substantial in the first 15 years after 2020 as regulation is tightened in China to the global-leadership standard which requires a considerable effort for OEMs to catch up. In 2030, costs are 19% higher in China compared to the baseline. Cumulatively, it represents an additional cost of €851bn approximately (or €860 per vehicle).

4.1.4.3 Price and profitability analysis

Price and profits in China are also affected by the rapid strengthening of regulation in the country. Figure 4.26 below shows that profits are expected to decline as costs increase and erode the high profit margins observed in this market in the baseline. In 2025, profits fall by 34% compared to the baseline. Cumulatively, the China case scenario represents a loss in profit of €330 bn (or €334 less per vehicle).

Figure 4.26: Changes in total profits in China in the China case scenario compared to the baseline

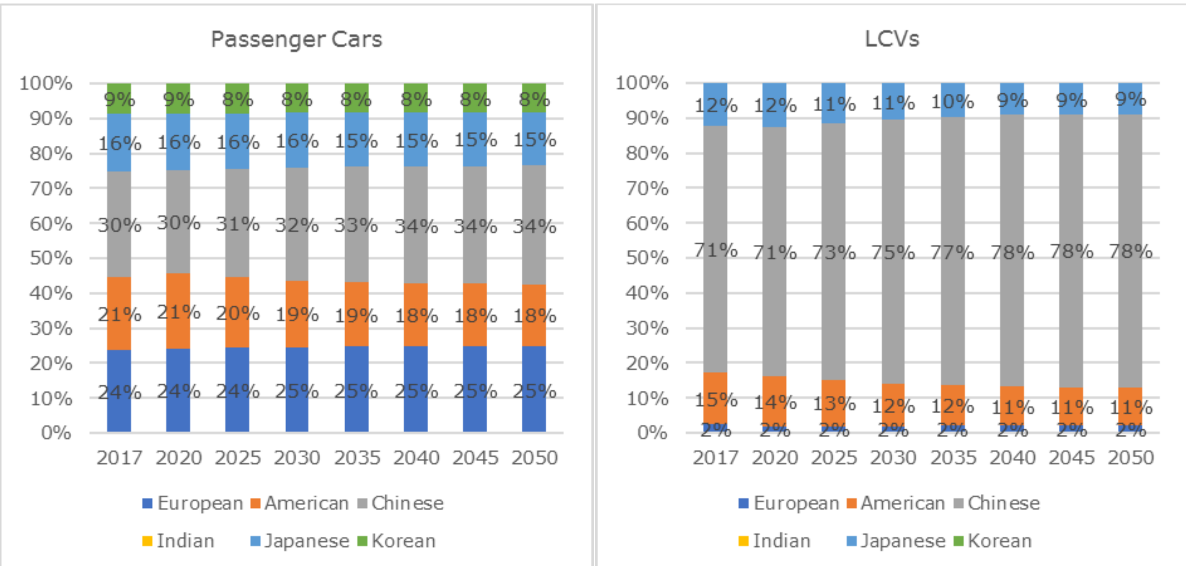


The impacts on price and profit of this scenario in China are very different from those observed in the EU scenarios for the EU market. The difference lies in the profit margins observed in these two markets. For China, the increase in cost contributes to squeezing profit margins to lower levels and reduces the average profit per vehicle, whilst in the EU, profit margins were already low and thereby the increase in costs leads to a higher price and average absolute levels of profit. The early shift towards e-mobility exacerbates this impact as the alternative powertrains have generally lower profit margins in China than their ICE counterparts.

4.1.4.4 Market share analysis

To understand the impacts of the China case scenario on the OEMs operating in this country, an analysis of the market shares in production in China was undertaken. As described in Appendix A.1, the current and future market shares of the different nationalities of OEMs in the baseline in China are presented in Figure 4.27.

Figure 4.27: Production in China by manufacturer's nationality in the baseline



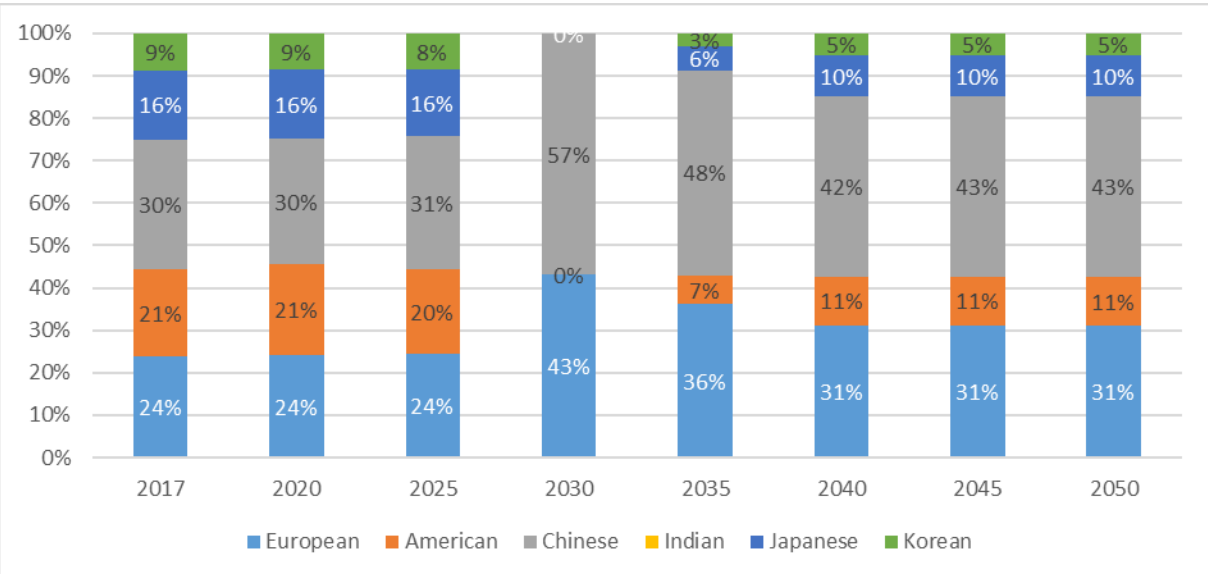
To model the regulatory shock in the China case scenario, it is assumed that the market shares of the manufacturers from countries where regulations are not as tight as in China (i.e. all other non-EU markets) will be affected. The impact on market shares for foreign OEMs was evaluated based on assumptions around the Chinese Government restricting access to the Chinese market, based on the assumption that they would not be able to fully comply with Chinese regulations after the jump in standards. This approach was adopted as opposed to applying any financial penalties to non-compliant foreign OEMs since research indicated that OEMs which do not produce vehicles to the standards mandated by the Chinese authorities are more likely to have access to the Chinese market restricted (as well as other soft measure such as 'shaming' of their brands), rather than suffer financial penalties (ICCT, 2016, p. 8).

In this analysis, the regulatory shock is assumed to take place in 2030. Manufacturers from countries where regulations are not as tight as in China are assumed to only recover half of their baseline market share by 2040, i.e. taking about ten years to be able to fully implement the technology that will allow them to meet the new more stringent regulations. The assumption is that these OEMs will be following their countries' regulatory trends and will therefore fail to meet the updated regulations immediately when the regulatory shock occurs due to long production lead times. This effectively means that these OEMs will be in breach of Chinese regulations and will therefore have their access limited to the Chinese market for a period of ten years (with the proportion of lost market share reducing linearly from a maximum in 2030, to zero in 2040). Nevertheless, they are not expected to regain fully their baseline market share due to reputational issues and given the difficulty in combatting the market power of those OEMs which captured their market share for the ten years they were excluded from the market.

The extent to which foreign OEMs' market access is restricted was modelled in two different scenarios. In the 'low' scenario, the production of entry-level vehicles by these OEMs is suspended from 2030 (returning gradually to half production by 2040), whilst in the 'high' scenario both the production of entry-level and mid-range vehicles is suspended from 2030 (again gradually returning to half production by 2040) from the market. This implies that luxury vehicles (and mid-range vehicles in the low scenario) produced by non-compliant OEMs will continue to be sold in the Chinese market, even by non-compliant OEMs – either because those vehicles are more readily able to adapt to the new regulations given their higher prices, or because of political pressure from foreign Governments.

Whilst manufacturers from non-compliant countries are affected in this way, other manufacturers with standards on a par with China's regulatory environment have an opportunity to capture additional market share in these vehicle segments for the same period (as well as Chinese OEMs themselves). For the purposes of the modelling, it is expected that EU and Chinese OEMs will capture the lost market share of all other foreign OEMs in the period 2030 to 2040 and half of their market share after 2040, in proportion to their original relative market shares in 2030. The underlying assumption is that EU OEMs will have unrestricted market access to the Chinese market given the EU's regulatory leadership position and that they will be able to rapidly fill the gap provided by other foreign OEMs to meet the additional demand in China. Figure 4.28 below shows the resultant market shares in the China case scenario, applied to the entry-level car segment in the low scenario and both the entry-level and mid-range car segments in the high scenario.

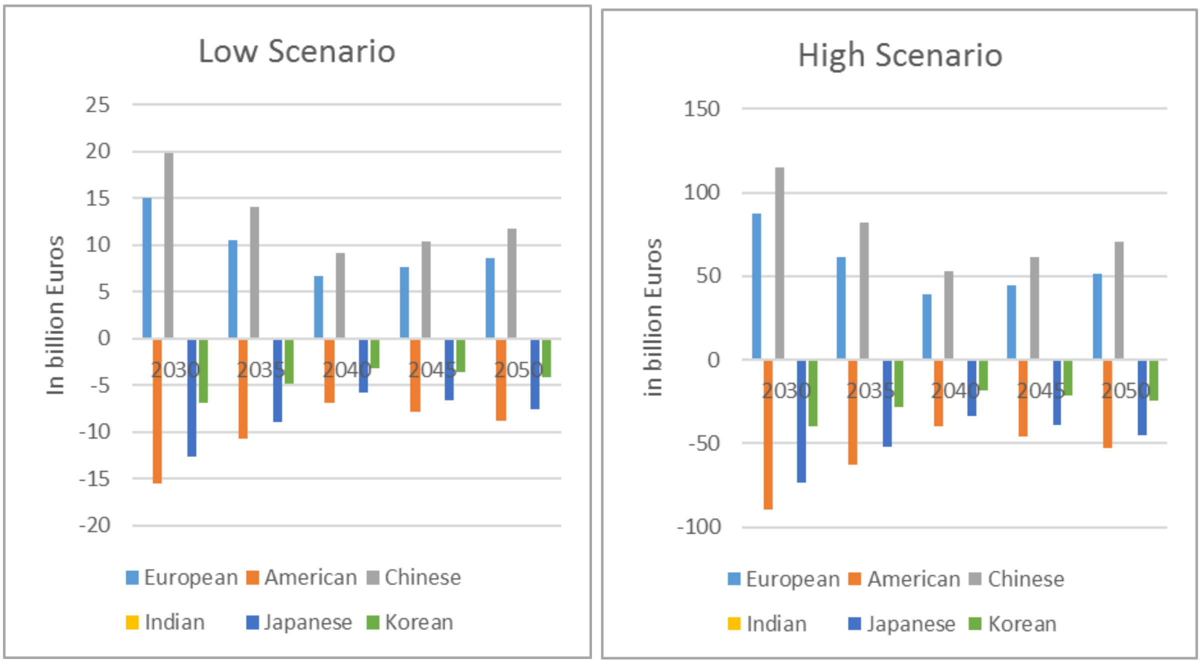
Figure 4.28: Production in China by manufacturer's nationality in the China case scenario for entry-level cars in the low scenario and for both entry-level and mid-range cars in the high scenario



Compared to the baseline market shares presented in Figure 4.27, the European OEMs together with the Chinese OEMs are the main beneficiaries from the regulatory shock as the EU is the only market to have regulation in place at the same level of ambition as China in this scenario. As a result, market shares of other foreign OEMs fall to 0% in 2030, slowly recovering to half their baseline level by 2040. For the EU, this scenario represents an opportunity to capture 43% of the market in 2030 and 36% in 2035 (compared to 25% in both years in the baseline), with the change applying to entry-level cars in the low scenario and both entry-level and mid-range cars in the high scenario. After 2040, EU OEMs are able to maintain a market share of 31% in this scenario compared to 25% in the baseline.

The increase in the market share of EU OEMs in the Chinese market has significant impacts on their costs, revenues and profits. Figure 4.29 shows the changes in revenues accrued to each group. Note that the charts include only the years for which there are changes compared to the baseline, and they represent the change per year in that year

Figure 4.29: Changes in total revenues by manufacturer's nationality in the China compared to the baseline



As concluded previously, both the European and Chinese manufacturers benefit from the China case scenario, obtaining additional revenues between 2030 and 2050 due to the higher penetration of their vehicles in the market. This occurs at the expense of other manufacturers which see their revenues decline for the same period. Cumulatively, the EU receives €183 bn of additional revenue in the low scenario and €1,073 bn in the high scenario (representing about €442-€2,590 of additional revenues per vehicle produced in the low and high scenarios, respectively). The increase in production of EU vehicles in China also entails additional costs and thus Figure 4.30 illustrates the net benefit for EU OEMs in each scenario (representing the change per year in that year).

Figure 4.30: Changes in total profit by manufacturer's nationality in China compared to the baseline

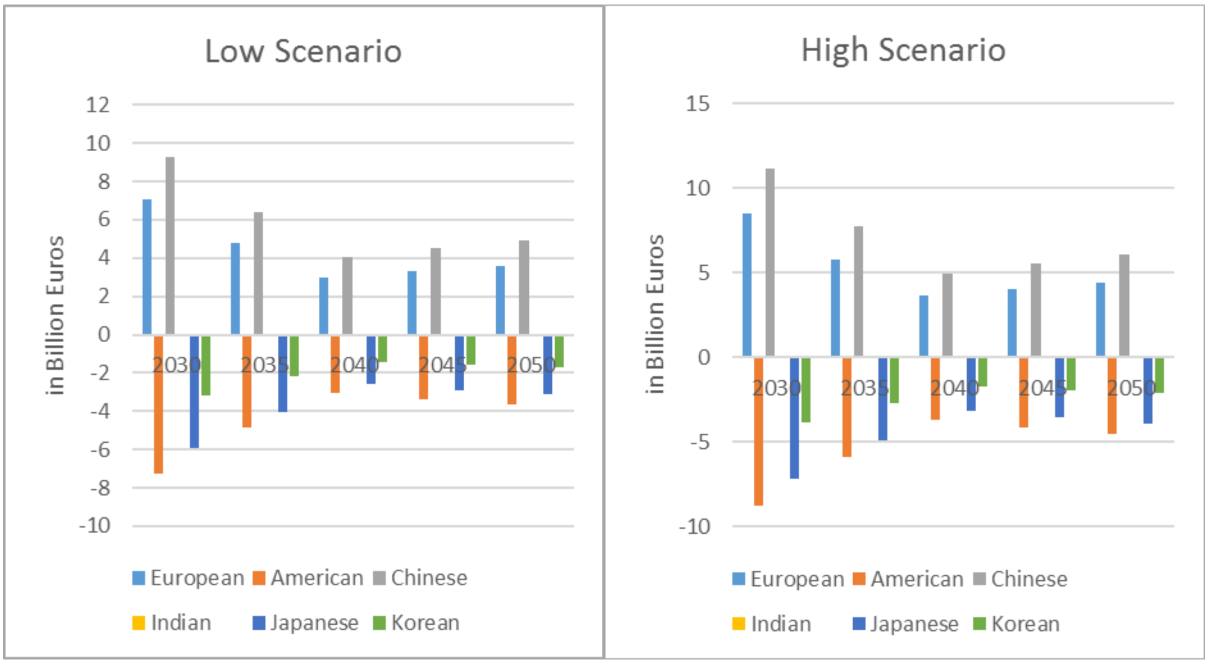


Figure 4.30 shows a similar outlook for profitability as the analysis above on costs. Profits shift away from the American, Japanese and Korean OEMs (note India is assumed to have no market share in China in the baseline) and towards EU and Chinese manufacturers as they gain market share between 2030 and 2050. In the whole period analysed, EU OEMs obtain €82 bn in additional profits in the low scenario and €100 bn in the high scenario (or €198-€241 of additional profit per vehicle produced in the low and high scenarios, respectively), a substantial increase in overall profits given that total profits for the EU OEMs are predicted to range between €10-18bn annually between 2017 and 2050 (as shown in Figure 4.9 above).

It can be concluded that the EU's leading position in setting progressively more ambitious regulations is likely to be a significant advantage for EU OEMs when responding to a regulatory shock in a foreign market such as China. A stringent regulatory environment in the EU would ensure that EU OEMs are well equipped to deal with changes in regulation in other countries as they would have already developed and introduced the necessary technology in time to maintain market access and even capture additional market from OEMs which are not as able to respond immediately, thereby resulting in higher revenues and overall profitability in the affected markets.

The higher market shares and extra revenue for EU OEMs also have implications for the wider EU automotive industry and the EU economy. These topics will be covered in more detail in Section 4.2.

4.2 Macro-economic modelling outputs

4.2.1 Baseline Scenario

Applying the scenario technique, the baseline mainly serves as a reference to mirror the effects of higher regulatory standards in the EU (and in some scenarios also in China) by comparing scenarios including this regulation with the baseline. Differences against the baseline are then interpreted as impacts of regulation in the consistent modelling framework.

4.2.1.1 Major assumptions

The GINFORS-E model simulation in the baseline meets the long-term economic development set out in the EU's Reference Scenario 2016 (European Commission, DGs for Energy, for Climate Action and for Mobility and Transport , 2016) for the Member States. For other major economies it reproduces macroeconomic development of the IEA's World

Energy Outlook (WEO) (IEA, 2016). As the WEO scenarios end in 2040, trends are used to project out to 2050. The baseline serves as a consistent projection of the world economy; it is not a forecast.

Global population projections are taken from the United Nations (United Nations, 2017). Energy prices and CO_2 prices develop according to the EU Reference Scenario 2016.

Specific assumptions about future automobile markets stem from the micro-economic model described above. This is especially important for future shifts towards electric vehicles, where assumptions around value shifts from the automotive industry towards the battery and electronics industry are made (see description in section 2.5 above). GINFORS-E only models the motor vehicle industry as a single industry.

The EU is modelled as the group of 28 countries that currently form the Union.

4.2.1.2 Overall economic development

In the baseline, GDP in the EU grows by about 1.4% per annum between 2020 and 2030. The growth path is slightly reduced after 2030. Economic growth is a bit faster in the USA at c. 2% p.a., taking the stronger demographic development into account. Long-term growth in China and India is expected to slow down as these economies mature. World trade volumes continue to grow a bit faster than World GDP until 2050.

In line with the EU Reference Scenario 2016 there are no drastic structural changes expected for the EU economies, neither in the macroeconomic components nor in the sector specific composition of GDP.

Table 4.3: GDP development in six markets in the baseline – annual average growth rates in %

	2020 - 2030	2030 - 2040	2040 - 2050
EU	1.4%	1.3%	1.2%
USA	2.0%	2.0%	1.9%
China	5.1%	3.3%	2.7%
Japan	0.7%	0.8%	0.9%
Korea	1.4%	1.2%	1.1%
India	7.2%	5.3%	3.2%

Source: GINFORS-E

4.2.1.3 Trade aspects of shifts in powertrains

Technological changes in powertrains raise the question of whether global scarcity of some resources may lead to contraints on EU production due to restricted access to these resources. The most likely scenario to lead to resource scarcity issues here is associated with the move towards electric drivetrains. For example, if all new vehicles are electric, increases in demand for some mineral commodities used in batteries are very substantial, as shown in Table 4.4. The highest increases and annual depletion ratios are reported for lithium and cobalt.

According to this projection for an all-electric future, the use of lithium will increase by almost 2900% compared to today's production. This corresponds to an annual depletion ratio of 7.2%, i.e. annual use for car batteries will then equal 7.2% of known global reserves. As shown in column 3, cobalt is the most critical raw material in terms of its scarcity for electric vehicle production. Nickel-Manganese-Cobalt (NMC) and Nickel-Cobalt-Aluminium (NMA) batteries have become standard technology in producing electric vehicles. Thus, the use of cobalt for batteries is growing: Whereas 25% of global cobalt demand in 2010 was used for batteries, forecasts see a share of 47% in 2020 (CRU, 2016).

For Europe, a UBS analysis predicts that 31% of total car sales will be electric vehicles in 2025. This number exceeds the expected global average of 14% which corresponds to 14.2 million vehicles annually in absolute terms. In this scenario, the proven reserves of cobalt would be reduced by nearly 5% and those of lithium by more than 1% every year assuming that today's technical construction of batteries does not change by then (UBS, 2017). According to the same source, technical progress will drastically reduce the need for these raw materials per kWh of battery capacity. New battery standards are expected to bring down the cobalt depletion ratio to 1.5% in 2025. The chance of a break-through in battery chemistry is supposed to be likely in the long term, i.e. the commodity depletion rates cannot be extrapolated beyond 2025.

Applying this to our modelling baseline, the use of lithium for car batteries in the EU will increase enourmously from about 546 tonnes in 2017 to about 34,000 tonmes in 2050, which is more than the global consumption of around 32,500 tonnes in 2015 (U.S. Geological Survey, 2017).

Table 4.4: Demand for rare materials in battery cells if all vehicles were electric

	Change of commodity demand in % of today's global production	Annual depletion ratio
lithium	2898%	7.2%
cobalt	1928%	33.9%
graphite	524%	2.5%
nickel	105%	3.0%
manganese	14%	n/a
Rare earths	655%	n/a

Source: (UBS, 2017)

Assessing the risk of a supply shortage, availabilities along the supply chain have to be considered. Firstly, some mineral resources are by-products and therefore, their mining capacities depend on the markets of other raw materials (CRU 2016). Secondly, the producing countries have to be taken into consideration. For example, Democratic Republic of Congo currently leads worldwide cobalt mining production. In 2016, more than half of all globally-extracted cobalt ore was mined in the Democratic Republic of Congo according to USGS. Labour and security standards in cobalt mining are low there. China is the leading producer of refined cobalt. Cobalt deposits within the EU exist only in Finland but refined cobalt is produced in several European countries such as Finland and Belgium. Thus, 24% of global cobalt metal production took place in Europe in 2013 (U.S. Geological Survey, 2015)[12].

China is also the largest producer of rare earth metals, manganese, graphite and refined nickel – other vital components in battery manufacturing. Access to these resources and diversification are very important for EU car and future battery producers.

Table 4.5: Largest producers of rare materials in battery cells in 2013

	country's contribution to global production
Lithium	Chile (45%), Australia (31%), Argentina (9%), USA (6%), China (5%)
Cobalt (ore)	DR of Congo (61%), China (6%), Australia (5%), Zambia (5%)
Refined cobalt	China (43%), Finland (13%), Belgium (6%), Zambia (6%), Australia (6%), Canada (6%)
Graphite	China (83%), India (7%), Brazil (4%)
Mined nickel	Indonesia (34%), Philippines (12%), Russia (9%), Australia (9%), Canada (9%)
Refined nickel	China (36%), Russia (12%), Japan (9%), Australia (7%), Canada (7%)
Manganese	China (29%), South Africa (21%), Australia (14%), Gabon (8%), Kazakhstan (5%), India (5%), Brazil (5%)
Rare earth metals	China (95%), USA (2%), Russia (1%), Australia (1%), Malaysia (<1%), Brazil (<1%)

Source: (British Geological Survey, 2015)

[12] The BGS has analysed EU28 plus Albania, Iceland, Macedonia, Montenegro, Norway, Serbia, Switzerland, and Turkey.

Although technological improvements in the material mix of batteries will enable a reduction in material use (e.g., the expected market entry year of new NMC battery cells using less cobalt is 2025 (UBS)), further research is needed to avoid bottlenecks or a depletion of resources. Substitution of materials can be problematic since the use of other materials can reduce efficiency of the products (U.S. Geological Survey, 2017). Recycling rates are not established yet since the market is nascent and used batteries in electric vehicles mostly have not reached the end of their lifecycle. According to the US EPA's report from 2013 (U.S. Environmental Protection Agency, 2013), recovery rates of batteries range from 60% up to 99.9%. Therefore, a high percentage of recycling is possible. Hence, an expansion of recycling measures will be necessary to cope with limitations of reserves of scarce ressources in the long run and to minimise the EU's reliance on external commodity suppliers to support its automotive industry.

Note that the above analysis does not necessarily mean that a supply shortage for some of these materials is inevitable. Experiences with peak oil and other non-renewable resources show that an increase in demand will raise prices, which will induce higher production in the future, thereby making more reserves economically viable and speeding up efforts to discover unknown reserves, as well as leading to substitution effects, more recyling and technological change. Temporary shortages cannot be excluded however and these could be crucial as OEMs and automotive suppliers select locations for large-scale battery production. But according to UBS (2017), only cobalt faces the issue of limited reserves, whereas for the other materials, current production capacity is the only bottleneck. New cell generations, however, will use much less cobalt. UBS reports a factor of 8 reduction in cobalt for the next battery generation that is expected in 2021. The chance of further break-throughs in battery chemistry will probably prevent cobalt shortages in the long term. An example for the possibilty to increase lithium production is related to the Tesla gigafactory in Nevada as a new lithium mine has been identified in Mexico only 320 km away, which can deliver up to 50 kt of lithium carbonate annualy.

Depending on different market forecasts, BEVs will reach significant markets shares by 2025 or 2030. By then EU car producers will need sufficient access to rare materials including lithium, cobalt, nickel, manganese and rare earth metals for batteries. R&D activities should try to reduce dependency on single materials, whilst maximising recycling rates will be crucial in helping to reduce dependence from a single supplying country and establishing a more circular economy.

The additional future costs for these raw materials are difficult to be estimated, as prices fluctuate over time and economies of scale and technical progress are expected to reduce the material per unit battery capacity drastically. The price for a tonne of lithium doubled from 2016 to 2017 for example. But additional supply might stabilize prices in the longer term, as the experience of the oil market shows. The market price for the lithium needed annualy in the Tesla gigafactory is about $450 million, but Tesla and the supplier have agreed upon a lower price for a five-year period (Fortune, 2016).

4.2.1.4 Socio-economic benefits/costs

A simple sensitivity analysis using the GINFORS-E model illustrates the benefits of the baseline against a scenario in which the share of electric vehicles remains low until 2050-held at its current level of almost zero. Under this scenario, EU CO_2 emissions would be about 235 Mt higher in 2050 than in the baseline as defined for this analysis. This result is supported by analysis by Öko-Institut et al. (2016) for the EEA, showing a CO_2 reduction of about 250 Mt against the EU 2013 reference. In monetary terms, i.e. taking into account the carbon price in the EU reference scenario 2016, these reduced emissions would account for about €21.5 bn savings in 2050. Fuel imports are also considerably lower in the baseline compared to the zero-EV scenario; the difference in the oil import bill reaches about €41 bn in 2050.

Along with reduced mineral oil consumption and increased electricity production in the baseline compared to a zero-EV scenario, additional benefits of the high penetration of electric vehicles in the baseline include much lower local air pollutant emissions (NO_x and particulates) and avoided health impacts. However, lower emissions from road transport itself are partly offset by higher electricity production and related emissions, e.g. of SO_2.

Emission effects depend on whether the additional electricity production is free of emissions (renewable, nuclear) or not. Öko-Institut et al. (2016) provides a more detailed analysis of the effects on emissions. Annual pollutant savings in value terms are calculated for scenarios 1 to 4 against the baseline in section 4.2.2.4.

Mandating higher levels of automation over time is also expected to deliver significant societal benefits. Whilst not possible to estimate in detail, the study provides an estimate which reflects the order of magnitude of the expected benefits. Higher levels of automation are expected to deliver important safety improvements by minimising human error. According to (Winkle, 2016) and (Casualty Actuarial Society Automated Vehicles Task Force, 2014), approximately 93% of road accidents are caused by human error. If able to reduce accidents by only 5%, the mandatory fitment of automation technology could represent 1,254 fewer fatalities, 15,045 serious injuries and 62,688 minor injuries (based on fatality data in the EU in 2015[13] (Eurostat, 2017)). To quantify these reductions, the most recent transport externalities handbook produced by Ricardo for the EC (Ricardo AEA et al, 2014) constitutes an appropriate source, covering average social costs (which include the costs for the person exposed to risk, the costs for the relatives and friends of the person exposed to risk and the costs for the rest of society) at market prices (in €2010). For the EU average, these were estimated to be €1.9 million in the case of a fatality, €243,100 in the case of a severe injury and €18,700 in the case of a slight injury. As a result, reducing accidents by 5% could account for €7 bn annually (€2.38 bn in fatalities, €3.66 bn in serious injuries and €1.17 bn in minor injuries). These figures give an idea of the magnitude of the safety benefits that could be obtained if accidents are significantly reduced by mandating higher levels of automation.

4.2.1.5 Supply chain impacts

On the cost side, the penetration of electric cars will strongly influence the supply chain. It has to be noted that large parts of these impacts are excluded from the scenario analysis below, as e-mobility (BEV and PHEV) reaches a production share of about 50% in 2030 and almost 100% in 2050 in the baseline and the deviation beyond this under the modelling scenarios is modest in comparison. It is expected that under the rapid transition towards xEVs in the baseline, roughly 25% of the direct costs of an average car produced in 2050 will be supplied by battery suppliers and powertrain electronics suppliers against only 2% today. This is expected to be mainly at the expense of other parts suppliers, whereas OEMs and raw material suppliers only face minor reductions of cost shares compared to today. The impacts on the automotive supply chain are discussed further in Section 4.3. Depending on the share of domestic production and labour intensity of batteries and powertrain electronics, job net impacts can be significant. Changes in qualifications and locations of jobs will be even higher.

In the baseline, as in the scenarios, it is assumed that battery production takes place in industries denoted by 'chemicals' and 'electrical machinery' and that the EU automotive industry maintains the same relatively low import shares for these industries with increased battery production in the future. In order to show the positive effects of increased domestic battery production, a sensitivity analysis was conducted which assumed that all batteries will be imported. If the EU is not able to establish domestic battery production with low import shares similar to those in the chemicals and electrical machinery industries, as assumed in the scenarios, the sensitivity analysis with GINFORS-E shows that EU imports of batteries and related materials would be about €5 bn higher in 2030. Additional imports reach €24 bn in 2050 in this sensitivity, with significant negative impacts on GDP. Employment in the EU is expected to be about 100.000 jobs lower in the sensitivity compared to the cases with domestic battery production. This sensitivity highlights the positive macroeconomic effects of establishing domestic battery production in Europe.

[13] For every death on Europe's roads there are an estimated 4 permanently disabling injuries such as damage to the brain or spinal cord, 8 serious injuries and 50 minor injuries (European Commission, 2017)

4.2.2 EU at varying levels of leadership (scenarios 1 - 4)

4.2.2.1 Overall economic impacts

Figure 4.31 shows the relative deviations in EU GDP for the four different scenarios against the baseline scenario. Scenarios 1 and 3 (gradual levelling and gradual overshooting of regulatory standards respectively) as well as scenarios 2 and 4 (one-off levelling and one-off overshooting of regulatory standards respectively) show a similar development to 2040 in terms of the shape of the curve, although the magnitude of the impact differs between the levelling and overshooting scenarios.

The effects of gradually levelling and overshooting regulatory standards in scenarios 1 and 3 start in 2025. In both scenarios, regulation has a negative impact on GDP. Due to the higher level of standards in scenarios 1 and 3, the EU GDP is about 0.1% smaller in 2025 than in the baseline scenario. The higher level of standards in scenario 3 widens this gap further in the year 2030.

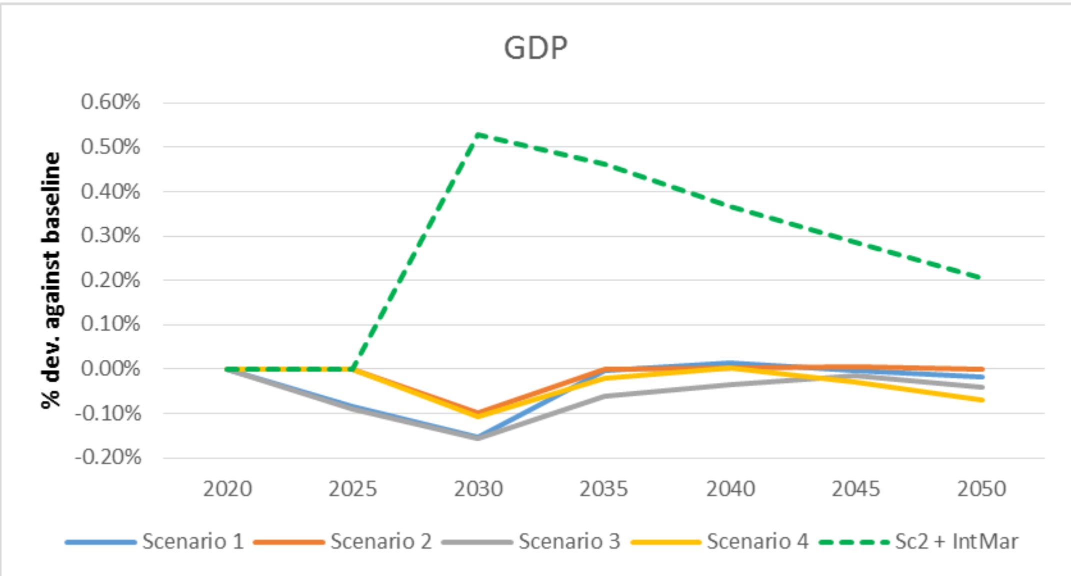
In 2025, there are no differences in EU GDP in scenario 2 and 4 against the baseline, since the one-off effects take place in the year 2030. The negative impacts of the one-off effects on EU GDP in scenarios 2 and 4 in 2030 are also smaller than in scenarios 1 and 3: the relative deviation against the baseline scenario is about 0.1% respectively in 2030.

After 2030, regulation is not tightened further compared to the baseline. The economy is recovering from the regulatory shocks in 2025 and 2030 respectively. The relative deviations of GDP against the baseline decrease gradually until 2050, but some path dependencies induce changes compared to the baseline after 2040. Employment is slightly higher than in the baseline in all four scenarios, so regulation reduces labour productivity a little bit in the long-term.

One-off levelling of the technological and regulatory standards by 2030 in scenario 2 is the best of the four scenarios regarding GDP, resulting in a marginally positive overall impact on GDP from 2035 onwards.

The inclusion of the internal market sensitivity in scenario 2 shows that protecting the internal market by regulation more than offsets the small negative effects of regulation (Figure 4.31). If stringent EU regulation reduces imports, this could increase GDP by about 0.5% in 2030 against the baseline (and by about 0.6% against scenario 2).

Figure 4.31: EU GDP in constant prices - % deviations against baseline



Cumulative GDP impacts of the four scenarios over the three decades from 2020 to 2050 are shown in Figure 4.32. The cumulative losses against the baseline range from €77 bn in scenario 2, to €353 bn in scenario 3. These are again small compared to the possible benefits of regulation due to aimed at protecting the internal market, as illustrated by the internal market sensitivity.

Figure 4.32: EU GDP in constant prices (2010) – cumulative deviations against baseline between 2020 and 2050

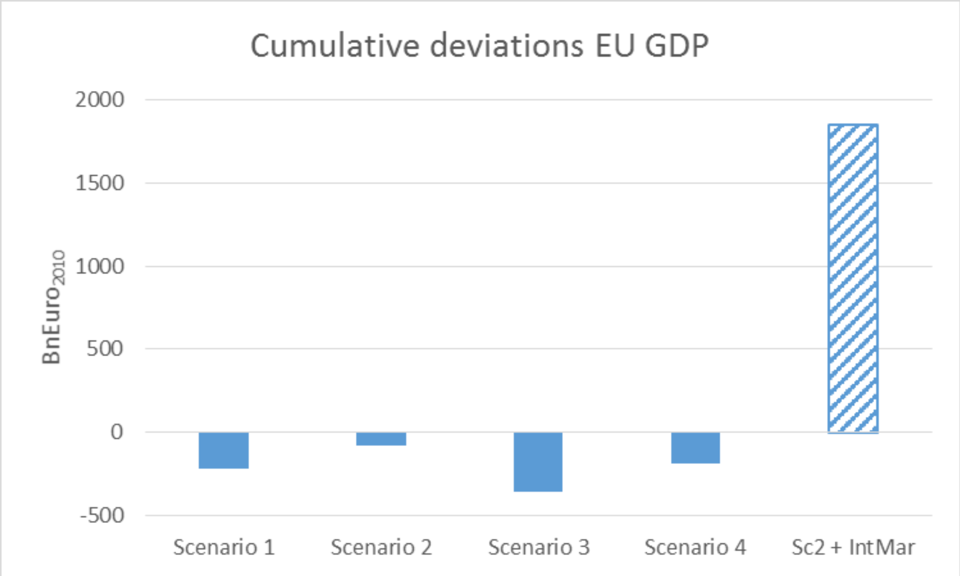
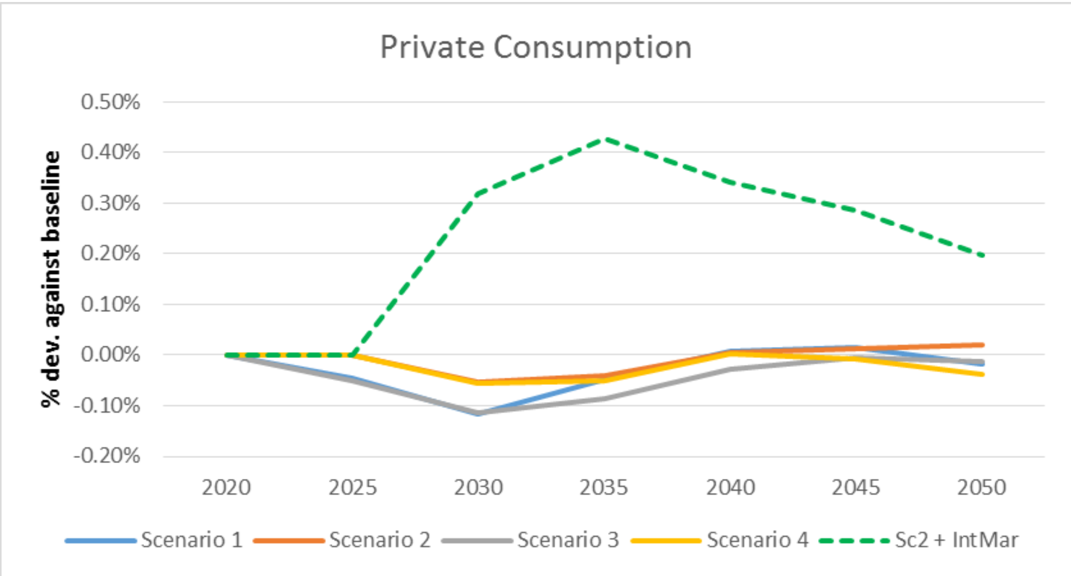


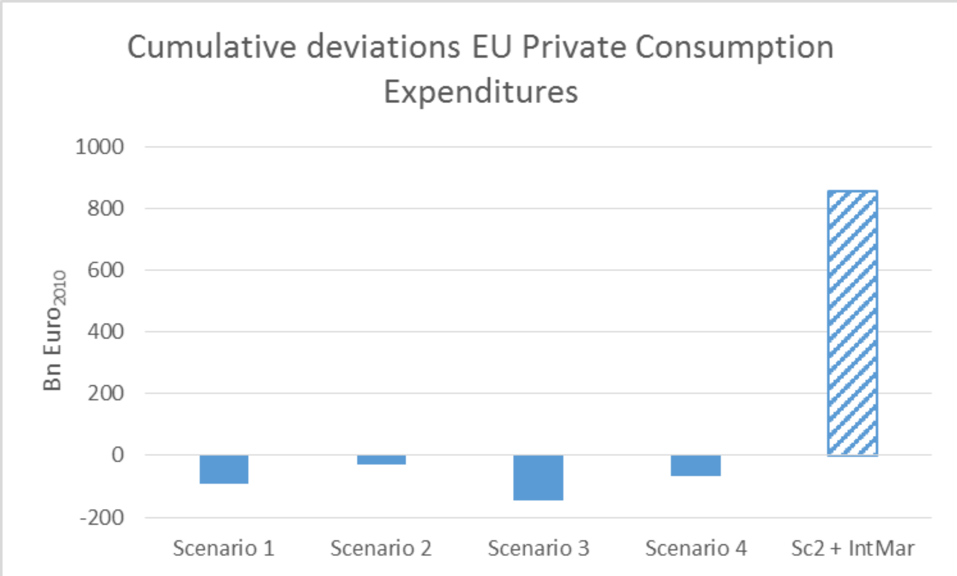
Figure 4.33: EU private consumption in constant prices - % deviations against baseline



The more stringent regulation in scenarios 1 to 4 also has a negative impact on private consumption. On the one hand, prices of cars increase due to higher production costs. The auto industry is able to pass over most of the cost increase to consumers. As a result, revenues will be higher than in the baseline. As cars are used in many industries and for public and private transport, cost and prices in other industries also go up due to the higher prices of vehicles. Private households have to reduce their expenditures on other goods. In 2030, the relative change in private consumption against the baseline scenario is about 0.1% lower in scenarios 1 and 3 and around 0.05% in scenarios 2 and 4 respectively. Results for the internal market sensitivity are again positive, reaching about 0.4% higher than the baseline in 2035. As private consumption depends on disposable income of the previous period in the model, the differences to the baseline lag behind GDP effects.

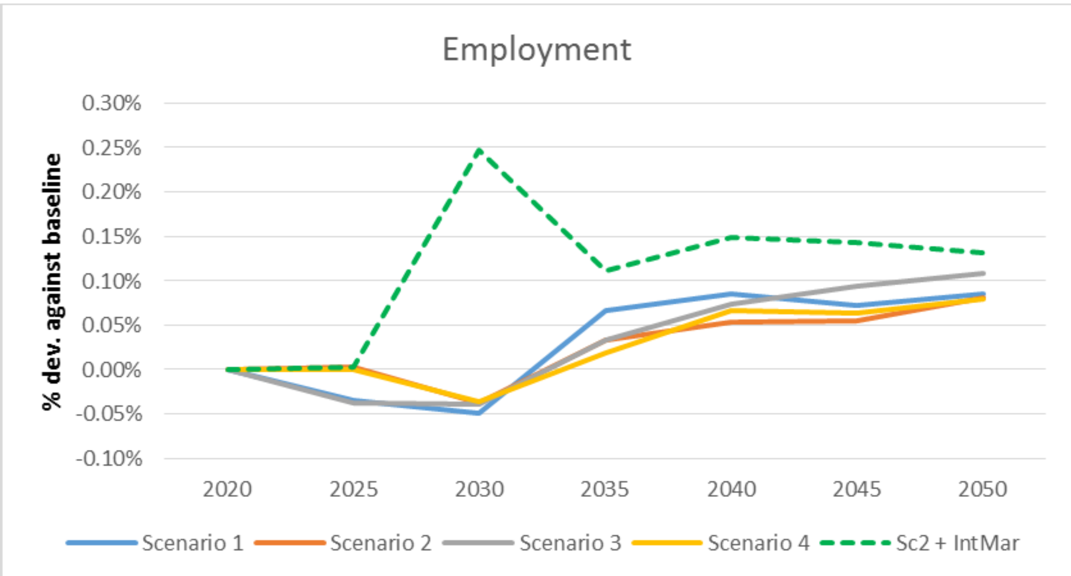
Cumulative impacts on private consumption of the four scenarios over the three decades from 2020 to 2050 are shown in Figure 4.34. The cumulative losses against the baseline range from €31 bn in scenario 2 to €147 bn in scenario 3. These are small compared to the possible benefits illustrated by the internal market sensitivity.

Figure 4.34: EU private consumption in constant prices - cumulative deviations against baseline between 2020 and 2050



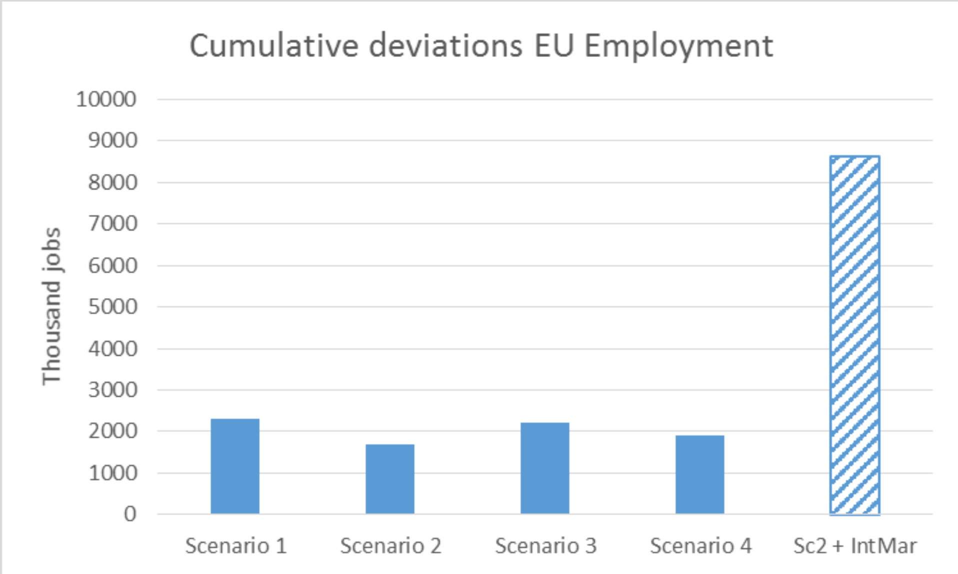
The tougher regulatory standards in scenarios 1 to 4 induce higher labour costs in the automotive industry given the requirement to incorporate additional technology/equipment on-board vehicles compared to the baseline, especially in the years 2025 and 2030. Nevertheless, output from most industries that are not part of the automotive supply chain is lower than in the baseline, which means less demand for labour. Overall, in scenarios 1 and 3, employment in the years 2025 and 2030 is about 0.05% lower than in the baseline. Employment effects are smaller in percentage terms than production effects due to slightly lower wages in the scenarios compared to the baseline. With the declining differences in regulatory costs against the baseline over time (these are nearly zero from 2040 onwards in scenarios 1 and 2), the negative differences in employment diminish and become even slightly positive after 2035. This increase in employment needs further explanation; small changes in the industry composition of GDP, of development of wages and labour productivity over time can change employment numbers, especially in the service sector, while the total wage ratio remains constant. In the internal market sensitivity, employment effects turn significantly positive.

Figure 4.35: EU employment - % deviations against baseline



Cumulative employment impacts of the four scenarios over the three decades from 2020 to 2050 are shown in Figure 4.36. The cumulative gains against the baseline range from 1.68 million employment years in scenario 2 to almost 2.30 million employment years in scenario 1. In the internal market sensitivity cumulative employment gains reach 8.6 million employment years.

Figure 4.36: EU employment - cumulative deviations against baseline between 2020 and 2050



At a macroeconomic level therefore, scenario 2, i.e. a one-off levelling of regulatory standards, represents the best option in terms of impact on GDP, consumption and employment. Whilst scenarios 1 to 4 illustrate the cost side of regulation, these should be viewed in the context of the various benefits which are not explicitly captured by these modelling scenarios, namely: benefits from curtailing foreign OEM access to the EU market, as illustrated by the internal market sensitivity, the significant value from reduced externalities through reduced CO_2, air pollutant emissions and accident rates and the benefits of adjusting the supply chain to better respond to the demand for xEVs and other new technologies, as illustrated through the sensitivity which identified significant benefits from establishing local battery production in the EU. Further benefits of regulation are illustrated in the China case scenario below.

4.2.2.2 Overall industry impacts

Table 4.6 shows the relative changes in EU production by the automotive industry against the baseline scenario in the year 2030, at the point when the differences in regulation and induced changes are the biggest compared to the baseline. Those industries, which supply the automotive industry with intermediate inputs relevant to electric vehicles in particular, are able to increase production due to the introduction of higher standards in the EU. These positive effects are visible for chemicals (batteries), electrical machinery (batteries and powertrain electronics), non-ferrous metals (including for example copper wiring) and non-metallic minerals (to which some lightweight materials have been allocated). Production of electricity increases due to higher demand from electric vehicles. Other selected industries including machinery and equipment, construction, wholesale and retail trade and hotels and restaurants have been selected to show the negative effect in most other industries, as consumption for cars increases due to higher prices, at the expense of all other consumption sectors.

In the scenarios this is driven by quite small differences in the number of electric vehicles compared to the baseline which increases the use of batteries delivered by the chemical and electrical machinery industries and lightweighting delivered by various industries, as well as tightened standards for safety and air pollution. A key assumption here is that consumers will increase their consumption share for cars (buying the same number of more expensive cars).

Table 4.6: EU production in constant prices by industry - % deviations against baseline

	2030			
Production	Scenario 1	Scenario 2	Scenario 3	Scenario 4
9 chemicals	0.5%	0.8%	0.8%	0.8%
11 rubber and plastics	0.7%	0.6%	1.1%	1.2%
12 other non-metallic minerals (glass)	2.7%	2.7%	3.0%	3.0%
13 iron and steel	0.5%	0.5%	1.1%	1.1%
14 non-ferrous metals	1.2%	1.7%	3.4%	3.7%
15 fabricated metal products	1.1%	1.1%	1.9%	2.0%
16 machinery and equipment	-0.4%	-0.4%	-0.5%	-0.4%
18 electrical machinery	1.7%	1.7%	3.3%	3.5%
21 motor vehicles	5.0%	5.1%	6.1%	6.2%
26 electricity	0.8%	0.8%	1.5%	1.3%
30 construction	-0.5%	-0.5%	-0.6%	-0.6%
31 wholesale and retail trade	-0.2%	-0.1%	-0.2%	-0.1%
32 hotels and restaurants	-0.4%	-0.4%	-0.4%	-0.4%

According to Figure 4.35 the overall employment effect of the higher standards is slightly negative in 2030. This is partly due to the scenario assumption that consumers will not reduce their demand for cars, but spend less for other consumption purposes. Besides the automotive industry itself, Table 4.7 mainly includes industries with a positive employment effect, which are linked to higher motor vehicle production. These are particularly electrical machinery for electric vehicles and components for autonomous driving, rubber and plastics where much of the lightweight materials included in electric vehicles are included, non-ferrous metals and chemicals (both relevant to battery production and electric drivetrains). Employment in other industries such as construction and in the service sector is slightly lower than in the baseline, due to the knock-on effect of reduced consumption in other sectors. The total macroeconomic effect in 2030 is slightly negative, but employment will recover afterwards (see Figure 4.35).

Table 4.7: EU employment in million by industry - % deviations against baseline

	2030			
Employment	Scenario 1	Scenario 2	Scenario 3	Scenario 4
9 chemicals	0.6%	0.6%	0.7%	0.8%
11 rubber and plastics	0.7%	0.6%	0.9%	0.9%
12 other non-metallic minerals (glass)	1.2%	1.2%	1.3%	1.3%
13 iron and steel	0.2%	0.2%	0.3%	0.3%
14 non-ferrous metals	0.4%	0.4%	0.8%	0.9%
15 fabricated metal products	0.7%	0.6%	1.0%	1.0%
16 machinery and equipment	-0.2%	-0.1%	-0.2%	-0.2%
18 electrical machinery	1.0%	0.9%	1.4%	1.3%
21 motor vehicles	3.2%	3.1%	3.8%	3.8%
26 electricity	0.1%	0.1%	0.2%	0.1%
30 construction	-0.3%	-0.3%	-0.3%	-0.4%
31 wholesale and retail trade	0.0%	0.0%	0.1%	0.0%
32 hotels and restaurants	0.0%	-0.1%	-0.1%	-0.1%

4.2.2.3 Trade flows

The higher shares of electric cars in the scenarios cause a reduced demand for fossil fuels (industry mining and quarrying). Since most of the fuels needed are imported into the EU, imports from the mining and quarrying industry category are lower than in the baseline. In scenarios 3 and 4 this reduction of the oil bill is bigger than in scenarios 1 and 2, due to the more ambitious regulations in place. Only a few industries with higher production such as chemicals, electrical machinery and other non-metallic minerals will increase imports compared to the baseline. Note however that this is significant given the strong linkages between the changes in these industries and increased battery content in cars and light commercial vehicles – the implication is that much of the increased demand for these components will be met by imports from outside the EU.

Table 4.8: EU imports in constant prices by industries - % deviations against baseline

	2030			
EU imports	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2 mining and quarrying (energy)	-1.4%	-1.5%	-3.0%	-2.6%
9 chemicals	0.0%	0.6%	0.5%	0.5%
11 rubber and plastics	0.3%	0.1%	0.2%	0.5%
12 other non-metallic minerals (glass)	1.4%	1.7%	1.5%	1.8%
13 iron and steel	-0.3%	0.0%	-0.2%	0.2%
14 non-ferrous metals	0.2%	0.7%	1.1%	1.6%
15 fabricated metal products	0.4%	0.6%	1.1%	1.5%
16 machinery and equipment	-0.5%	-0.3%	-0.5%	-0.3%
18 electrical machinery	2.7%	2.4%	5.4%	5.3%
21 motor vehicles	-0.1%	0.1%	-0.2%	0.0%

Changes in EU imports in the scenarios mean changes in exports for other countries. Table 4.9 shows for scenario 1 some percentage differences to the baseline in international trade flows in 2030, which do not differ strongly between the countries. Note that in practice, it would be expected that countries with a strong presence in the battery manufacturing sector, such as China and Korea, might take more of the share of the increased imports. This is analysed in a sensitivity analysis in section 4.2.1.4, which shows the significant benefits that the EU could access if it ensured that it developed a strong domestic battery production capability. This dominance of certain markets in the production of batteries and extraction of key battery-related materials is discussed further in section 4.2.1.3.

Table 4.9: EU imports in constant prices by country and industries - % deviations against baseline

	SCENARIO 1 2030				
	CN_to_EU	US_to_EU	JP_to_EU	KR_to_EU	IN_to_EU
9 chemicals	-0.1%	0.1%	0.4%	0.0%	0.0%
11 rubber and plastics	0.3%	0.3%	0.2%	0.1%	0.3%
12 other non-metallic minerals (glass)	1.4%	1.7%	1.6%	1.6%	1.4%
13 iron and steel	-0.4%	-0.3%	0.0%	-0.4%	-0.4%
14 non-ferrous metals	-0.1%	0.2%	0.6%	0.2%	-0.5%
15 fabricated metal products	0.4%	0.4%	0.4%	0.4%	0.5%
16 machinery and equipment	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%
18 electrical machinery	2.8%	2.1%	2.7%	2.7%	2.6%
21 motor vehicles	0.1%	-0.3%	-0.1%	-0.1%	-0.2%

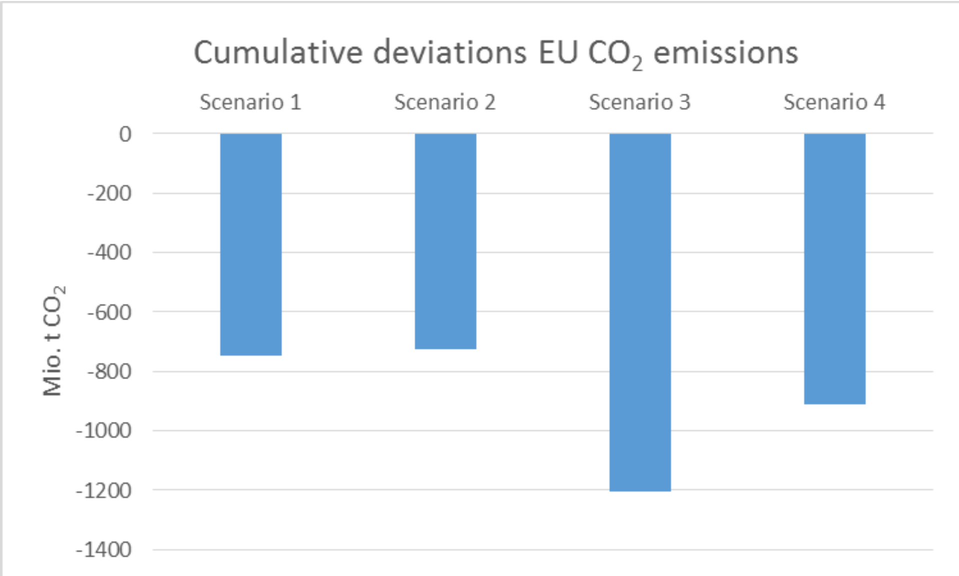
4.2.2.4 Socio-economic benefits/costs

Annual savings in total CO_2 emissions against the baseline reach a maximum of between 36 Mt (scenario 2) and 61 Mt (scenario 3) in 2035, five years after the goal of increased regulation is achieved. Scenarios 1 and 3, with their gradual introduction of higher standards, achieve the highest overall savings, given the increased length of time during which baseline standards are exceeded.

The impact estimated includes the reduced usage of gasoline and diesel, offset partially by the corresponding increase in electricity production. The maximum annual reductions in mineral oil imports are in the range of €6 bn (scenario 2) to €12 bn (scenario 3). For further impacts on local emissions and health see section 4.2.1.4 above.

The cumulative reduction in CO_2 emissions reaches between 728 Mt in scenario 2 to 1,206 Mt in scenario 3 for the period between 2020 and 2050. Total reduction in oil imports for the period range from €100 bn (scenario 2) to €240 bn in scenario 3.

Figure 4.37: EU CO_2 emissions in Mt – cumulative deviations against baseline between 2020 and 2050



If the yearly CO_2 emissions are multiplied with the carbon prices in the baseline, the monetary value of these internalized externalities reaches between €34 bn and €58 bn for the period from 2020 to 2050. Carbon price assumptions are taken from the EU Reference Scenario 2016[14].

Furthermore, according to additional analysis, annual pollutant emission savings in scenarios 1 to 2 against the baseline will reach 3.3 kt for NOx and 54 tonnes for PM in 2030. Due to more stringent regulation, savings reach about 7.9 kt for NOx and 112 tonnes for PM in scenarios 3 and 4. With current damage costs for NOx of 4,000 to 12,000 €/t and for PM between 23,000 and 67,000 €/t (EEA, 2014), the totals will range between € 132 million and € 948 million for NOx and € 1.2 million to € 7.5 million for PM annually. These numbers may be considered as quite small, but damage costs per unit of emissions may increase strongly in the future and will be much higher in cities.

[14] Prices per tonne of CO_2 increase from €15.5 in 2020 to €34.75 in 2030 and €91.30 in 2050 (European Commission, DGs for Energy, for Climate Action and for Mobility and Transport, 2016).

Figure 4.38: Value of EU CO_2 emissions savings in bn. € 2010 – cumulative deviations against baseline between 2020 and 2050

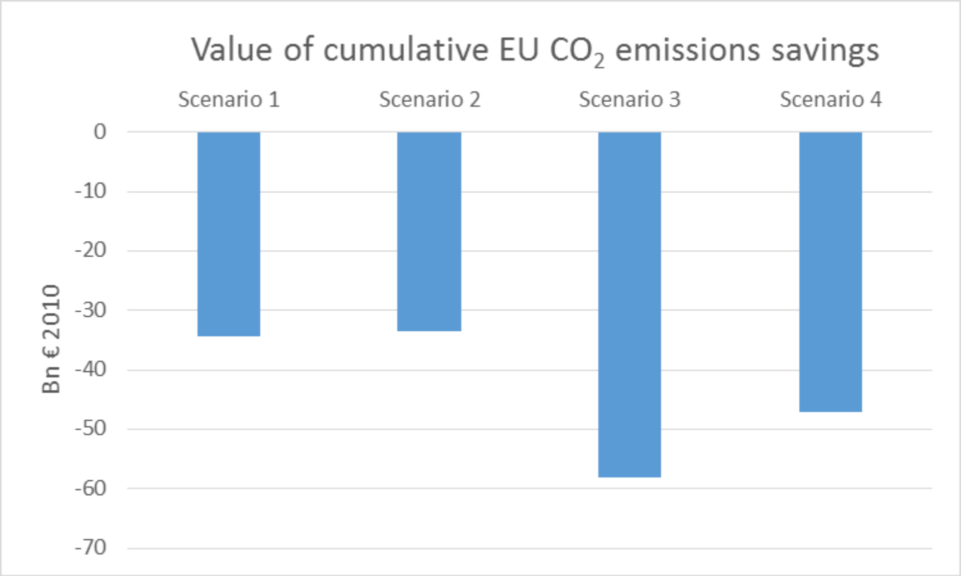
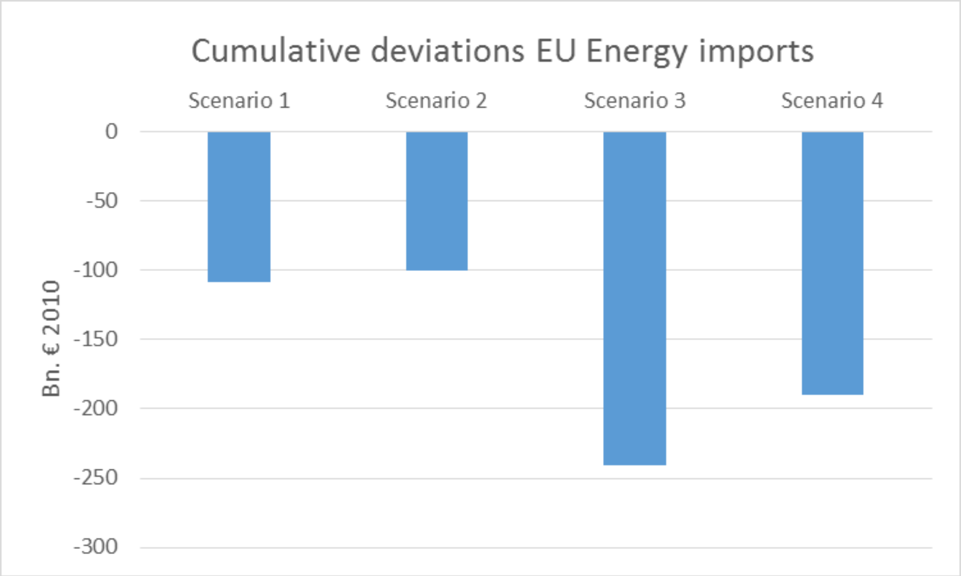


Figure 4.39: EU energy imports in bn. € 2010 – cumulative deviations against baseline between 2020 and 2050



4.2.2.5 Conclusions

Unilateral regulation of the EU automotive sector has a slightly negative macroeconomic impact in the short run, when considered in isolation, i.e. ignoring the potential impact of increased regulation on the ability of the EU industry to protect its internal market, as well as to innovate, differentiate its products with premium offerings abroad, or meet new stringent foreign regulatory standards in the future, thereby increasing exports.

Indeed in this scenario, prices for motor vehicles are expected to increase in the EU due to more stringent regulation. In turn, those industries using motor vehicles will also increase their prices, since they have to balance their higher costs. Nevertheless, significant socio-economic benefits are also created by the increased regulation in scenarios 1 to 4, including lower CO_2 emissions and local emissions, positive health effects and reduced oil imports.

One-off levelling of the technological and regulatory standards by 2030 in scenario 2 is the most attractive of the four scenarios in terms of GDP, with only a modest peak reduction of c. 0.1% in 2030, rapidly reverting to small positive GDP impacts beyond 2035. If the potential benefits of regulation are considered in the internal market sensitivity, macroeconomic effects of regulation are expected to be positive, whilst additional benefits can be achieved from the internalisation of external benefits and from initiatives to bring more battery production in-house

4.2.3 Freezing of EU regulations (scenario 5)

4.2.3.1 Overall economic impacts

In the short run, the freezing of EU regulations from 2020 has only small impacts on the EU economy, as domestic vehicle producers can reduce costs compared to the baseline. At the same time however they would be likely to face additional international competition, as the internal market will no longer be protected due to ambitious regulation. Furthermore, the freezing of EU regulations is likely to reduce the external competitiveness of the EU automotive industry in the long run as EU companies lose market share in third markets due to inferior, non-compliant products. Despite the initial cost savings, the overall effect is expected to turn negative after 2035. GDP and private consumption are 0.3% lower than in the baseline in 2050, whilst negative employment effects reach 0.4% (or 950.000 jobs) in 2050.

Figure 4.40: EU GDP in constant prices - % deviations against baseline

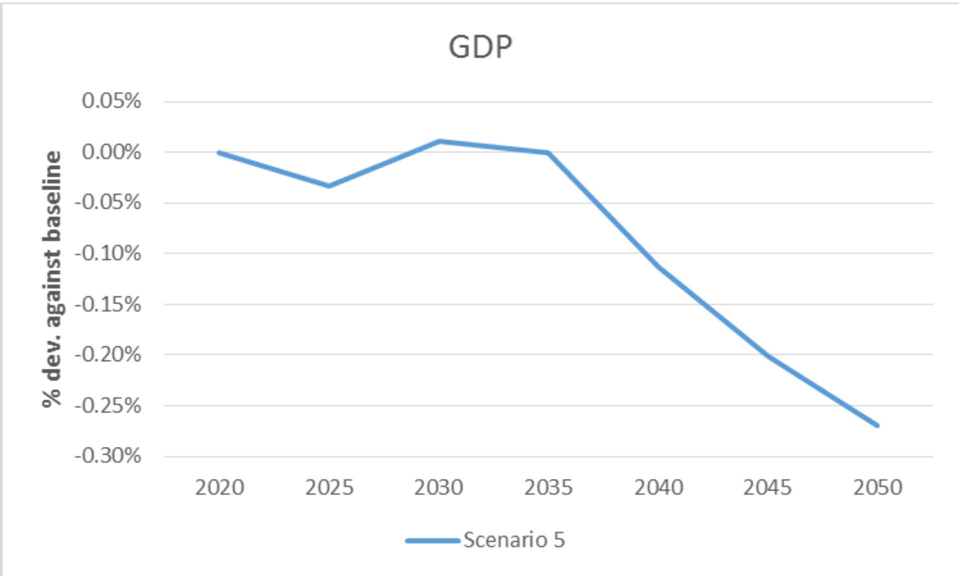


Figure 4.41: EU private consumption in constant prices - % deviations against baseline

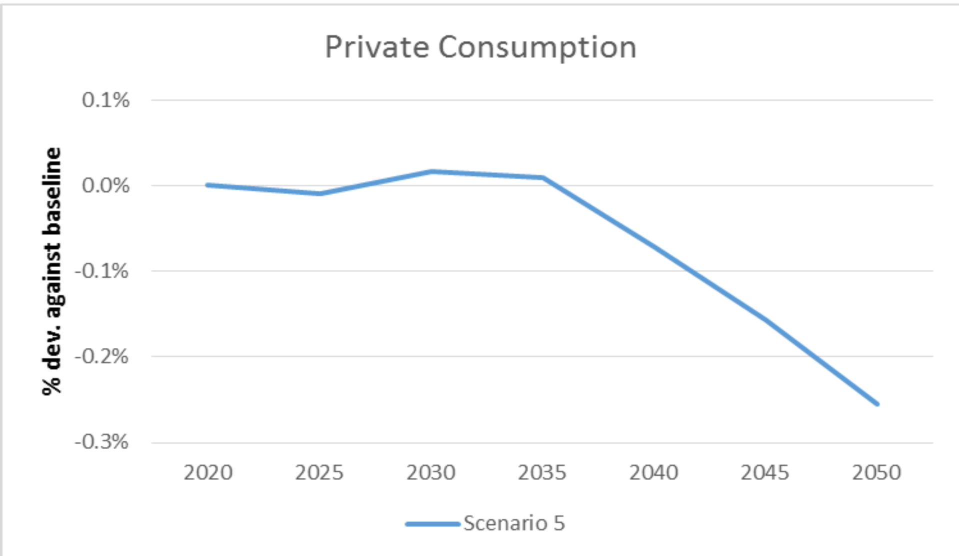
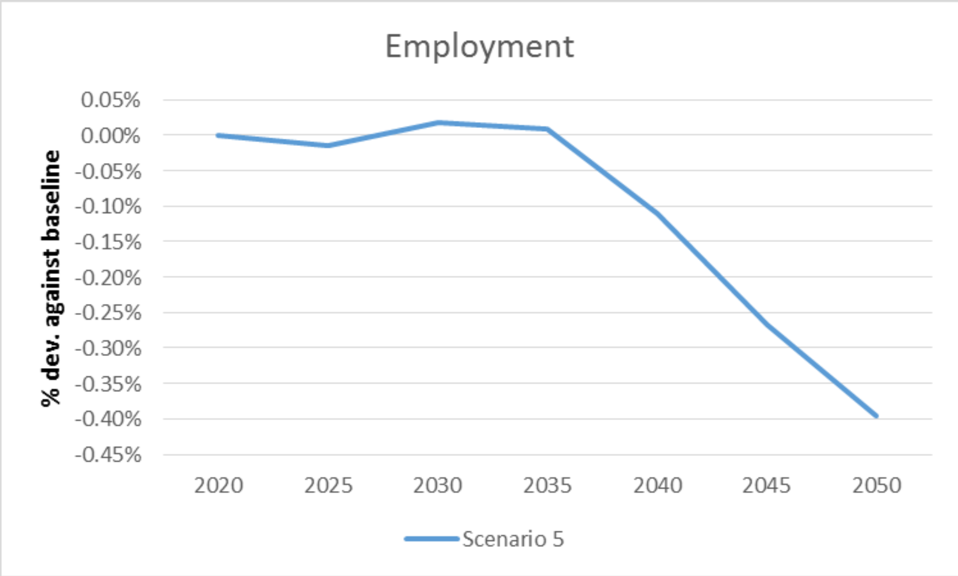


Figure 4.42: EU employment - % deviations against baseline



4.2.3.2 Overall industry impacts

Due to the scenario design, EU motor vehicle production in monetary terms is modelled to be substantially lower compared to the baseline – as a result of the reduced cost of producing vehicles in the scenario compared to the baseline. Imports decrease only slightly, which means higher import shares. Negative effects are also visible for employment. Industries supplying the motor vehicle industry such as fabricated metal products or non-ferrous metals also have to reduce production. This impact is more pronounced for those industries that could supply batteries or lightweight materials such as chemicals, other non-metallic minerals and electrical machinery. But for most other industries, the lower costs of motor vehicles are favourable in 2030 and they are predicted to increase production and employment.

Table 4.10: EU production, employment and imports by industry - % deviations against baseline

	2030		
Scenario 5	Production	employment	imports
9 chemicals	-1.5%	-0.7%	-2.6%
11 rubber and plastics	-0.9%	-0.9%	-0.8%
12 other non-metallic mineral (glass)	-3.9%	-1.7%	-2.0%
13 iron and steel	-1.0%	-0.2%	-1.5%
14 non-ferrous metals	-3.5%	-0.7%	-3.1%
15 fabricated metal products	-2.4%	-1.2%	-2.5%
16 machinery and equipment	0.5%	0.3%	-0.3%
18 electrical machinery	-2.2%	-1.1%	-3.5%
21 motor vehicles	-7.9%	-4.2%	-1.5%
26 electricity	-1.9%	-0.2%	0.0%
30 construction	0.5%	0.3%	0.0%
31 wholesale and retail trade	0.0%	-0.1%	0.0%
32 hotels and restaurants	0.4%	0.1%	0.0%

4.2.3.3 Socio-economic benefits/costs

Without a change from ICE to electric powertrains, CO_2 emissions and oil imports will be much higher in scenario 5 than in the baseline. Differences reach 196 Mt of CO_2 and €40 bn. in 2050. Multiplied by the carbon prices described in section 4.2.2.4, the additional CO_2 emissions account for € 172 bn between 2020 and 2050.The pollutant emissions in scenario

5 increase by about 23 kt for NOx and almost 400 tonnes for PM against the baseline in 2050. Given the current damage costs, the totals range between € 927 million and € 2.8 bn for NOx and € 9 million to € 26.4 million for PM in 2050. The socio-economic costs of freezing current regulation are thus substantial.

4.2.3.4 Conclusions

The scenario reveals small economic advantages in the short run, which quickly turn negative. At the same time heavy socio-economic costs and energy security issues of minimal industry regulation come along with the freezing of EU regulations.

4.2.4 Strengthening of Chinese regulations to global-leadership standards (China case scenarios)

The China scenarios show the potential benefits for EU OEMs of the increased EU regulation scenarios if higher regulation is unilaterally introduced in China. Given the EU's lead global leadership position in 2030 in terms of regulatory standards, EU OEMs would be able to rapidly respond to a regulatory 'shock' in the Chinese market, thereby claiming additional market share (as described in section 4.1.4.4 above) and increasing sales and profits accordingly. These effects strongly depend on assumptions about the future share of EU OEMs in the Chinese market and the transmission of higher sales in China to the EU economy. The effects are implemented in the model for the low and the high China cases as follows:

- Higher production of EU OEMs in China (i.e. localised production of EU OEMs) will increase production from the EU motor vehicle industry, as well as imports (cars, parts, etc.) along established supply chains. Import shares as defined for the baseline are assumed to remain unchanged. This means that relations between production of EU OEMs in China, parts supplied by Chinese companies, parts supplied by EU companies producing either in China or Europe, and imports from EU OEMs are assumed to remain at current level. Overall, higher localised production and exports of the EU motor vehicle industry (OEMs and suppliers) will increase their output and have positive effects on the EU economy.
- Higher sales volumes (and in some cases prices) in China increase the profits of EU OEMs in China. OEMs will partly use the additional profits to invest in EU production sites. Additional investment in EU will have positive impacts on the EU economy.

Two different cases that build on scenario 2 (the best performing of the EU regulatory scenarios) are compared to show a range of possible effects. In the 'high' China case (the case where all non-complying non-EU OEMs are banned from selling mid-range and entry-level cars in China) the EU motor vehicle industry will increase exports considerably compared to the EU regulatory scenario. Additional EU exports reach almost €20 bn in 2030 and €14 bn in 2050. About one quarter of additional profits of EU OEMs of €8.5 bn in 2030 and €4.5 bn in 2050 is invested in the EU.

In the 'low' China case (the case where all non-compliant non-EU OEMs are banned from selling entry-level cars in China) additional exports just reach a much more conservative €2 bn in 2030 and €1.2 bn in 2050. Additional profits and assumed investment in EU are lower than in the high case, standing at €1.8 bn additional investment in 2030, and €0.9 bn in 2050.

Note that a regulatory shock is only modelled for 2030 in China. In reality, further regulatory shocks may be expected from China, as well as other globally competing markets, at different points in time. Nevertheless, the results from this specific scenario construct serve to demonstrate that more stringent regulations in the EU are crucial for EU OEMs to be able to remain competitive in those markets in the face of these regulatory shocks.

4.2.4.1 Overall economic impacts

Figure 4.43 presents the relative changes in EU GDP for EU scenario 2 and the two China case variants plus the internal market sensitivity against the baseline scenario. In the China high case scenario building on scenario 2, GDP is expected to be higher than in the baseline.

Positive impacts increase over time and reach 0.23% in 2050. In the China low case scenario the positive effects for the EU economy are too small to balance the negative effects of regulation in scenario 2 in 2030. After 2035 GDP is also expected to be higher compared to the baseline.

Taking into account the sensitivity analysis on the internal market in addition to the China case scenarios and EU scenario 2, GDP is expected to be 0.7% higher than in the baseline in the high case in 2030. The impact is expected to slightly decrease to 0.5% in 2050. In the low case, the positive GDP effect ranges between 0.55% in 2030 and 0.4% in 2050.

Figure 4.43: EU GDP in constant prices - % deviations against baseline

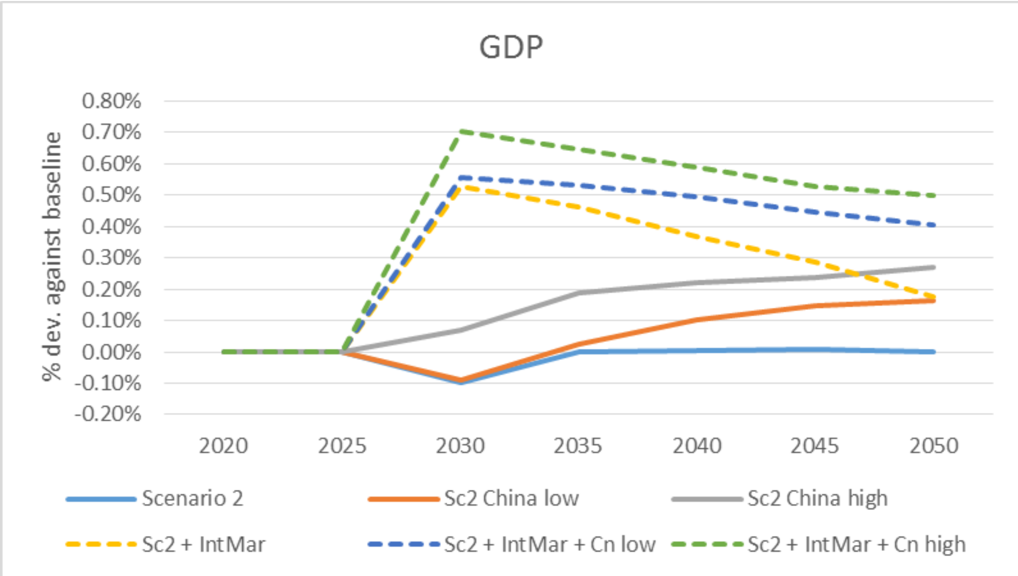
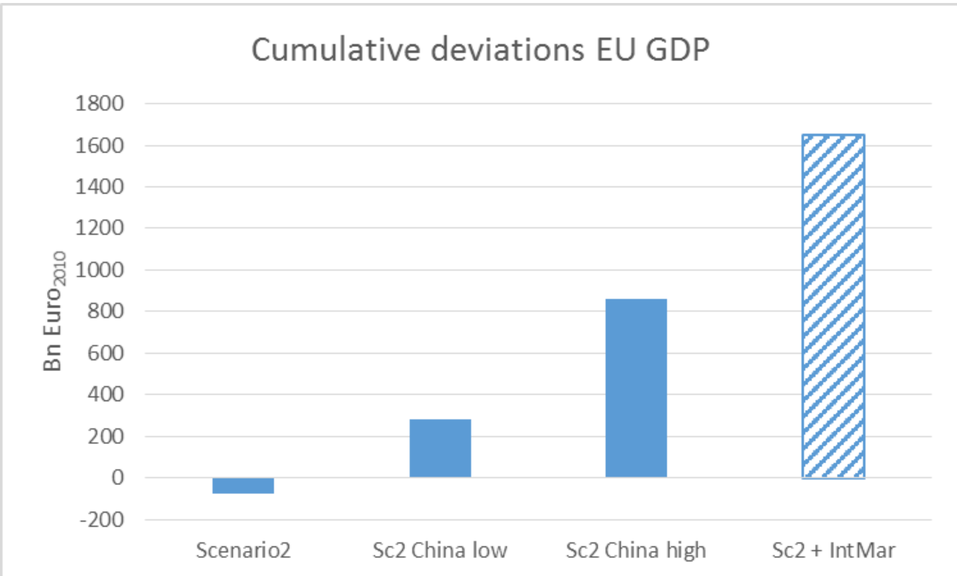


Figure 4.44: EU GDP in constant prices (2010) – cumulative deviations against baseline between 2020 and 2050



4.2.4.2 Conclusions

The China case scenarios show that the impacts of higher regulation in China for EU OEMs would be increases in markets shares, sales and profits because the mandated Chinese regulatory standards would already have been reached in Europe. They thereby illustrate the benefit side of the equation in a single major global market, where the cost side of the equation is the cost of EU regulation in the EU home market.

For scenario 2 and the high China case, additional EU exports and OEM revenues can more than balance the negative economic impacts of one-off levelling of the technological and regulatory standards by 2030. When considered alongside the fact that increased regulation in the EU could help EU OEMs to secure better access to markets other than only China and that higher regulations in the EU under scenario 2 could also reduce the market share of non-EU OEMs in the EU (internal market sensitivity), the overall benefits highlighted from this analysis are significant. Additional benefits for the EU economy may come from domestic battery production, whilst the internalisation of externalities also brings benefits.

4.3 Impact on Tier 1 suppliers

This section represents the main output from analysis of the impact of the regulatory and technology trends on the Tier 1 automotive supply industry. The analysis focuses on two of the most important trends which are likely to affect suppliers globally, namely the transition towards e-mobility and the advent of connected and autonomous vehicles (CAVs). Specifically:

- Section 4.3.1 describes the impact that a largescale shift towards e-mobility may have on the automotive supply chains, in particular Tier 1 suppliers. Much of the quantitative data referenced in this section was retrieved from a UBS electric vehicle teardown report (UBS, 2017).
- Section 4.3.2 then goes on to discuss the additional impacts that connected and autonomous vehicle (CAV) technology will have on automotive supply chains, again focussing mainly on Tier 1 suppliers.

4.3.1 E-mobility

Electric vehicles (EVs) have the potential to hugely change the dynamics of the automotive market. With diesel engines currently under scrutiny for their harmful pollutant emissions and bans being implemented because of air quality concerns in several European cities, there are strong drivers for the production of EVs. Without diesel, it may be difficult for automakers in Europe to hit CO_2 targets for new cars and vans, thereby further raising incentives for them to speed up EV development as opposed to transitioning to petrol powertrains. Indeed, OEMs and suppliers have dramatically increased their EV production targets over the last 12 months; for example, VW expects to have 20-25% of battery-electric vehicles in its sale mix by 2025 (excluding plug-in hybrids) and Daimler 15-25% (UBS, 2017).

This transition towards increased penetration of EVs presents a potential significant threat for both OEMs and traditional Tier 1 suppliers, though opportunities also exist. In fact, the increased speed of the transition could be better than feared for OEMs; better EV production economics and higher-than-expected growth has the potential to result in improved and earlier returns on EV-related investments, leading to improved profitability for OEMs and suppliers alike. Better economies of scale and component cost reductions will also contribute towards lowering the costs of meeting post-2020 CO_2 targets in Europe.

Nevertheless, a rapid shift away from ICE vehicles could put huge sunk investment costs at risk, for example advanced diesel efficiency technologies, whilst reduced vehicle complexity and a lack of experience in fields such as battery production, power electronics and electric drivetrains, could see traditional Tier 1 suppliers content reduced on EVs, whilst OEMs may also see a shrinking percentage content in EVs, as other non-traditional automotive industries benefit from their long-standing expertise in these fields, e.g. batteries. Both Tier 1 suppliers and OEMs will need to find other areas of differentiation to preserve brand value and pricing power.

The impacts of the e-mobility transition on Tier 1 automotive suppliers are discussed in the following sub-sections, whereby the impact of the extreme case of a 100% transition to EVs is considered. Clearly the extent of the impact will be proportional to the actual penetration of EVs in the new vehicle fleet, however the extreme scenario provides a good estimate for the opportunities and threats to the industry from the rise of EVs.

Even though the discussion below considers impacts of a 100% EV world, the realistic effects seen on the market are long term, with the revenue pool for affected sectors shrinking/growing gradually as ICE vehicles get scrapped and replaced by EVs. However, clearly the changes will happen over decades, and the impact will become more meaningful only after 2030 as EV penetration climbs above 15%.

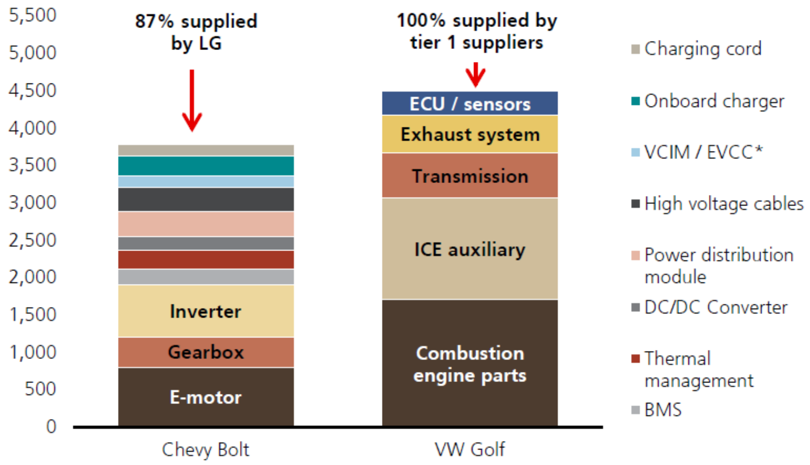
4.3.1.1 Vehicle production: Powertrain

Impact of e-mobility world

Within a 100% EV world, the share of traditional Tier 1 suppliers involved in the powertrain development and production could be significantly reduced. Figure 4.45 illustrates this trend through the difference in powertrain components (excluding battery pack costs) between the Chevrolet Bolt and VW Golf in the US, with 100% of the ICE powertrain being OEM or Tier 1 supplied, compared to much of the EV powertrain being supplied by 'non-traditional' automotive suppliers (with just one electronics company supplying 87% by value of the powertrain for the Chevrolet Bolt[15]). (UBS, 2017).

If this trend is replicated more broadly across the industry with the shift towards an increasing penetration of EVs, there will be a clear need for Tier 1 suppliers to adjust their product portfolios to include as wide a range as possible of electric powertrain components, in order to insulate themselves from a wholesale switch to alternative suppliers. Conversely, a significant opportunity exists for established suppliers of electric motors and associated components, if they are able to position themselves to gain access to the automotive industry.

Figure 4.45: Powertrain components of the Chevrolet Bolt vs. VW Golf (US$)



Source: (UBS, 2017)

In addition to the changes in components described above, the adoption of EVs leads to a decreased mechanical complexity within the powertrain; e-motors have fewer parts than internal combustion engines and many of the parts are 'non-traditional'. For example, the total number of moving parts in the Chevrolet Bolt powertrain compared to a VW Golf is 24 and 149 respectively (an 84% decrease for the EV compared to the ICE vehicle). With bearings aside, this stands at 3 moving parts for the electric powertrain compared to 113 for the ICE (UBS, 2017). As well as reduced complexity and therefore sales opportunities for suppliers, less machining is generally required for e-motors. It is estimated that up to 80% of cutting tool work needed in car manufacturing happens in the combustion engine, so this illustrates further the pressure on Tier 1 suppliers from the reduced complexity of EVs. The total value of powertrain-related original Tier 1-supplied components could, in the worst case scenario, drop by up to 87% (based on the fact that 87% of the Chevrolet Bolt's powertrain is supplied by non-traditional Tier 1 suppliers), which if scaled to the EU

[15] Note that the total price of the Chevrolet Bolt's powertrain components (excluding battery pack) are predicted to be 10-25% cheaper in 2025 compared to today's costs, nevertheless this will still represent a significant component of overall vehicle costs.

industry could result in a loss of revenue of up to $130 bn by 2019[16] for traditional Tier 1 suppliers.

This reduction in parts may be seen as a positive for OEMs, as e-motors are significantly easier and less costly to manufacture, with lower cost and less labour input required, as shown in Figure 4.45 – potentially thereby allowing for improved margins after volume-cost reductions have been achieved. However, the Tier 1 supply chain could see significant negative implications associated with this reduced complexity, even if they successfully develop the required product offering to maintain their large current market share in future drivetrain technologies.

Outlook for Tier 1 suppliers

Based on the above, it is expected that suppliers of parts exclusive to ICE powertrains and lead acid batteries, for example Faurecia and Rombat would be at risk, as well as certain maintenance and servicing providers (discussed more in section 4.3.1.4). The market place for bearing companies such as Schaeffler and SKF, as well as Sandvik and Kennametal in the machining/cutting industry would change significantly. Suppliers without strong exposure to advanced safety, automation or electrification trends will likely face unfamiliar competitors from high technology sectors or potentially the threat of takeover by them as they aim to gain access to carmakers.

For vehicle OEMs and their Tier 1 suppliers to be able to compete and maintain a firm grip on the powertrain industry, it is key that they develop their own motors and other electric powertrain components. This trend has already begun, for example in the Japanese market Honda Motors and Hitachi's auto parts division are investing in a joint EV motor company, where they will develop, produce and sell EV motors. To compete in developing lower-emission cars, companies in Europe are also finding partners so they can share the cost burden associated with this new technology: Daimler has invested heavily in setting up an e-technology centre in Germany, where a Mercedes-Benz plant will start producing electric powertrains in a bid to maintain a strong presence in the "green" auto industry, whilst BMW developed its own electric motor and drivetrain for the BMW i3 and i8 which it manufacturers itself in Germany, and VW has invested $17 million to begin production of electric motors at its transmission plant in Tianjin, China from late 2018 (Automotive News Europe, 2017).

The largest opportunities for new entrants rest with the dominant producers of electric motors and associated components (such as LG and Panasonic), with the electric motor market expected to reach $22 bn by 2022 (Allied Market Research, 2016). Note that both these players are Asia, however a number of EU players could be well positioned to benefit here, such as Continental and Valeo.

4.3.1.2 Vehicle production: Power Electronics and Batteries

Impact of e-mobility trend

Even though the mechanical complexity within EVs is much lower than that of ICE vehicles, the electronics content of EVs is significantly higher, in terms of both power electronics required to manage the electric powertrain and other electronics required due to the increased electrification of other components (e.g. heating) and infotainment features of these vehicles. For example, the electronics content of the Chevrolet Bolt is estimated at $3,000 higher than that in the ICE VW Golf, in terms of cost to the OEM, whilst the average semiconductor content in an EV doubles that of a combustion engine vehicle. As such, e-mobility creates an opportunity for electronic technology companies to enter the automotive industry and contribute to a large proportion of vehicle manufacturing. Indeed, for manufacturing the Bolt, the share of Tier 1 suppliers from outside the traditional supply chain is 56% (UBS, 2017) whilst electronic components in the BMW i3 account for almost 13% of the total cost of manufacturing, with over 70% of this coming directly from battery and infotainment components (Munro & Associates , 2015).

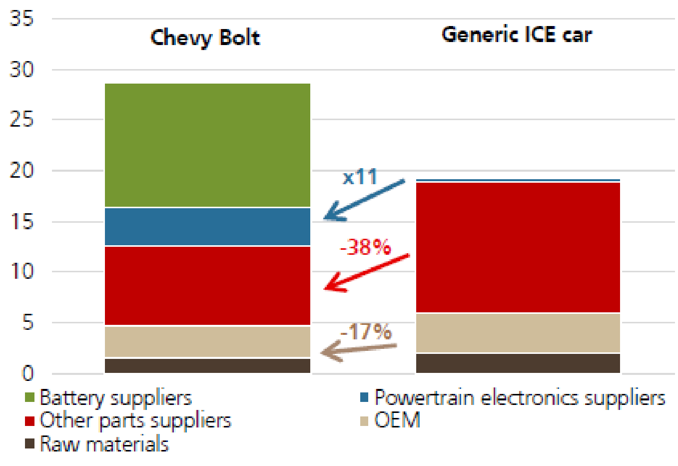
[16] Note this is based on 23% EU share in global vehicle production (ACEA, 2017) and global powertrain market value predictions of $658.3bn (Marketsandmarkets , 2014) .

The opportunity exists for a small number of specialist suppliers to supply large parts of the electric powertrain, with the powertrain electronics supplier content for a Chevrolet Bolt being 11 times that on a traditional ICE vehicle. In fact, it is thought that by 2027 the power electronics market for electric vehicles will be worth $300 bn (IDTechEx, 2017). Conversely, a large threat could exist to existing Tier 1 suppliers whose electronics offering is not sufficiently well-developed to take advantage of the opportunities presented by the shift to e-mobility. Analysis of the Chevrolet Bolt shows that, according to today's predictions, traditional Tier 1 suppliers could lose up to 38% of the current value of components included in typical ICE vehicles, with the transition to EVs, if they do not update their product offering accordingly (UBS, 2017).

Other than power electronics, the key area where a value shift is likely to occur with the advent of widespread EV use is in the provision of batteries. Figure 4.46 illustrates that, alongside the 38% reduction in costs attributed to traditional Tier 1 suppliers, a new contribution from battery suppliers becomes the single biggest Tier 1 cost in the Chevrolet Bolt. It is estimated that the size of the battery market in Europe by 2025 could be worth €8.9 bn[17]. Whilst the percentage contribution of battery costs to overall vehicle costs will reduce in the future, with cheaper and higher capacity batteries being key to making EVs more appealing (it has been forecast that by 2025, battery pack costs will have declined by approximately 33% (UBS, 2017) and, by 2030, energy density is expected to nearly double over the same period (Blackrock, 2017)), this new category nevertheless will continue to be a major component of future Tier 1 supply chains.

Few battery pack manufacturers have sufficient capacity to serve a rapidly expanding market for EVs, with major players such as LG Chem and Samsung SDI having large capacity NMC (Nickel Manganese Cobalt) production plants, whilst Panasonic (used mainly in Tesla vehicles) has an extensive cylindrical NCA cell (Nickel Cobalt Aluminium) manufacturing capacity. None of these major players are EU-based and there are no large-scale battery plants operating in Europe currently. There is some battery manufacturing capability due to players such as Saft Batteries and EnerSys, but this is limited (for example Saft's Nersec facility in France has a production capacity of 60-120MWh compared to Tesla's Nevada Gigafactroy with a production capacity of 150,000MWh (150GWh)) and will need to grow significantly to compete with the likes of Tesla, LG, Panasonic and BYD. In the short term this could result in a shift towards greater imports of non-EU content into EU-made EVs, until major investments are made in the EU in this sector. However, European OEMs are already responding, with Daimler currently investing €500 million for a new battery Gigafactory in Kamenz, Germany to go into operation in mid-2018. Production capacity is as-yet unknown but expected to be in the GWh range (Electrek, 2017).

Figure 4.46: Vehicle content on Tier 1 level by sub-sector ($)



[17] Note this calculation is based on estimated battery pack costs in 2025 of $6,732 (UBS, 2017) and total EV (BEV & FCEV) market production predictions from the market trends modelling of 1,327,514 vehicles in the EU in 2025.

Source: (UBS, 2017)

Outlook for Tier 1 suppliers

The transition towards greater penetration of EVs presents a significant threat to traditional Tier 1 suppliers due to the significantly expanded requirements for powertrain electronics and batteries (often originating from new entrants into the automotive industry), with corresponding decreases in traditional ICE parts. From the electronics perspective, it is expected that major semiconductor firms such as Infineon, ST Microelectronics, Freescale, Intel, Bosch, NVIDIA, Renesas, Micron and Qualcomm will benefit and further increase their range of parts that are certified to meet the robust and resilient requirements of the automotive industry. Large opportunities also rest with the dominant producers of electronic components, such as the South Korean company LG and the Japanese company Panasonic, but a number of EU players such as Continental and Valeo could too be well positioned to benefit here (Continental and Valeo have less exposure than many other suppliers to the 'legacy' combustion engine business so are well suited to the transition of the future industry (UBS, 2017)). Other traditional Tier 1 suppliers such as Magna, Delphi, Harman, and Denso are already reviewing their product offerings, business models and supply chains to ensure they are designing components relevant to the industry's evolving needs – for example Magna is building Jaguar's first fully electric vehicle from 2018 (Magna, 2016), whilst Delphi has spin off its traditional ICE business (Detroit Free Press, 2017).

With regards to EV batteries, supply to non-Chinese OEMs is quite concentrated, with LG Chem, Samsung SDI and Panasonic being the only leading players with sufficient manufacturing capacity to meet the needs of a rapidly expanding e-mobility market. Whilst OEMs are bringing ever growing choice in terms of EVs to the market, substantial advances to their and their suppliers' in-house electronic engineering capabilities would be needed to be able to compete on this scale with foreign-made batteries. It is therefore doubtful that European OEMs will commit large sums of money into their own battery cell manufacturing in the short-medium term, due to the high capital intensity and lack of technological edge. It is expected instead that the current arrangement of utilising partnerships between EU OEMs and electronics companies will continue, e.g. Tesla, FCA and VW have partnered with Panasonic, whilst Daimler, Renault and GM cooperate with LG Chem. Nevertheless, support from the European Commission in terms R&D support or subsidies could help OEMs with investments in battery production. Efforts to support the battery industry in the EU are already underway, for example through the Battery Flagship Initiative and the SET-Plan Action no. 7 (Declaration of Intent: "Become competitive in the global battery sector to drive e-mobility forward") (European Commission, 2016). Longer-term it is likely that OEMs and Tier 1 suppliers will begin to invest in battery manufacturing capability in order to reverse the value shift away from their industries caused by the advent of EVs. Additionally, new EU entrants such as Northvolt may also establish significant battery manufacturing capacity in the EU, but from outside the traditional automotive supply chain.

4.3.1.3 Vehicle production: Other Components

Many other components of an EV are similar to those in ICE vehicles, for example:

- Interior fittings
- Lighting
- Paintwork

The impact on traditional Tier 1 suppliers' and OEM supply chains will therefore most likely be neutral when considering these components. However, these components make up a small overall fraction of Tier 1 value in a vehicle (considering the cost of the Bolt's battery pack alone is over 40% of entire vehicle cost (The Guardian , 2017)) and the bigger threats exist to the components discussed above.

4.3.1.4 Vehicle production: Aftermarket Business

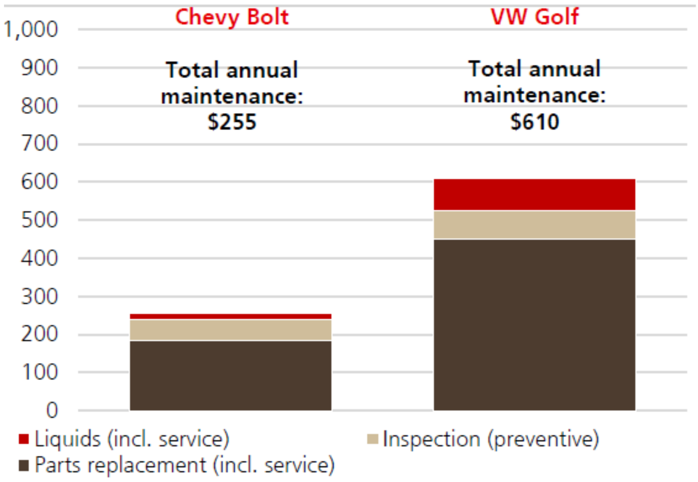
Impact of e-mobility trend

E-motors generally have stronger and linear torques, shorter response times, a wider usable rpm range, no "cold start" issues, and no energy-consuming idle running, which all contribute to making the powertrain more efficient and more durable compared to an ICE powertrain. This effectively reduces service costs and increases vehicle longevity.

Indeed, except for rotating tyres and cabin air filter replacement, EVs do not require any maintenance for the first few years. For example, for the Chevrolet Bolt the first maintenance is required after 5 years or 150,000 miles (whichever comes first), whereas the VW Golf requires servicing every 10,000 miles. Not only do fewer parts need replacing due to the lower number of wearing on mechanical parts (with fewer resultant pre-emptive inspections), EVs also do not require a regular change of fluids such as engine oil.

When considering a complete transition to e-mobility therefore, the aftermarket industry would change substantially; it is predicted that in a 100% EV world the aftermarket revenue pool would drop by approximately 60% compared to a traditional ICE vehicle or >€340 per vehicle per year per vehicle, as shown in Figure 4.47 (UBS, 2017). Overall, this could result in a loss of revenue for the industry of approximately €397 bn (from 2015 levels) (McKinsey&Company, 2016).

Figure 4.47: After-sales revenue pool shrinks up to 60% ($)



Source: (UBS, 2017)

The only sector where maintenance costs would increase is with regards to tyres, which would need to be replaced more often due to the higher kerb weight of EVs and the higher torque of electric motors. It is assumed that tyres would wear at an increased rate equivalent to the percentage difference in kerb weight, i.e. the Chevrolet Bolt has a 22% difference in kerb weight compared to the VW Golf, hence the tyres would wear 22% faster (UBS, 2017). This represents an opportunity for tyre makers, however as energy density in batteries keeps increasing and battery weight per kWh keeps decreasing, the difference in curb weight might gradually disappear in the long run.

Outlook for Tier 1 suppliers

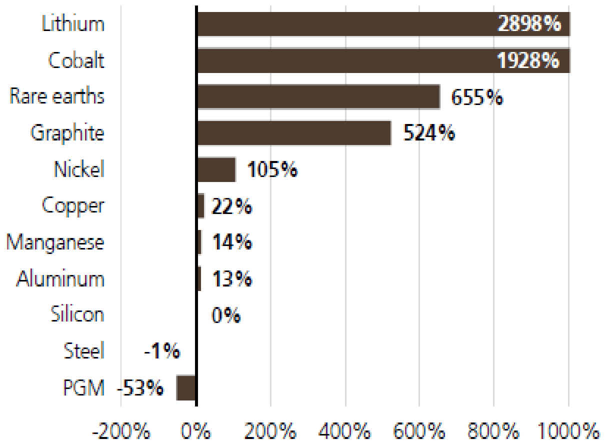
Based on the above, less maintenance is expected to be required on EVs, therefore posing a major challenge for dealerships (whose business model typically relies on generating >40% of their gross profit in service and maintenance) (UBS, 2017) and specialist maintenance companies. This is in addition to the investment required for maintenance professionals to be trained in maintaining high-voltage electrical components, power electronics, batteries and electric motors. In addition, the spare parts business, which represents approximately 35-50% of OEM revenues in mature markets like Europe and the US (GitaCloud, 2016), has the potential to reduce in size in the long-term affecting many suppliers for example Lucas Electrical, who supply various automotive aftermarket parts in the UK. However, original Tier 1 tyre suppliers such as Michelin, Dunlop and Goodyear stand to potentially benefit in the short and medium term.

4.3.1.5 Vehicle production: Impact on Materials Supply Industry

Within a 100% EV world, significant changes are likely to occur in the commodity market in terms of materials used in the automotive industry for the production of batteries and e-motors, with knock-on impacts on associated trade flows. The impact on international trade flows are described in detail in Section 4.2.1.3. Figure 4.48 below illustrates these changes in terms of overall demand from the materials supply industry for these and other materials used in xEVs in a 100% EV world, as a percentage of today's global production.

As illustrated, the proportion of steel used is expected to reduce, due to the increased use of lightweight components made of composites or metals including aluminium and magnesium. However, even in a 100% EV world this incremental decline in demand would be marginal in the context of the global steel supply industry. Aluminium demand could however increase by as much as 13% compared to the current market size – with a 70% increase in aluminium content on vehicles expected due to its increasing use as a lower density material for the frame structure to replace steel and compensate for the weight of the battery (UBS, 2017). With the increased use of electric motors and higher-power on board electronics, copper use is also expected to increase significantly, by up to 22% on a global scale in a 100% EV world.

Figure 4.48: Incremental commodity demand in a 100% EV world (% of today's global production)



Source: (UBS, 2017)

Nevertheless, the commodity supply industries that will be proportionally most affected by a transition towards EVs are those related to battery active materials (lithium, cobalt and graphite), which will see a boom in a 100% EV world. Where there is no native production capacity within the EU, the impact on future import trade flows for these materials will be significant, as described in greater detail in Section 4.2.1.3.

The commodity supply chain in the lithium battery market would be most disrupted by a rapid EV penetration increase, in particular for lithium, cobalt and graphite. A potential concern is the pricing and availability of these raw materials. It is estimated that current global reserves of cobalt could be exhausted by 2030 if the EV market share rose to 12.5% from under 1% today (Blackrock, 2017). Supply is also dependent on potentially risky Cental African supply, where political uncertainty poses a significant threat. Mining companies are already planning to ramp up production of cobalt, expecting a demand surge. The price has doubled between May 2016 and 2017 (Blackrock, 2017) both in anticipation for this demand surge, and due to the unstable political situation in the Democratic Republic of Congo. With regards to lithium, much of the world's lithium comes from the "Lithium Triangle" in Chile, Argentina and Bolivia where there is expected to be sufficient supply in the near-term. Nevertheless, the reliance on a relatively small number of countries for this commodity could in the future prove restrictive.

Similarly to battery active materials, rare earth metals typically used in e-motors (including for example dysprosium) could face demand shocks in a rapidly evolving EV world, with the supply industry also needing to plan for and adapt to these expected challenges. The supplies are highly dependent on China which dominates the global trade (China holds 95% of the world's dysprosium). Nickel demand is also expected to increase by 105% due to being a cheap main component of EV battery packs, although current elemental supply is plentiful. Finally, an obvious loser among global commodities would be the platinum group metals (platinum and palladium etc) which are used in ICE emission treatment solutions.

Within a high-penetration future EV world, issues with geopolitics and supply chains for these various commodities could arise in the race for countries to become the global leaders in EV production. The commodity supply chain will need to insulate itself from these risks, as well as the risks from breakthrough new technologies, through developing a broad portfolio of materials supply offerings and working closely with national and EU Governments to secure stable supply. Investing in increased recycling rates and R&D to support technological advances may help to mitigate some of these risks and provide further opportunities for the commodities supply chain. Advances are already being made in this area, e.g. demand and reliance on risky cobalt supply is to be moderated as next generation NMC cell chemistry moves from 1-1-1 to 8-1-1 early in the next decade (increasing ratios of cheaper Nickel and decreasing more expensive cobalt and manganese), and e-motor magnets are being developed with less/no rare earths which may help the global rare earth supply chain meet EV demand growth.

One further key area where changes are anticipated, which is not covered in Figure 4.48 above, is in the field of lightweight materials, which often go hand-in-hand with electrification. For example, carbon-fibre-reinforced polymer (CFRP) composites for vehicles can help to make cars lighter, more fuel efficient and safer, and these are likely to become much more heavily used in an EV world, where significant penalties exist for carrying excess weight, given the knock-on impacts on range and/or additional battery capacity requirements. Indeed, the all-electric BMW i3 has the highest CFRP content of any mass-produced passenger car, with CFRP contributing to a 30% weight reduction compared to using conventional materials (e.g. steel) for the c. 150 parts that have been switched to CFRP (Plastix World, 2013). Advances are already underway in fibre, resin and composite part production which will lead to a $6 bn market for automotive CFRPs globally by 2020 (Munro & Associates , 2015).

It is predicted that there will be a significant mainstream automotive adoption of CFRPs and other lightweight materials in the mid-2020s as costs continue to fall, and companies throughout the Tier 1 supply chain will need to position themselves to take advantage of this transition. This is already happening, with the announcement of various direct partnerships between automotive OEMs or Tier 1 suppliers and carbon fibre players – this kind of approach is essential when considering the production of carbon composites, given the complex manufacturing process and large up-front investments required to build manufacturing capacity. For example, one of the major hubs for automotive carbon composites has been created by Japanese composite manufacturer Toray partnering with Tier 1 supplier Magna and Plasan Carbon Composites (Automotive News, 2014), whilst BMW has a minority stake in SGL Carbon, its key development partner in creating structural components and body panels for its i series of cars (Automotive News, 2013). Other European carbon fibre players that could benefit in the future include Zoltek Zrt, Hexcel and Cytec Engineered Materials.

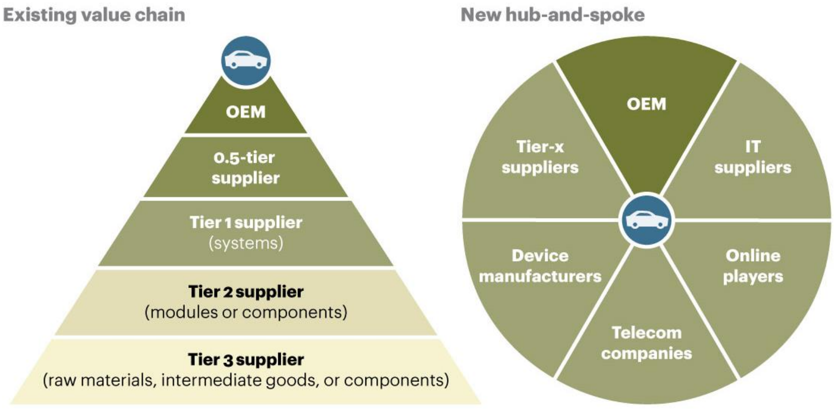
Finally, in terms of in-life materials consumption, the transition to EVs is likely to have an impact on oil consumption. This is covered in more detail in Section 4.2 of the main quantitative modelling results.

4.3.2 Connected and Autonomous Vehicle (CAV) Technologies

The rise of connectivity and automation has the potential to be a major contributor to the transformation of the automotive industry that is underway. It could open up a wide array of opportunities not just for the automotive sector but for a range of adjacent sectors too, creating a multitude of new business models and monetisation opportunities, with an estimated annual global value of approximately $560 billion by 2035 for the core services around self-driving vehicles, alongside significant safety benefits (25,000 serious accidents (2014-2030), and 2,500 lives saved over the same period) (Drive West Midlands, 2016).

The wide adoption of CAVs in the future is likely to cause a significant change in ownership relationships, usage and design of future vehicles. In this new mobility system, the traditional linear value chain that can be seen on the left in Figure 4.49 will be altered, and may evolve towards a more web-like or hub-and-spoke arrangement as shown on the right. The finished vehicle will remain in the centre, surrounded by indispensable and in some cases interconnected parts of a 'wheel' including: Tier 1 suppliers, the OEM, telecom companies, device manufacturers, and software and tech giants. Previous hierarchical supplier relationships may evolve into networks of specialised technology experts and integrating platform providers. Partnerships will be developed which may be complex, non-traditional and potentially disruptive.

Figure 4.49: Disruptive value chain in the future automotive industry



In order to successfully benefit from this transition, participating players (OEMs, Tier 1 suppliers and new market entrants) will need to strategically choose their future role and where to contribute within the supply chain, to claim their share of revenue within the automotive industry. Sections 4.3.2.1- 4.3.2.5 discuss at a high level the likely impacts of CAVs on the automotive supply chain, with a focus on five areas seen as key in the transition, namely: processing power, software, connected technologies, mapping and hardware.

4.3.2.1 Processing power

The advent of increasing levels of automation places a growing requirement for processing power on-board CAVs, going significantly beyond the relatively simple electronics included in more traditional vehicles. In fact, the market for autonomous driving chips has been predicted to grow by a factor or 36 between 2017 and 2025 (from around \$0.2 bn to \$7.2 bn) (MarketWatch, 2016). However, tapping this market will require large investments in R&D and manufacturing.

Given that sales in the automotive market alone will not justify these investments, established companies with experience in (and an ability to draw revenue from) adjacent industries such as consumer, mobile or data processing are therefore best positioned to serve this demand for improved processing power, and obtain sufficiently attractive returns on investment in doing so. Indeed, many established high-tech companies, including semiconductor players which may not have traditionally participated in the automotive sector, are now actively pursuing ADAS (advanced driver-assistance systems) and other autonomous driving-related opportunities, either by adapting existing products or developing new ones.

New-entrant automotive suppliers are best placed to benefit here, with companies such as NVIDIA, Intel, Panasonic, Qualcomm, Samsung and Sony pursuing opportunities related to sensors, electronic control units (ECUs) and microcontroller units (MCUs), and systems on a chip. NVIDIA is a good example here and currently one of the market leaders in supplying high-powered chips to the automotive sector. It started making graphics chips for the gaming, smartphone and tablet industries before branching out into automotive in 2010 and specific autonomous technology in 2015. Its powerful Tegra X1 chip can process images from various data sources, such as cameras, radar, and laser imaging, whilst also enabling machine learning for automotive systems. Its autonomous driving platform is currently being developed through partnerships with companies including automakers, Tier 1 supplier and start-ups, such as Audi, Mercedes-Benz, Volvo, Tesla, Bosch, ZF, and Toyota.

In addition, many start-ups and other small to mid-size companies in the high-tech and automotive sectors are trying to capture market share, including Europe's Hawk-Eye Innovations, GestureTek, and IntelliVision, all of which have specialised expertise in image processing and computer vision. Along with NVIDIA, ARM, Qualcomm and Intel are also large chip makers who are ramping up to meet the demand of the future automotive industry. Given the lack of specialist experience or economies of scale from other industries, established Tier 1 players are unlikely to benefit from this opportunity, except through partnerships with the aforementioned companies.

4.3.2.2 Software

With the widespread deployment of CAVs over the next 10 years, a key differentiating source of value in the automotive industry will not only be vehicle parts, engines and physical engineering, but also appropriate levels of competency in complex software development. Software will be used to deliver a wider range of features and services, including mobility services, advanced safety, location-based services, in-vehicle content, and remote analytics. As such, software competence is increasingly becoming one of the most important enabling factors for developing autonomous vehicles, with the program code for modern cars having approximately as many instructions as an aeroplane flight computer and with more than 100 million lines of code on average expected in each vehicle by 2020 (Deloitte, 2016).

In a CAV future, a large portion of a vehicle's value is thought to lie in software (approximately 40% (ATKearney, 2016)). The software companies involved could be technology firms, existing OEMs, or automotive suppliers that recognise the opportunity and make an early move to capitalise on it.

Two of the most critical new elements of automated driving technology are high accuracy mapping (discussed in more detail in section 4.3.2.4) and prediction & decision algorithms, both being mainly software-based requiring specific sectoral expertise and large upfront investments in capital and development time. These software decision-making algorithms, run on Electronic Control Units and will be required to make sense of the myriad of data received from a vehicle's sensors. They will synthesise the environmental surrounding of a vehicle in real time and provide output to the driver or specify how the system should actively intervene in vehicle control. This will require some of the most complex in-car software integration ever created, and is an area which will need substantial work due to reputational risks faced by vehicle manufacturers because of safety aspects. By 2030, the market for this new software could reach $10-20 billion depending on business models applied. Within this sector, it is accepted that software and content providers could achieve the highest margins (technology companies with know-how in apps and operating systems e.g. Google, Apple Continental, Elektrobit, S1nn, Redneck).

Incumbent suppliers could face their biggest competitive challenge from software players outside the industry, such as consumer electronics companies, start-ups, and technology giants of today, as more and more of the additional functionalities (e.g. perception and localisation systems, decision algorithms etc.) provided by vehicles (and thereby revenue) becomes software driven.

Companies like Tesla, Google and Apple develop most of their core software themselves, but generally OEMs and Tier 1s have either outsourced large parts of their software developments or initiated acquisitions to bring in more talent, thereby increasing their software capabilities over the last decade. For example, Tier 1 supplier Continental purchased Elektrobit automotive and its 1,900 engineers for $680 million in June 2015 to meet demands of its OEM customers and currently has 11,000 professionals in the field of software development. Other examples include Bosch acquiring ProSyst (a company specialising in software and middleware), German auto parts maker ZF acquiring US based supplier TRW, and GM acquiring Cruise Automation to bring in-house ADAS capabilities as well as hiring more than 8,000 software developers itself.

As the entire industry moves through these transformational changes, more industry players will need to adapt their organisations, potentially to facilitate greater collaboration and to reflect that software is the key enabler for innovation and new business models. This will require strategic decisions regarding how to acquire the necessary expertise and whether this will be built up internally through hiring, through acquisitions, or outsourced to external vendors. Where in-house development is the chosen route, OEMs and Tier 1 suppliers will need to build up their skills for software development to match new competitors' capabilities and fulfil new requirements (e.g. cyber security, faster innovation cycles), complementing this with the capabilities of partners in a common ecosystem.

4.3.2.3 Connected: infotainment and cellular communications

As stated in section 4.3.2.2 the future of CAVs will not be dominated by hardware and mechanics only, but will also be driven by advances in software, including new features such as interconnection and car-centric communications. In 2014, 20% of all new car-buyers would have switched car brands for better connectivity features (McKinsey & Company, 2014), and this is set to increase; Indeed, global annual industry revenues from connectivity are expected to increase six-fold from approximately €30 billion in 2014 to €170-180 billion in 2030 (McKinsey & Company, 2014). By 2020, it is expected that 75% of all new cars will come with internet-connected infotainment systems (Drive West Midlands, 2016). Opportunities arise for a number of both traditional and non-traditional automotive supplier industries, including:

- Within CAV technology, the driver and passengers will interact with the vehicle's different systems, (primarily infotainment and connectivity features but increasingly autonomous systems such as ADAS) through the technology layer **Human Machine Interface** (HMI). This business is still dominated by traditional suppliers such as Continental and Visteon, for whom a significant opportunity exists with the further development of CAVs and infotainment. For example, Continental has an integrated, dedicated infotainment and connectivity business unit within its interior division, which fosters multiple external partnerships, for example with Google, IBM, and Cisco systems.
- Regarding **infotainment**, many OEMs and suppliers have developed their own proprietary branded systems (e.g. BMW IDrive, VW Discover, Audi Virtual Cockpit and Mercedes-Benz COMAND), drawing where necessary from external suppliers, including for dashboard units and the software that runs them, and enables them to interact with other devices in the car, such as smartphones. Tier 1 suppliers such as Harman, Continental, and Delphi are focusing on improving their development capabilities in this area, to maximise their prospects in this rapidly growing sector. For example, Harman made three critical strategic acquisitions, buying software companies S1nn, Sympothy Teleca, and Redbend, and *has obtained contracts from Daimler to provide next-generation telematics control units in Daimler cars.* However, a variety of new entrant software players, including giants like Apple, Google and Baidu, are trying to capture a share of the infotainment space; today most OEMs offer in-vehicle smart device mirroring systems such as Apple CarPlay and Android Auto and if these relationships are developed further, a clear threat exists to those Tier 1 suppliers who are not equipped to navigate this varied software ecosystem.
- Mobile radio devices will be key to enabling the development of connectivity on vehicles for telematics, safety and infotainment-related applications. A range of technologies are currently under being developed to meet these needs, both by traditional Tier 1 suppliers and new entrants. Traditional Tier 1 electrical and electronic system suppliers include Valeo which acquired Germany's Peiker in December 2015 to gain access to its on-board telematics and mobile connectivity technology in order to build secure high-speed connectivity solutions. Among the new entrants that are set to benefit are conglomerates Cisco Systems and NXP Semiconductors who banded together in 2013 to invest in Cohda wireless (wireless communications for automotive safety applications), as well as specialist suppliers such as Kymeta and Veniam. Beyond these existing market players, the next step in ensuring reliable and high-speed connectivity will be 5th generation mobile networks that can operate at rates 100 times faster than current LTE technology, working alongside other technologies such as 802.11p-based communications. These technologies will be an important contributor to ensuring real-time provision of information in rapidly changing situations. Already many new entrant telecom

players, including Vodafone, Huawai, Nokia, Ericsson, Qualcomm and NVIDIA, are showing a strong interest in the automotive sector, for example through sector associations such as the 5G Automotive Alliance (5GAA), and are looking to displace traditional Tier 1 suppliers from the sector. Clearly in this rapidly evolving space, there is a need for existing Tier 1 manufacturers to remain closely involved in developing new products and setting future connectivity standards, either through in-house product development or through partnerships and acquisitions.

- Finally, connected vehicles will increasingly communicate over mobile networks (LTE and in the future 5G) and will generate substantial growth in data transmissions (for safety, telematics and infotainment purposes) that will additionally benefit the telecommunications industry.

4.3.2.4 Mapping

In order for autonomous vehicles to operate safely, detailed mapping is critical for the vehicle's ability to understand and react to its surroundings, as well as to ensure it takes the fastest, most efficient routes without driver intervention. High accuracy real-time complete maps must be available to provide information for the environmental models that vehicles use for path and trajectory planning. These sophisticated navigation aids use high-quality granular map data and dynamic real-time geospatial information (for example for hazard warnings and traffic updates). Access to this granular map data will be a vital necessity to enable autonomous driving to happen.

OEMs and other players in the automotive industry are looking for low-cost methods to construct and maintain maps. Some of the most recent solutions include deploying 'mapping cars'; these vehicles are equipped with 3D lasers and 360º high definition cameras to help capture data and usage patterns on the roads, which can then be integrated into vehicles through methods such as vehicle data sharing. Map developers are leveraging data from sensors installed on commercial fleets, such as FedEx, as well as GPS data from drivers.

Nevertheless, due to the effort and investment required to maintain granular map data, this market is increasingly becoming an oligopoly with only three major players on a global scale (TomTom, HERE, and Google including its acquisition of Waze in 2013). It will be very hard for traditional Tier 1 suppliers or OEMs to compete with these providers and this may partially justify Audi, BMW and Mercedes' decision to acquire HERE maps from Nokia in 2015 for $3.1bn, in order to reduce their reliance on the likes of Google. Uber is another player that is in the process of reducing its dependence on Google maps and expanding efforts to build out maps and mapping data for its self-driving cars. It will gather the data through its mapping cars, which are already on the roads in many parts of the world. They have additionally purchased deCarta, a new entrant start-up supplier which specialises in location APIs, in-map searches and turn-by-turn navigation systems. The ability for Uber to produce this mapping data could be appealing to automakers, for example Mercedes Benz has announced it would deploy its autonomous vehicles through their fleet.

Going forward however and given its potential relevance for saving lives by enabling C-ITS and autonomous driving, governments might choose to encourage the map market to open up and enforce open access and the exchange of map data, including car-generated data gathered by OEMs.

4.3.2.5 Hardware

Today, the value for an average automobile is made up of 90% hardware components and 10% software components, however in the future hardware's value share could decrease significantly, with profits increasingly associated with software differentiation (ATKearney, 2016).

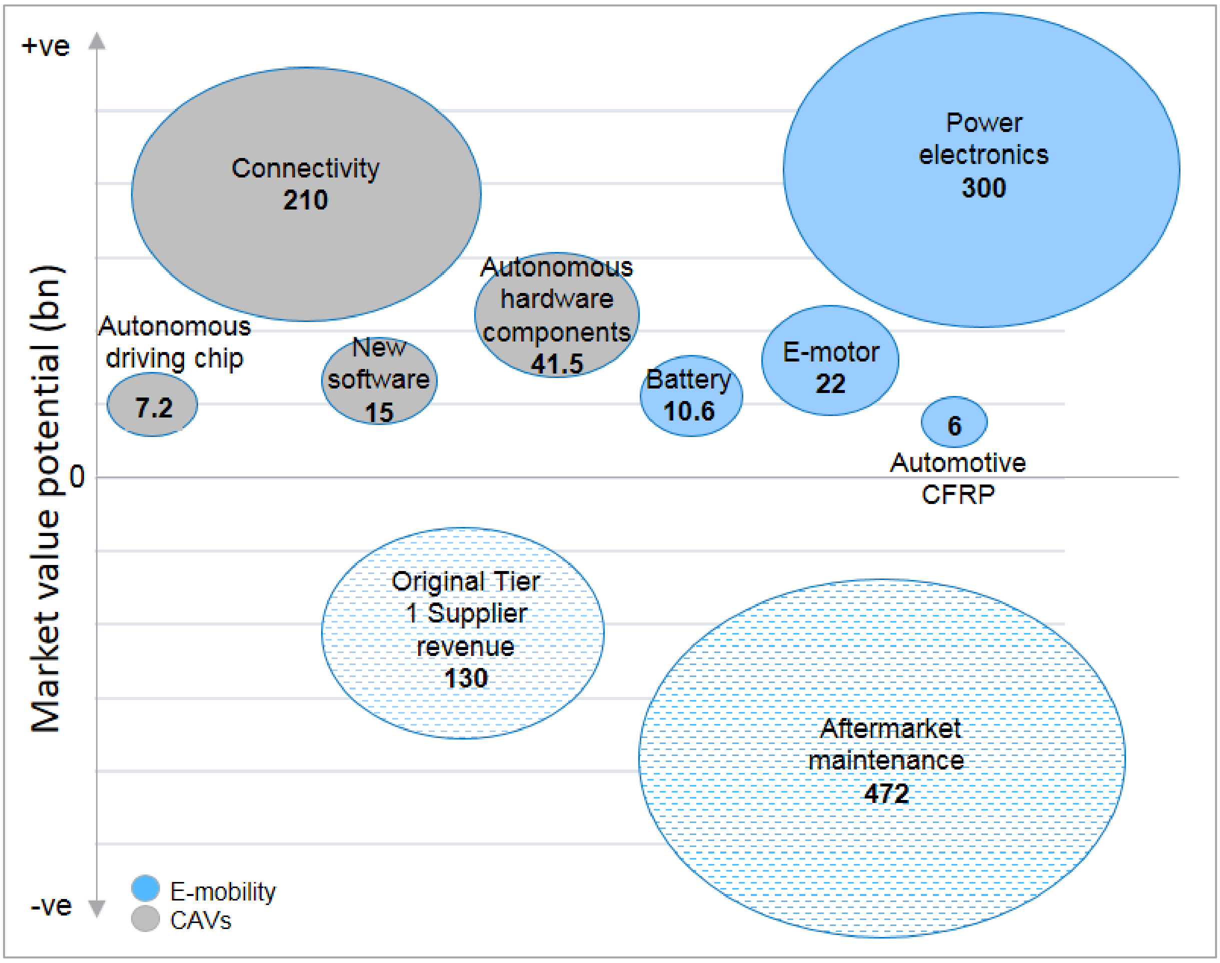
Nevertheless, the market for autonomous driving hardware components will grow, with equipment such as cameras, sensors, liDAR, actuators and communication systems, will (with the exception of "intelligent" cameras) most likely continuing to be provided by OEMs and a core group of Tier 1 suppliers. By 2030 it is estimated that the entire market for new components will be approximately $30-40 billion (Roland Berger , 2014). However, despite incumbent OEMs and Tier 1 suppliers continuing to dominate because of their sectorial expertise, it is likely that these products will become increasingly commoditised and that lower value shares may reduce profitability on these products.

To counter this trend, traditional Tier 1 electronics hardware component suppliers such as Valeo, Delphi, and Continental are trying to improve individual sensors as well as optimising system performance through better sensor fusion (the coherent combination of data from multiple sensors). Inter-sensor communication is a major challenge because it requires high bandwidth and solutions for preventing network overloads. For example, suppliers are gradually expanding their value chain coverage into ADAS/AD component development, thereby creating a new competitive threat from their own supply base: Valeo signed a technology cooperation agreement with Mobileye to develop front-facing camera systems and sensor fusion, whilst Delphi made a strategic investment in Quanergy to jointly develop a low-cost lidar system, and Continental acquired ASC's Hi-Res 3D Flash lidar business and its technology for using laser beams to measure distance to objects.

4.3.3 Overall conclusions on the impacts of e-mobility and CAV technologies on Tier 1 suppliers

It can be concluded from the analysis above that the trends towards increased prevalence of e-mobility and CAV technologies are poised to bring about significant opportunities to the traditional automotive Tier 1 supply industry if it is able to rapidly develop or acquire new capabilities, but severe risks are also presented to incumbent players who fail to adapt quickly enough. Figure 4.50 below illustrates and summarises the expected benefits and risks generated by both trends, as described in the analysis in this section.

Figure 4.50: Market value potential (US$ bn) for e-mobility and CAV technologies between 2020 and 2030



When taking into account the main components described in the analysis and displayed in Figure 4.50, the new market potential for e-mobility could create opportunities worth up to $339bn, and for CAVs $273bn between 2020 and 2030[18].

Nevertheless, in the absence of efforts from traditional Tier 1 suppliers to adapt to the changes at hand, the market could be re-defined by new and non-traditional suppliers (e.g. electronics, software giants and telecoms companies) which could gain a significant portion of the market and generate high-value business, to the detriment of traditional Tier 1 suppliers. Indeed, with a higher share of electronics required for EVs and CAV technologies, it is anticipated that non-automotive electronics companies could supply up to 87% value of an EV powertrain in a worst-case scenario, becoming a central player in the automotive industry to the detriment of conventional Tier 1 suppliers which are affected by the decreased mechanical complexity within the powertrain requiring fewer parts, of which many will be non-traditional. As a result, Tier 1 suppliers could see their revenue drop by $130 bn between 2020 and 2030. Similarly, the aftermarket maintenance industry could see revenues drop by over $470 bn due to the reduced complexity and improved reliability of xEVs.

This new paradigm highlights an opportunity (and to some extent a necessity) for partnerships and M&As between traditional Tier 1 suppliers and new entrant players (e.g. electronics, software companies). This will be especially important for Tier 1 suppliers and OEMs in order to counter any value shifts from hardware to software capability, or from traditional drivetrain components to electric drivetrains.

For the aftermarket sector, the tyre industry is likely to benefit from these disruptive technologies in the shorter-term but dealerships and spare parts suppliers in particular are expected to suffer and have their revenue pool drop by up to 60%.

[18] Note that the relatively simple method used to estimate the various market impacts may result in there being some overlap between these figures. Other opportunities also exist which may not be accounted for here.

5 ANALYSIS OF THE L-CATEGORY MARKET

5.1 Introduction

This section presents our analysis related to L-category vehicles as part of this study. In the absence of robust quantitative data on the cost and material breakdown for different L-category vehicles, this section provides a qualitative assessment of the impacts of the various market, regulatory and technology trends observed in different markets on the competitiveness of the EU automotive industry. The main conclusions from the L-category analysis are then summarised in Section 6.1 below.

5.2 Scope

The scope of the analysis covers light two-wheel powered vehicles, two-wheel motorcycles and light/heavy quadricycles in the EU and the five other countries of interest to the study (US, Japan, South Korea, China and India), up to 2050. Note that in the EU there are several sub-categories of vehicle in the L-Category segment. These are shown in Table 5.1 below, with those corresponding to the scope of the study highlighted in bold. Whilst the scope of the analysis below is broadly restricted to these categories, there is some overlap with adjacent categories and these are discussed at the relevant points in the report.

Table 5.1: EU definitions of L-category vehicles

Category	Definition
L1e-A Powered Cycles	Pedals; Power up to 1,000w (electric or combustion); Power assist cut-off over 25km/h; May have 2, 3 or 4 wheels.
L1e-B Mopeds	**Maximum power up to 4kW; Maximum speed up to 45km/h.**
L2e Mopeds with three wheels	Mass less than or equal to 270kg; 1 or 2 seats.
L3e Motorcycles	**L3e-A1: Less than or equal to 11kW power; Power-weight ratio of less than or equal to 0.1kW/kg.** **L3e-A2: Less than or equal to 35kW power; Power-weight ratio of less than or equal to 0.2kW/kg.** **L3e-A3. More than 35kW power**
L4e Motorcycles with side-cars	
L5e Tricycles	Mass greater than or equal to 1,000kg; Maximum 5 seats. L5e-A passenger vehicles; L5e-B commercial goods vehicles.
L6e A. Four wheels. A vehicle with four wheels whose unladen mass is not more than 350 kg, not including the mass of the batteries in case of BEV's, whose maximum design speed is not more than 45 km/h, and whose power does not exceed 4 kW.	Light quadricycles: maximum design speed ≤ 45km/h; mass in running order ≤ 425kg; engine capacity ≤ 50 cm3 if a PI engine or engine capacity ≤ 500 cm3 if a CI engine; maximum of two seating positions. Light quadricycle with power less than or equal to 4kW.

Category	Definition
L6e B. Four wheels	**Light quadricycle mobility. Enclosed passenger compartment; Power less than or equal to 6kW; Two sub-categories: passenger and goods.**
L7e-A. Four wheels. Other than that classified for the category L6, whose unladen mass is not more than 450 kg (650 kg for those intended to carrying goods), not including the mass of batteries in the case of BEV's, whose power does not exceed 15 kW.	Heavy on-road quadricycle: Two sub-categories: A1. Maximum two straddle seats and handlebar steering; A2. Maximum two non-straddle seats.
L7e-B1. Four wheels	Heavy all-terrain quadricycle. Maximum two straddle seats and handlebar steering; maximum design speed ≤ 90km/h; wheelbase to ground clearance ratio ≤ 6.
L7e-B2. Four wheels	Maximum three non-straddle seats; maximum power ≤ 15 kW; wheelbase to ground clearance ratio ≤ 8.
L7e-C. Four wheels	Maximum power ≤ 15 kW; maximum design speed ≤ 90km/h; enclosed passenger compartment. Two sub-categories: CP. Maximum four non-straddle seats; CU. Maximum two non-straddle seats plus load area criteria.

Note that the above definitions exclude:

- EAPC (Electric Assisted Pedal Cycle): Electric assist, power ≤ 250W (UK 200W). Pedals power cuts of when speed exceeds 25km/h.
- Self-balancing vehicles e.g. Segway
- Electric two wheel scooters with no seats
- Mobility aids for the physically handicapped with maximum speed less than or equal to 6km/h.

5.2.1 Electric bicycles

Low-speed electric bicycles do not require Type Approval. For this reason, electric bicycles are excluded as a formal focus area for the analysis. Electric bicycles come in a number of forms, including:

- Pedelecs, which is a European term that means a bicycle with an electric motor that only functions on condition the cyclist pedals (i.e. an EAPC),
- E-bikes, which are bicycles with a motor that functions by turning the throttle, so irrespective of the cyclist pedalling: an e-bike can have pedals as well, but the human and the electric sources of power are not linked.

The term EAPC, electric bicycle or e-bike is therefore generic and includes pedelecs, e-bikes and combinations of these types. High-speed electric bicycles (S-pedelecs) can attain 45km/h using a more powerful motor, and these are classed as mopeds requiring type approval.

Whilst not formally in scope, the report does discuss EAPCs for two main reasons. First, in some markets there is evidence that the use of these vehicles has occurred as a substitute to existing internal combustion engine motorcycles, mopeds or scooters (which are in scope). This is particularly relevant to the case in China.

Second, there is not necessarily regulatory consistency around the world with respect to electric powered two-wheel modes of transport, an issue that also applies to the L-Category segment as a whole. In the US, for example, a 'Neighbourhood Electric Vehicle' (NEV) is defined as having four wheels, electric propulsion, and within one mile (1.6km) can reach a speed of more than 20 miles per hour (mph) (32km/h) but not more than 25 mph (40km/h) on a paved level surface. It must have a 17-digit conforming vehicle identification number (VIN) and a gross vehicle weight rating (GVWR) of less than 3,000 pounds (1,360kg). It must be certified to meet Federal Motor Vehicle Safety Standards (FMVSS) to be registered and operated on public streets, roads, or highways. A 'Low-Speed Vehicle' is similar to an NEV, but with an internal combustion engine. In the case of China the 'Low Speed Electric Vehicle' has essentially emerged in a policy and regulatory vacuum. At the end of 2016 it was reported that China was considering regulation, because up to this point electric vehicles with a speed of less than 100km/h had no rules governing production and use. Primarily found in rural and lower-tier urban markets, these vehicles could also be uninsured, below desired safety performance standards, and the drivers might lack qualifications.

These instances illustrate that not only are there regulatory differences in L-Category definitions around the world, but also that the situation is quite dynamic as the technologies, the market and the nature of regulation co-evolve.

5.2.2 Scooters

The precise categorisation of scooters can also be difficult, and this is an issue that is not necessarily treated consistently by different data sources or regulatory definitions around the world. Broadly, scooters, also referred to as mopeds, are powered two-wheelers with a 'step-through' frame, and stylistically they tend to have smaller wheels than most motorcycles, along with a front fairing to protect the rider. They generally fall under the L1e-B EU classification, which falls in the scope of this study. Electric scooters/mopeds have the same design format as those with internal combustion engines and therefore the same Type Approval requirements.

5.3 Descriptive and quantitative analysis of market trends

To understand the future competitiveness of EU L-category vehicle manufacturers, it is important to assess current and future market trends in terms of production and sales of vehicles. By providing an understanding of the size of the EU market and the markets of current and future competitors, the analysis demonstrates the potential market opportunity which EU manufacturers can capture if they are successful in reinforcing their competitive position in those markets.

The analysis covers trends in production and sales of L-category vehicles (including light two-wheel powered vehicles, two-wheel motorcycles and light/heavy quadricycles) for the EU and the five other countries of interest to the study (US, Japan, South Korea, China and India) up to 2050. The following sections describe the data collection exercise to assess current trends in production and sales of powered two-wheelers as well as the methodology followed to produce forecast up to 2050. An analysis of the results is provided. Regarding quadricycles, only a qualitative analysis could be undertaken due to the lack of data.

5.3.1 Data sources and methodology

Data was only available for powered two-wheeler production, as well as new registrations data. Data were provided by IMMA (the International Motorcycle Manufacturers Association), for all the markets considered (except South Korea) between 2005 and 2015. It is worth noting that the powered two-wheelers data provided does not include any of the e-bike types described above. Although these vehicles are outside the scope of this study, there is some considerable overlap between the definitions of e-bikes as a whole, and of electric scooters. Electric scooters are often allocated to the e-bike segment in various data sources, but in effect may constitute a light powered two-wheel vehicle. In China, e-bikes are classified as bicycles if they weigh less than 40 kg and reach a maximum speed of 20 km/h (Weiss, et al., 2015) . This implies that light and low-power electric scooters, which may be classified as mopeds in other countries, may be considered a bicycle in China and hence may not be included in the data. Light electric two-wheel vehicles with a speed of between 20 km/h and 50 km/h, and weighing more than 40 kg, are classified as a scooter/moped, or motorcycle. To provide a more comprehensive analysis, the share of all types of e-bike which corresponds to electric scooters were added subsequently by the consultancy team to the production and sales data for China and India. This will be particularly relevant to identify the impact of increased use of electrified two-wheelers on more traditional internal combustion engines (ICE) two-wheelers.

Projections to 2050 were based on an extrapolation of the historical trend and assumed that growth will be flat in all markets from 2030. Estimates for the Indian market (for 2020 for production and 2026 for sales) were based on a report by the Indian Brand Equity Foundation (IBEF, 2016). For the remaining (more developed) markets, growth rates were assumed to smoothly converge to 0% in 2030 based on the historical trend. Insights from stakeholders helped to refine the analysis and validate the growth assumptions in future periods.

5.3.2 Overview of market trends

The market for L-category vehicles is very specific to the country in question. In general terms, in developed countries, L-category vehicles are being increasingly used for sports, leisure and recreation purposes, but there is also a strong and growing use of scooter-type vehicles for mobility purposes. In developing countries these vehicles are often used as a functional mode of transport.

The extent to which L-category vehicles compete with or are supplemental to other vehicles classes and transport modes also varies widely by country. There are many types of 'non-car' mobility solutions that are country-specific, and which have varying degrees of overlap with the formal EU definitions applied to L-category vehicles. In turn, this means the extent to which other countries outside the EU offer market potential or indeed a competitive threat to the EU L-category segment also varies. On the other hand, the rise of e-bikes, although in many instances not included in the L-category class, can substitute in part the use of L-category vehicles. The extent to which e-bikes in general, and EAPC (pedelecs) in particular substitute for traditional pedal cycles is unknown, but may be growing in significance, particularly for short-range commuting. Similarly, the extent to which e-bikes substitute for other L-Category vehicles is also unknown, but in the EU at least it appears to be of limited significance thus far. In other markets, notably in Asia (e.g. India, China, etc), e-bikes are already becoming a significant modal choice, eroding the market share of traditional motorised scooters/mopeds in particular.

The following sections discuss these particularities of the L-category vehicle market and provide an analysis of the production and sales trends in the different markets.

5.3.2.1 The use of L-category vehicles for functional and/or leisure purposes

An important general distinction between markets is the use of L-category vehicles for functional and/or leisure purposes. In broad terms, L-category vehicles (however defined) in developing markets are primarily seen as a means of transport or as functional mobility. For example light two-wheelers are seen as offering the required mobility in cities that are rapidly expanding in spatial extent, and doing so at reasonable cost compared with average incomes. This observation also applies to electric bicycles in China, and to auto rickshaws in India. In India it is reported that one in every three households have a two-wheeled means of transport, and that even a majority of car owners prefer to use a powered two-wheelers for commuting, a reflection of the difficulties of congestion on roads in the country. Only 5% of households own a car (livemint, 2016). Thus 33% of Indians use a powered two-wheeler to commute to work, while a further 31% use bicycles.

In the EU, Japan and the US the role of light two-wheeler L-category vehicles for transport is less important than in developing countries, with notable exceptions such as Italy, Spain and Greece where L-category vehicles are traditionally used for commuting. However the use of scooters has been growing in importance in the EU (again more strongly in Southern European countries). Stakeholders have indicated that this trend is particularly noticeable in large urban centres, where high levels of congestion foster the use of motorcycles and scooters as alternative to cars. In addition, Low Emission Zones (LEZ) in place in major cities tend to exempt L-category vehicles, giving these vehicles another advantage over cars in the urban context. Whilst most models are not formally L-category vehicles, it is worth noting that the rate at which electric bicycles are being adopted in some EU markets (for example the Netherlands, Germany, Sweden and Denmark) is growing and this also demonstrates the growth in the use of two-wheelers as a transport mode. Indeed the EU concept of the 'pedelec' is increasingly being adopted as a commuter vehicle and for other activities such as shopping.

Two-wheel motorised L-category vehicles have a distinct cultural or lifestyle component in the EU and US, related to their use in leisure and sport. An example is the 'born again' biker - typically over 50 years old and returning to motorcycle use after many years (see e.g. (CEBR, 2015)). A recent phenomenon that illustrates this point regarding lifestyle and image is the emergence of the so-called 'adventure' category of motorcycle and the decline of the 'easy rider' image most closely associated with Harley Davidson motorcycles ((The Guardian, 2015); (Dagord, 2015)).

The lifestyle and cultural component of two-wheel motorised L-category vehicles / motorcycles also to some degree reflects developments in the car market, again led by the EU and US, towards the establishment of 'experience centres' where owners can use their vehicles to the maximum of their potential (e.g. Land Rover) and the growth of track day events for owners by specific brands. Indeed, some products such as the Morgan 3 Wheeler appear almost entirely intended for track day racing, despite being road-legal. Hence in the powered two-wheeler market, including that for electric bicycles, there is increasing development of products suited for long-distance touring, racing, and off-road sports applications. Whether the products are actually used in these applications is a different matter, but consumers are buying into the lifestyle and image, not necessarily the reality. Motorcycles are used for everyday transport in the developed economies, but the high value products tend to be in these applications. It is indicative that in Japan the average age of new-model purchasers in 2015 was 52.9, up 1.5 years from the previous survey (in fiscal year 2013), and that functional transport needs such as commuting was the primary reason for purchase for only half of all purchasers (JAMA, 2016) . Hence these mature markets continue to sustain a relatively high rate of technology development and associated price premiums, which is useful to the continued strength of the existing industry in the EU, and to some degree acts as a barrier to low-cost market entry.

5.3.2.2 The impact of e-bikes in the L-category vehicle market

Although bicycles are outside the scope of this study, it is worth reflecting on their impact on the L-category vehicle market. In particular, outside of the EU, e-bikes are increasingly substituting some mopeds and other L-category vehicles in their use for transport in the urban context. It should be emphasised that there is a great diversity of designs under the general heading of e-bikes or electric-powered two-wheelers. This diversity of design solutions around the world makes consistent and stable classification impossible. Moreover, while regulations and legal definitions may or may not appear to place some e-bike categories as directly analogous to existing L-Category vehicles, it is not just those specific e-bike categories that may be used as substitutes by consumers in the market. In other words, consumers may be making choices over the use of a low-speed pedelec versus a traditional motorbike or ICE scooter, even though the latter are much more powerful, faster and with longer range. This is already the case in China where the ban on ICE two-wheelers in some cities is driving the growth in the e-bike market (Institute for Transportation & Development Policy and the University of California, Davis., 2015). This study considers the case in their 'high shift' cycling scenario where e-bikes replace in part gasoline-powered two-wheel scooters and motorcycles in China.

In the EU the substitution effect of e-bikes in general, and of pedelecs in particular, appears to be more limited. Nevertheless, in China motorcycle output has fallen significantly since 2009 and there has been a dramatic rise in electric bicycle sales to over 35 million units per annum, and with an established parc of about 200 million. Prices in China for e-bikes are typically under €300, the technologies are often simple (for example sealed lead acid batteries), and models are designed for urban use. It is also worth noting however that some Chinese cities are already restricting or banning the use of e-bikes due to safety concerns (Forbes, 2016) , targeting mainly these low cost options.

In the EU, the impact of e-bikes is anticipated to be limited. In short-range applications there may be substitution with traditional bicycles, or perhaps with public transport services such as trams or buses. In the medium range applications such as commuting there is some scope to impact on the traditional powered two-wheeler market, but that scope is limited by the range and speed of e-bikes in general and of pedelecs in particular (although electric scooters/mopeds may be a more likely substitute here in the future). In reality there is much debate over the question of whether e-bikes are an additional or supplementary mode, or in some senses competing with public transport, cars or L-category vehicles. Much depends upon context. In the case of China, which has the greatest experience of e-bikes, the emergence of the sector can be attributed to a combination of government actions (such as banning ICE motorcycles from urban areas), network issues (congestion, weak public transport) and economic changes (growing income). Nevertheless, the banning of some e-bikes on safety concerns and the continued increase in purchasing power of the population may result in e-bikes being a temporary transport mode on a pathway to car ownership. China now comprises over 90% of global production and sales of e-bikes (Wells & Lin, 2015). With domestic demand likely to flatten in future years and future regulatory controls likely, producers are likely to look increasingly to export markets including the EU.

In the EU, local government authorities are trying to encourage bicycle use in general – including e-bike use. The high-end applications have been leading the growth of electric bicycles in the EU and US, but as the market expands, so more opportunities are emerging for low-cost electric bikes – the majority of which are likely to come from China. Some Chinese brands are already present (e.g. Giant), while other Chinese manufacturers supply established EU or US brands. In the EU, the expectation is that by 2020, 30% of the market for bikes will be electric (Bosch, 2016). The Accell Group from the Netherlands is the leading European producer of e-bikes, but again large numbers are expected to come from China. The US mostly imports e-bikes from China or Taiwan. Japan is expected to increase imports of e-bikes from China

In contrast to China however, an EU pedelec for commuting and leisure purposes can typically command prices of €2,000 and employ lithium-ion batteries along with sophisticated power management systems. High-performance sports e-bikes may have retail prices up to €15,000, whilst a range of EU-manufactured e-bikes use features such as carbon-fibre frames and frame-integrated battery packs. This illustrates the quite different offerings in the EU compared to developing markets and the potential difficulty that both EU manufacturers may have competing in markets like China and vice-versa.

With regards to India, the study by the University of California, Davis (2015) highlights that e-bikes are not expected to compete with gasoline two-wheelers in the case of the Indian market, unless there are policy changes aimed at this.

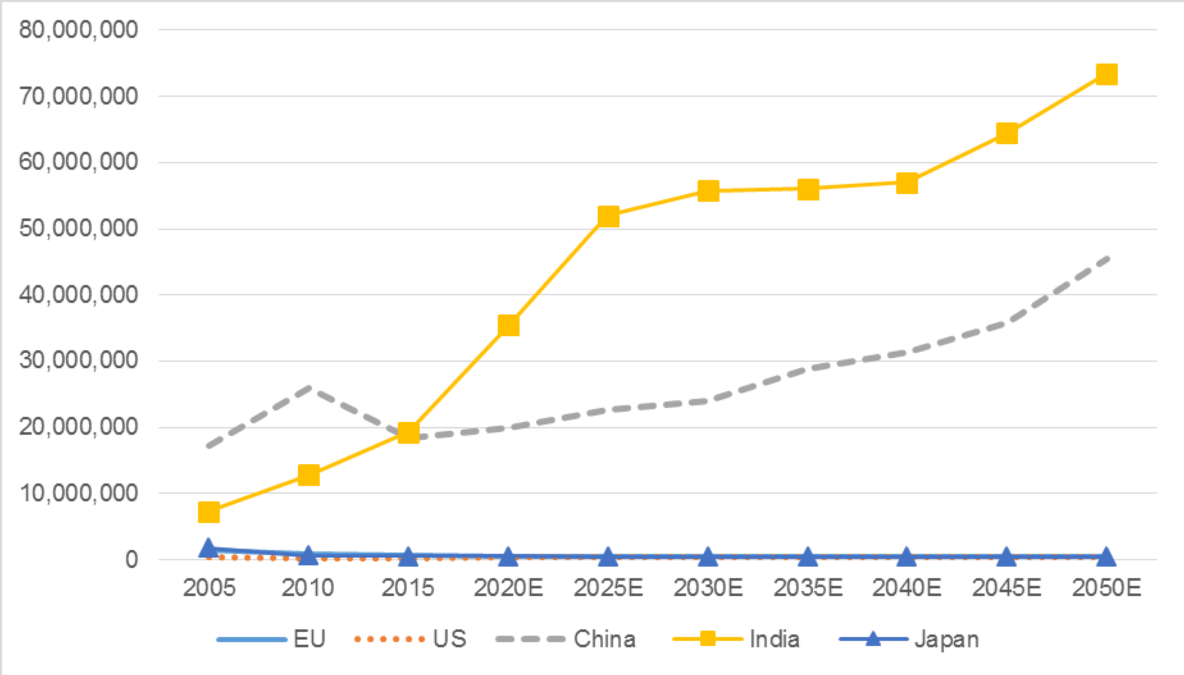
Overall therefore, whilst bicycles are outside the scope of this study, there is a share of the e-bike market which can be classified as light powered two-wheelers, as is the case of electric scooters in China. It is expected that electric scooters will remain a modest element of the total e-bike market in the range 5-10%. Advances in Li-ion batteries and continued cost reductions could make the electric scooter segment more attractive as a means to exploit the greater acceleration, top speed and range that more advanced batteries will offer. However, electric scooters are substantially more expensive than e-bikes. Growth in market penetration for electric traction on two-wheel machines is expected in general to be faster than that for cars, chiefly because the power-to-weight ratio is more attractive in the two-wheel applications, whilst range expectations tend to be significantly lower for these vehicles. Trends will, however, vary by country or region in their impact and significance.

In the case of China it is expected that the total e-bike segment will continue to grow, albeit at a slower than historic rate up to 2020. Renewed growth from 2025 to 2035 is dependent upon three main factors: continued growth in GDP per capita; further rural-urban drift; and a benign regulatory environment. Thereafter growth in e-bike production and sales is expected to fall as a consequence of the growth in traditional and low-speed electric cars, and continued per-capita GDP growth. In India, fewer e-bikes are expected to be produced and sold in the country compared to China as the higher-income households that own a means of transport tend to own a car or a two-wheeler and the regulatory environment is less supportive. Traditional bicycles are more prevalent among the less wealthy households but still not widespread (livemint, 2016). Within the electric two wheeler category, a greater proportion of electric scooters is expected in India when compared with China.

The particular features of the market discussed above have an impact on the production and sales of L-category vehicles, which will be discussed in more detail below.

5.3.2.3 Powered two-wheelers production

Figure 5.1 - Production of Powered Two-Wheelers in Key Markets, 2005-2050



E - Estimate

Source: IMMA data (2005-2015)[19] *and internal analysis*

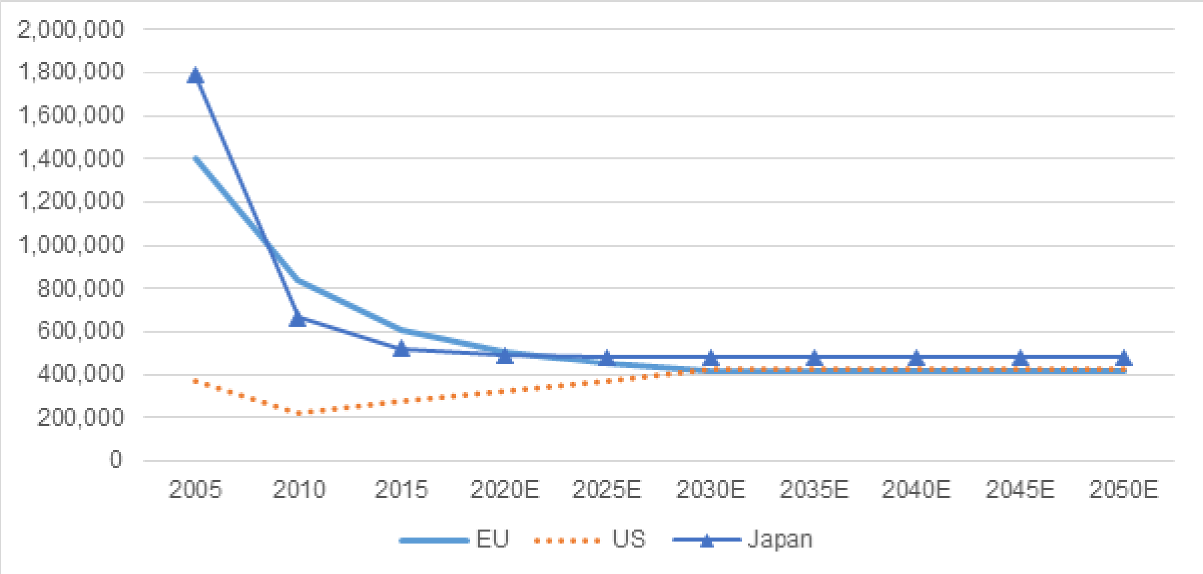
Production of powered two-wheelers (covering both light and heavier powered two-wheelers) in the referenced countries was 28 million in 2005 and increased to 39 million in 2015, as Figure 5.1 illustrates. It is worth noting that the production volume was augmented with data on e-bikes classified as light powered two-wheelers, i.e. electric scooters/mopeds. China was the largest producer of powered two-wheelers in 2005 with 17 million vehicles produced. Its production volume increased until 2010 and then declined in 2015, which is likely motivated by the bans on ICE two-wheelers in some cities which have reduced domestic demand for these vehicles, as discussed above. India became the largest producer of powered two-wheelers in 2015 with 19 million units produced. This upward trend in India reflects the increasing purchasing power of the population as well as a rise in population. This upward trend is likely to slow beyond 2020 as regulations tighten in a similar way as they already have in China with the banning of ICE vehicles from city centres.

In future years, production is expected to increase significantly in India, first to 2025 driven by the continued increase in population and purchasing power in the country, following the historical trend. The market is then expected to slow down, as a result of India following a similar path to China in terms of its national and local electrification strategies. For example, in the past India has enacted urban policy measures in order to redress environmental concerns. Most notable was the decision to pursue the use of CNG in buses and auto rickshaws in the major metropolitan areas in 2001; as of 2017 there is a push to

[19] China and India's data have been augmented with data on the share of e-bikes that correspond to electric scooters; further information on methodology is provided in section 5.3.1

remove diesel taxis as air quality continues to deteriorate in cities such as Delhi. There is likely to be a relatively stable period between 2030 and 2040 when the decrease in production of ICE two-wheelers is expected to be offset by the increase in production of electric scooters. After 2030, growth in India is expected to accelerate, reaching 73 million units produced in 2050, as the price of electric scooters is anticipated to fall compared to ICE two-wheelers and thereby foster demand for these vehicles in India. China is anticipated to remain the second largest producer out to 2050 and its production is expected to grow steadily due to the increase in use of electric scooters in substitution of the ICE two-wheelers banned in urban centres as well as the modest increase in population.

Figure 5.2 - Production of Powered Two-Wheelers in Developed Markets, 2005-2050



E – Estimate

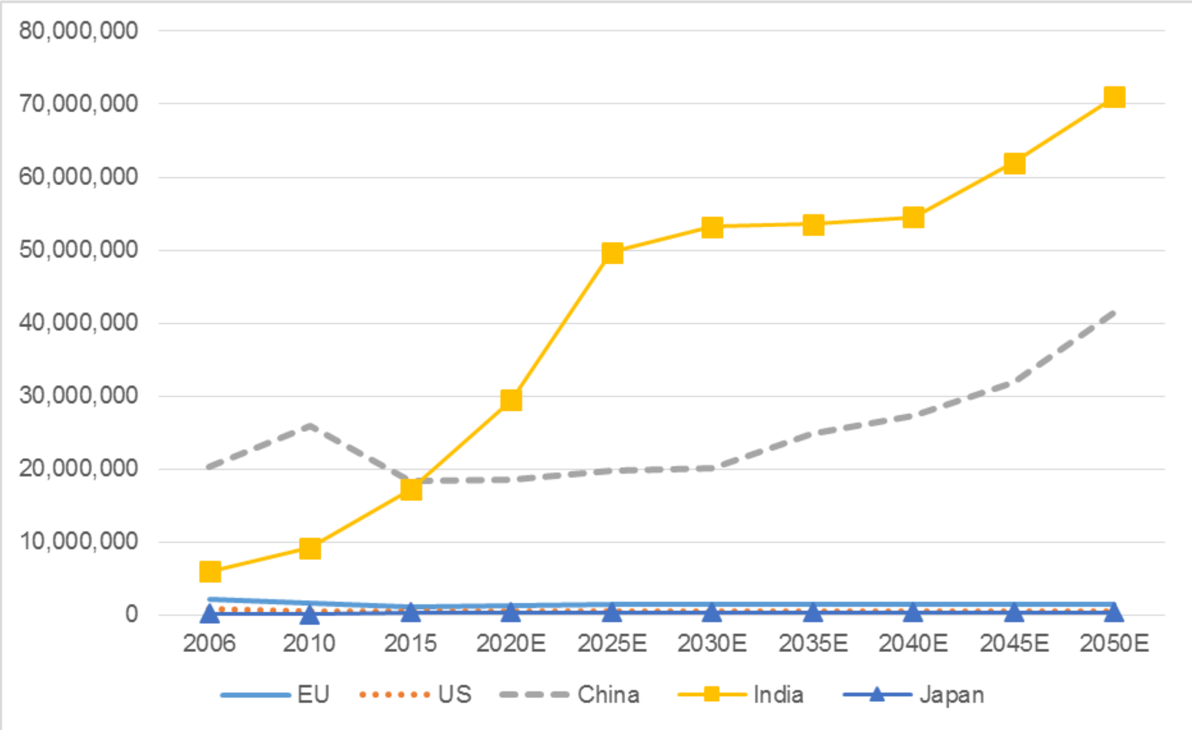
Source: IMMA data (2005-2015) and internal analysis

Figure 5.2 provides a clearer picture of the relative contribution of developed countries to the total production of powered two-wheelers. In Japan, there was a sharp decline in production from 2005 until 2015, dropping below EU production levels in 2010. In particular, motorcycle production in Japan has declined substantially over recent years, chiefly as a consequence of locating production in core markets in Asia, India and elsewhere. Production in the EU also decreased substantially between 2005 and 2015. The downward trend in the EU can be explained by the economic crisis which decreased demand for these vehicles, whilst the persistent economic problems in Southern European countries means that demand has not picked up again. Production in the US decreased in 2010, probably associated with the financial crisis, but recovered in 2015, reaching 276,000 units produced.

Japan and the EU will likely observe further decreases in production, due to offshoring of production for external markets, as well as reduced population in the case of Japan. After 2030, production in the two markets is expected to remain largely flat. In the US, production is anticipated to recover after the 2008/09 financial crisis and reach its 2005 level, after which it is likely to remain constant as L-category vehicles continue to be used for leisure purposes. It is worth noting that South Korea is missing from this analysis due to lack of data. This could be associated with the ban on larger motorcycles on motorways in this country which may have a strong negative impact on demand.

5.3.2.4 Powered two-wheelers sales

Figure 5.3 - Sales of Powered Two-Wheelers in Key Markets, 2006-2050



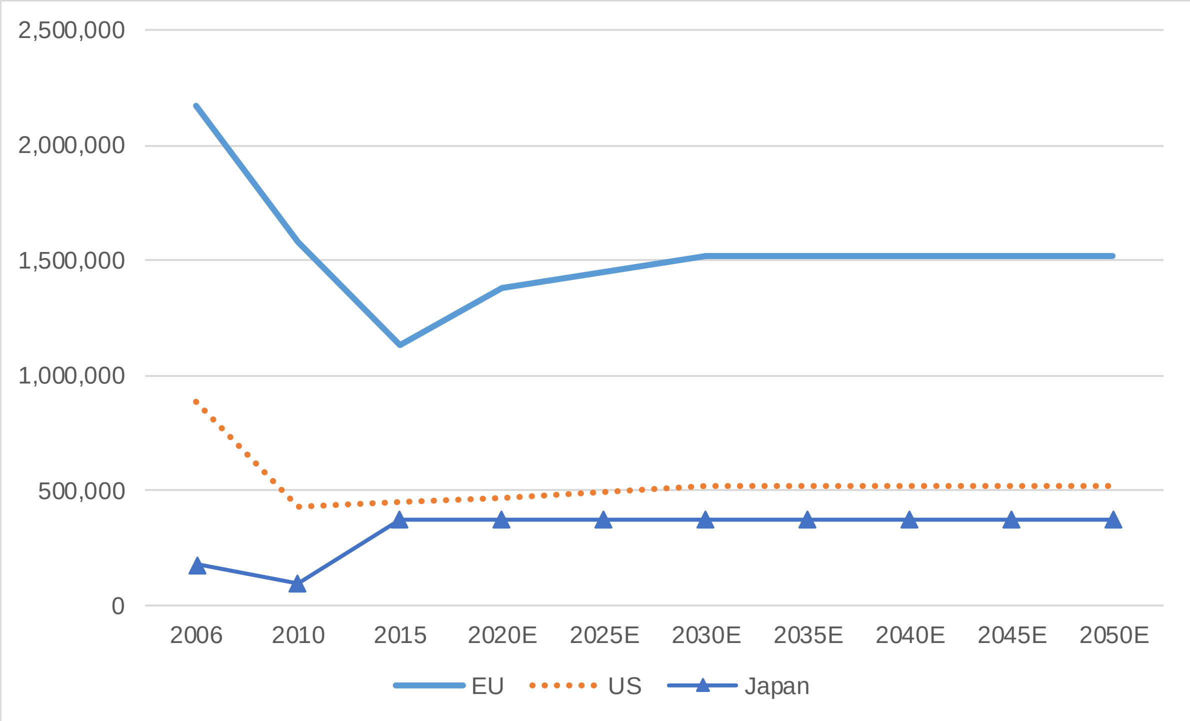
E – Estimate

Source: IMMA data (2006-2015)[20] *for all countries except the US, US data (2006 – 2015) from MIC* (revzilla, 2015) *and internal analysis*

Sales follow a similar trend to production for most countries as Figure 5.3 shows. Total sales also increased between 2006 and 2015. China is the largest market in this period followed by India, whose sales increased significantly and caught up with China by 2015, which is likely to be driven by the same factors and trends discussed in the production analysis above (Figure 5.1). The developed economies show a substantially lower level of sales. A clearer picture of the market trends in these economies is provided in Figure 5.4.

[20] China and India's data have been augmented with data on the share of e-bikes that correspond to electric scooters; further information on methodology is provided in section 5.3.

Figure 5.4 - Sales of Powered Two-Wheelers in Developed Markets, 2006-2050



E – Estimate

Source: IMMA data (2006-2015) and internal analysis

As in the case of production, sales in the EU declined between 2006 and 2015. The US trend also shows the dip in sales in 2010 which accounts for the financial crisis but sales increased to 2015. Sales in Japan, on the other hand, do not follow production. Sales decreased slightly between 2006 and 2010, and then between 2010 and 2015 increased to a level higher than achieved in 2006. The difference between the trends in production and sales in Japan could be explained by the fact that production in Japan is mostly destined for export and therefore fluctuations in sales have little impact on the production trend. The latter is more likely explained by the move towards more localised production in formerly export markets, as well as the decrease in demand from foreign markets, including the ones represented here.

In the future, India is expected to become the largest market for powered two-wheelers, overtaking China, following the same trends as for production. Sales of two-wheelers in China are anticipated to continue to increase steadily as ICE two-wheelers are banned from cities and substituted by electric scooters. It is worth noting that the gap between production and sales in China is expected to increase after 2015, which could be explained by an increase in exports of Chinese production.

With no significant benefits expected from population or purchasing power increases as in China and India, sales in the EU are expected to recover slowly after the crisis to 1.5 million units in 2030, reaching the pre-crisis volumes supported by growth in e-bikes and other new urban vehicle concepts in the future. After 2030 they are assumed to remain flat as the market reaches maturity, however innovative mobility concepts in the L-category segment could provide upside opportunities in the future. Sales in the US are only expected to increase marginally until 2030 and remain at a constant level up to 2050. Japan has a volatile historical trend and thus future sales are expected to remain constant throughout the period considered.

5.3.2.5 Quadricycle Market

Qualitative analysis of the quadricycle market was undertaken since data on production and sales of quadricycles is limited and due to the heterogeneity of international markets.

The countries analysed provide distinct solutions for this sub-category (Nieuwenhuis, 2016), (Santucci, et al., 2016). In the EU, quadricycles are mainly present in France and to some extent in Italy and Spain. In France, these vehicles are known as VSP (Voitures Sans Permis). The main producers in the country include Aixam-Mega, Ligier, Chatenet and Bellier. In France the VSP has traditionally been associated with rural applications, and used by the very young, the elderly, or those that for some reason have lost their licence. The market has declined significantly, in part because of the high relative cost of VSPs compared with mainstream small M-category cars. It is also important to make a distinction between passenger and freight quadricycles; in the EU, Piaggio produces heavy quadricycles for delivery of goods, i.e. for last-mile delivery.

The US has a specific category of quadricycles classified as US Neighbourhood Electric Vehicle (US NEV) which is the closest to the EU L-category definition, but these are very much positioned as vehicles for applications away from normal roads (e.g. university campuses; holiday or retirement complexes, golf courses, etc). NEVs include any four-wheeled electric vehicle with a gross vehicle weight rating of less than 3,000 lbs (1,361 kg). The vehicle must have a speed limit of 25 mph (40 km/h) (U.S. Department of Transportation, 2012).

In Japan the kei class of mini-cars has traditionally occupied a market space that is below typical M-category vehicles, but larger than L-category. The kei class definition (determined by physical external dimensions, vehicle weight and engine size) has been enlarged over time, in part to allow Japanese vehicle manufacturers to export into other markets. The prospect of further downsizing this class to allow for lightweight and small urban electric vehicles has been explored via prototypes. While this sub-category of kei cars does not yet have regulatory status, it was a defined area of interest from around 2013 onwards, with several manufacturers developing prototypes to run in urban niche experimental settings. One interesting example is the Toyota i-road[21]. This is a concept with three-wheels (two at the front), electric power, and 35mph top speed along with 30 mile range, whilst only being 870 mm wide. Such vehicles might constitute a threat to the current EU quadricycle L-category segment in the future, although a major foreign OEM entering the quadricycle market in the EU at volume in the future could also present an opportunity for EU manufacturers to enter an expanded quadricycle market. Note that the Japanese government had recently introduced legislation that is expected to negatively impact the sales of kei class vehicles and could thus contribute to the end of this niche category (TTAC, 2017) (New York Times, 2014). This is likely to be driven by the government's intent to encourage Japanese OEMs to produce cars that are more widely accepted and can therefore be sold to a global audience. This could also significantly affect the development a smaller kei class vehicle.

A further potential threat to the EU quadricycle market is presented by a concept introduced by Nissan and the City of Yokohama in 2017: a round-trip car sharing service featuring the Nissan New Mobility Concept, an ultra-compact electric vehicle derived from the Renault Twizy. This type of vehicle is being developed into a recognised New Mobility vehicle class, with a power output below 8kW, carrying up to 2 passengers and maximum speed of 30 km/h (Japan's Ministry of Land, Infrastructure, Transport and Tourism, 2012), and could be a direct threat to the equivalent vehicle class in the EU.

China has an important segment of low-speed electric vehicles (LSEVs) which are similar to the US's NEVs (autoblog, 2014), (Quartz, 2017). They consist of low-speed (max 70 km/h), short-range and small-size electric passenger vehicles, using basic battery (usually lead-acid) and electric motor technologies. This segment has emerged over the last decade or so entirely informally, and in distinct contrast to the officially-supported 'new energy vehicle' (NEV) programme aimed at M-Category vehicles. LSEV sales experienced a considerable growth between 2012 and 2015, with more than 600,000 units sold in 2015 and an estimated 1 million LSEVs sold in 2016 (Xinhua, 2016). There are multiple entrants with a wide diversity of models characterised by limited speed and range (typically under 40 km/h and 40 km), but also by very low cost compared with M-Category vehicles. With batteries fitted, these vehicles are heavier than an EU L-category vehicle, but if the EU develops as a market for low-speed electric vehicles then some companies in this Chinese

[21] See http://www.toyota-global.com/innovation/personal_mobility/i-road

segment may be well-placed to capture market share, subject to meeting regulatory standards in the EU.

There is no meaningful industry or market for four-wheel L-category vehicles in India or South Korea. In India the presence of large numbers of three-wheel vehicles (auto rickshaws – three wheel motorised vehicles able to carry four adults and used in a similar manner to taxis) is a distinctive feature that has largely prevented the emergence of a four-wheel L-category segment. The ownership of vehicles is modest (only 5% of households own a car), and personal mobility is often achieved via the use of auto rickshaws. There is now a quadricycle segment defined in the Indian law, which entered into force in October 2014 (Ministry of Road Transport and Highways, 2014) and a number of models are planned (e.g. the Bajaj Qute), but these vehicles are unlikely to meet EU regulatory standards in order to secure market share in the EU.

5.3.3 Trends in vehicle ownership

The concept of the vehicle is changing. The vehicle is no longer just a product, over which there is ownership, but is increasingly being perceived as a means of transport, which provides a mobility service. This is evidenced by the increase in the provision of services such as car sharing, ride sharing, and ride hailing and the interplay with connected and autonomous vehicle (CAV) technologies in the case of shared autonomous vehicles. Together these elements are leading to a move towards a new concept of Mobility-as-a-Service (MaaS).

For L-category vehicles, MaaS may open up more market opportunities for this sector. The majority of services might be provided by electric-powered vehicles in urban contexts as recent examples demonstrate. eCooltra is an electric scooter sharing service which was introduced first in Barcelona in 2016 and is now present in Madrid, Rome and Lisbon (CleanRider.com, 2016) (Cooltra, n.d.). A similar service is provided by Coup (owned by Bosch) in Berlin and Paris (Bloomberg, 2017). It therefore seems that smart mobility allied to e-mobility for the scooter segment has been quite successful in providing mobility services in urban centres and could represent an alternative source of growth for the sector.

5.3.4 Impacts of market trends on the competitiveness of EU manufacturers

The market trends described above paint an overall positive picture for EU L-category manufacturers with well-focused strategies, despite a number of threats to the EU market, particularly from Chinese (and in the future Indian) manufacturers. A summary of the competitiveness impacts is provided for each L-category segment relevant to the study in the sub-sections below. Note that these opportunities and threats are discussed without addressing the context of local regulatory and technology trends which may affect the competitiveness of EU manufacturers in the various markets of interest. These trends are discussed in detail below.

5.3.4.1 Light two-wheeler market

It is clear that two high potential opportunities for the EU L-category market in terms of volume of sales, are the Chinese and Indian light two-wheeler markets. The very large growth in both these markets as consumer purchasing power increases presents a potential opportunity for EU manufacturers if they are able to position themselves to produce the relatively low cost, functional scooter-sized two-wheelers characteristic of these markets.

As both these markets rapidly shift towards electric two-wheelers due to existing or expected bans on ICE engines in urban centres however, it will be important for EU manufacturers to adapt their offering in order to continue to compete in these markets. This is particularly important given the rapid rise in relatively low-cost locally-manufactured e-bikes and electric scooters being produced in China already, and likely to be produced in India as the e-bike market there accelerates in the mid-late 2020s.

Given the rise of these low-cost, high-volume e-bike manufacturers and the rise in the use of e-bikes in the EU, there is clearly also a potential threat from Chinese (and in the future Indian) manufacturers gaining significant market share in the EU unless sufficiently-stringent regulation is in place to prevent relatively low specification models being sold in the internal market.

In addition to the significant export opportunity presented above, there is also an opportunity for EU manufacturers to sell more conventional ICE and electric light two-wheelers within the EU, as these modes become more attractive in the urban context with increasing congestion issues and pollution control measures becoming stricter.

5.3.4.2 Powered two-wheeler market

Regarding the powered two-wheeler market, there are indications of some limited growth occurring in developed markets including the EU, representing an opportunity for EU manufacturers, particularly for those manufacturers of specialist 'lifestyle' products.

There may also be increased export opportunities to both developed markets for these products, as well as to China and India where an increasingly wealthy middle class is using its increased spending power to purchase luxury branded EU products. These two markets may be of particular interest to EU OEMs, given the lower manufacturing costs and high price premium that can be associated with luxury-branded products. Indeed, our research indicates that a typical luxury BMW bike can be sold in India for up to 3-4 times the price of a similar bike in the EU, potentially leading to very high margins for these products.

Alternatively, the markets in India and China support large-scale local manufacturing both of domestic brands and of EU brands (for example BMW's partnership with Bajaj to produce the KTM Duke and Triumph's recent announcement of a partnership with Bajaj for local vehicle production (Triumph, 2017)). These may become significant sources of imports into the mid-range market in the EU in the future given an anticipated cost advantage. India has local production of BMW, Honda and Yamaha motorcycles with significant aspirations for export (Mundy, 2017).

5.3.4.3 Quadricycle market

The international quadricycle market is highly heterogeneous, with different markets have very different regulatory definitions for this class of vehicle. As such we do not see any significant export opportunities for EU manufacturers to the other markets of interest to this study, without greater regulatory convergence. Conversely however, there are likely to be only limited opportunities for foreign OEMs to sell their quadricycle designs into the very specific EU market for these products.

5.4 Key trends affecting the competitiveness of the EU L-category vehicle industry

Other than the impact of the market trends discussed above, the competitiveness of EU L-category manufacturers is largely influenced by trends in regulation, policy and technology through their impact on the costs of producing vehicles and the capacity to sell them in the different markets. The legislation in force in the six key markets of interest impose specific and diverse requirements on vehicle design, components and performance. In order to sell their vehicles in each market, manufacturers need to ensure their vehicles are in compliance with the country's regulations. This can have important cost implications and a knock-on effect on their profitability, thereby affecting their ability to compete in those markets.

Two main branches of L-category vehicle regulation were considered and analysed for this study:

- Environmental regulation: influences the environmental performance of vehicles. Legislation in this field can be further sub-divided into regulation on CO_2 emissions/fuel efficiency, on the one hand, and regulation on pollutant emissions, on the other hand.
- Safety regulation: affects vehicle design, components and performance. Safety legislation can have different aims ranging from crashworthiness (passive safety) to crash avoidance (active safety).

It is worth highlighting the strong link between regulatory requirements and technology trends. Compliance with stricter legislation is often made possible by investment in more advanced technologies or a change in materials and components. In the case of environmental regulations, stricter environmental performance is likely to require progressively larger investments in lightweighting and e-mobility. Safety regulations, on the other hand, are heavily linked to innovations in connected and autonomous vehicle (CAV) technology as an active safety measure to minimise road accidents. These three technology trends have therefore been analysed in conjunction with the regulatory and policy trends described above.

While rules and regulations may define the product boundaries to a greater or lesser extent, and economic circumstances may define similar cost boundaries, a key feature of the competitiveness of the EU automotive industry has historically been design innovation alongside technology innovation – and this may also be the case with respect to the L-category segment in the future. Historically, the EU automotive sector has benefitted from advanced automotive sports such as MotoGP and F1, which in turn have allowed major vehicle manufacturers to translate technology innovations in those sports applications to vehicles for the mainstream markets.

Through fully understanding the regulatory, policy and technology-specific context in the various markets of interest, we can gain a more in-depth understanding of the degree to which EU manufacturers are equipped to respond to changes in regulation, policy and technology in these markets compared to their local competitors.

The analysis provided in this section will thus contribute towards understanding how regulatory and policy changes affect technology and therefore our assessment of how the competitiveness of EU L-category manufacturers will evolve in the future in all six relevant markets. This section is divided into two sub-sections that address each one of the trends summarised above in more detail. Each sub-section summarises the regulation in force in the markets of interest, elaborates on expectations of future developments and establishes the link with the technology trends previously identified. At the end, each sub- section also provide a discussion on the impacts of these trends on the competitiveness of the L-category industry in the EU.

5.4.1 Environmental trends

Environmental regulations for L-category vehicles are mainly associated with efforts to reduce pollutant emissions due to their damaging effects on public health. Ambient air pollution is already a serious problem in the urban centres of the majority of the markets of interest, being responsible for to 3.7 million premature deaths globally every year as well as respiratory and other health issues (WHO, n.d.). Transport is a top contributor to this growing concern, which has led governments to develop policies and regulations that limit pollutant emissions of all vehicles, including L-category vehicles. Vehicles on the road also emit large quantities of CO_2 and other Greenhouse Gases (GHG) that contribute to climate change. Nevertheless, in the case of L-category vehicles, CO_2 emissions do not tend to be regulated due to the small contribution of this vehicle category to overall transport emissions. In fact, only one of all the markets of interest (China) has put in place regulation to reduce CO_2 emissions from L-category vehicles.

Pollutant emissions regulations are in place in all the markets assessed. They are often defined as standards that establish limits to a group of pollutant emissions but the type of emissions controlled and acceptable levels tends to vary from country to country. Other air quality policies include limits on ambient pollutant concentration levels, restrictions on the types of vehicles that can operate in specific locations (e.g. access control depending on air pollutant emissions standard) as well as targets to introduce electric vehicles (EVs).

In order to comply with the regulations, manufacturers can install emission control technologies that allow their vehicles to meet the pollutant emissions limits from the date the legislation enters into force. As limits become progressively more stringent, it is expected that manufacturers will need to resort to more advanced technologies and materials (for example electrification of powertrains, lightweighting) in order to reduce emissions substantially.

The following sections provide more detail on the environmental regulations set by the six markets and how these are likely to change in the future. Technology trends such as e-mobility and lightweighting are also discussed for all markets given their role in enabling manufacturers to meet the environmental regulation. This section concludes with a discussion on the impacts of these trends on the competitiveness of EU L-category vehicle manufacturers.

5.4.1.1 Environmental regulations and policy trends in the different markets

Pollutant emissions regulations in the markets of interest for this study tend to follow EU legislation, which is seen as leading in this area. The exception is the US which sets its own standards following California's lead. Japan, South Korea and China have been closely following the Euro emissions standards, with increasingly shorter time-lags in implementation. Similar to M-category vehicles, India's standards will significantly increase in stringency and skip a level, thereby reducing the lag with the EU's standards. However there is not expected to be any significant move beyond EU standards in the near-medium term in any of these markets.

With regards to CO_2/fuel efficiency regulations the arrival of the new US administration promises to have substantial implications for the future of environmental regulation in the US itself and more widely. Key recent measures include a refusal to sign up the US to the latest carbon emissions targets (the Paris Climate Accord), and the efforts to minimise the Environmental Protection Agency's role. In spite of this, several individual cities and states in the US have since declared their intention to pursue carbon emissions reductions, notably California. However, the overall impact may be to dilute the significance of the US in defining future regulatory and policy trends with respect to carbon emissions, including those from vehicles. The US has not been leading in terms of L-category vehicle regulation in any case, but again initiatives at state (e.g. California) or city level (e.g. New York) in respect of air quality may do more to stimulate the local market for zero emissions L-Category vehicles including motorcycles.

On the other hand, future policies in China are likely to be key to the fortunes of the global L-category sector, particularly in terms of the EU L-category manufacturers and their access to the Chinese market, depending on the scope and severity of environmental regulation in China. That China already has fuel economy regulations for powered two-wheelers is a significant indicator of a willingness to take the segment seriously and to move into a globally-leading regulatory position. Chinese government policy at national or first-tier city level is very hard to forecast, but the willingness to recognise the nascent Low Speed Electric Vehicle segment suggests a desire to retain and support this segment, whilst policies to ban ICE engines from L-category vehicles in city centres also illustrate the significant influence that China's localised policies can have on the L-category market and on EU manufacturers' future ability to access this market.

Overall, as successive legislative targets for toxic emissions have been introduced in the leading vehicle manufacturing countries so there has been a process of regulator convergence in terms of the ways in which vehicles are tested, and the absolute performance expected. The convergence is not however absolute. As the entire global automotive industry is engaged on a transition away from internal combustion engines the main concern for the future of the sector in terms of emissions performance may not be solely regulatory. Rather, the industry will increasingly be shaped by the incentives and other support offered by governments to assist in this transition in terms of both battery electric vehicles and fuel cell vehicles, including in the realm of electric charging or hydrogen refuelling infrastructures. This will be further developed in the next section on the e-mobility trend.

Pollutant emissions standards in the various markets do not necessarily apply to quadricycles in all markets. Indeed, this vehicle's environmental performance is not always regulated, as some quadricycle markets tend to be very small. These vehicles may be special exceptions or classes of use such as agriculture or military, or as in the case of the Chinese Low-Speed Electric Vehicles class the regulatory system has to catch up with a market reality. The fact that this type of vehicle's definition is specific to the market further complicates future harmonisation, although Japan has previous experience of defining a 'new' regulatory space in term of the kei class, which could be deployed in creating a novel 'micro commuter' class of vehicle. On the other hand, quadricycles are usually fitted with a diesel engine and are therefore likely to be affected by wider changes in public support for diesel vehicles. Europe has traditionally provided a strong market space for the use of diesel engines, and hence has enacted regulatory provision that has allowed a degree of latitude in emissions performance for diesel engines. In the US there is no separate provision for diesel engine emissions. However, the continued repercussions of the VW diesel scandal has seriously undermined political support for the continued use of diesel engines in the EU.

The sub-sections below provide more detail regarding environmental regulation for L-category vehicles in the specific markets of interest.

European Union

For L-category vehicles, Regulation (EU) 168/2013 (2013) [22] defined Euro 4 standards which are in place from 2016 (for L3e, L4e, L5e, and L7e) and 2017 (for L1e, L2e, and L6e), and provisional Euro 5 standards which will be implemented from 2020. It is worth noting that Euro 5 has equivalent requirements to Euro 6 for LDVs, despite the numbering difference.

The European Commission has already started considering the new emission requirements beyond Euro 5 for L-category vehicles. It has commissioned a study to assess potential post-Euro 5 elements including in-service conformity testing requirements, off-cycle emission requirements, an expansion of the PM limit scope and introduction of a PN emission limit for certain (sub-) categories of L-category vehicles (TNO et al, 2017). This indicates that post-Euro 5 regulation could potentially include a requirement similar to RDE for LDVs as described above. Stakeholders suggested that the earliest implementation of the RDE requirement would be 2025. Regarding Euro 6, stakeholders consider that implementation could occur from 2025/2030 at the earliest.

United States

Regarding L-category vehicles, motorcycle standards vary by engine displacement (EPA, n.d.). The current standards have been in place since 2006 for Categories I and II (engine displacements up to 279 cc). Standards for Category III (displacements from 280 cc) have been introduced in phases: Tier 1 since 2006 and Tier 2 since 2010. Federal motorcycle standards follow California's standards with a lag of approximately two years (Ricardo, 2015). There appears to be little appetite for making regulation more stringent in terms of toxic emissions, or to bring forward regulation on GHG emissions.

Japan

For L-category vehicles, motorcycle emission standards have been in place since 2013. New standards will be in effect from 2017 and are to be based on Euro 4 standards (albeit with differences) (Ricardo, 2014), (Continental, 2015), (Ministry of the Environment, 2012). Stakeholders suggested that a decision on harmonisation with Euro 5 is expected in summer 2017 and could be implemented from 2020.

South Korea

For L-category vehicles, standards follow European legislation. Euro 3 (2013) is currently in place and Euro 4 is planned to be introduced from 2017 (MEV, 2015), (The Hankyoreh, 2015), (The Hankyoreh, 2015), (Ricardo, 2015). The segment is not considered significant in South Korea, whilst no local policies are expected to tackle air pollutant emissions from L-category vehicles, for example by reducing their use in cities.

China

Fuel economy standards

China is the only country worldwide to have implemented fuel consumption standards for two and three-wheelers (TransportPolicy.Net, 2016). Standards were first implemented in July 2009, for new type approval models and in 2010, for all vehicle sales and registrations.

[22] Corrigendum issued on 23 March 2016 (2016)

More recently, the Chinese MIIT proposed fuel-consumption standards for two- and three-wheeled vehicles (motorcycles and mopeds) (ICCT, 2017). If confirmed, the new standards will come into effect beginning in July 2018, for new type-approval models and beginning in July 2019, for all new vehicle sales and registrations. The fuel efficiency standards are stepped according to engine size, and distinguish between three-wheel and two-wheel vehicles as well as between automatic / manual and petrol / diesel versions. The proposed new limits range from 2 l/100 km to 8 l/100 km.

Air pollutant emission standards

Emission standards for L-category vehicles also follow European legislation (Ricardo, 2015). Current standards which have been in place since 2010 (for 2 wheeled motorcycles and mopeds) and 2011(for 3 wheeled vehicles) are China Stage III and are equivalent to Euro III (GB14622-2007 (2007) for and 3-wheeled motorcycles and GB18176-2007 (2007) for mopeds). Regulation for Stage IV has been drafted and it is expected to follow Euro 4 limits to be introduced not long after they are in effect in Europe after 2016 (MEP, 2014), Draft Regulation (2014), (Shanghai Motor Vehicle Inspection Centre, 2012). Following the EU's lead, Euro 5 could also be introduced in the near future according to stakeholders. China plans to keep pace with regulatory developments in other markets in order to achieve sustained exports of motorcycles.

Other Policies

The Low speed EV (LSEV) category was given official status in 2016, and the Chinese MIIT announced the intention to regulate this sector for the first time (Bloomberg, 2016). These vehicles will continue to be excluded from the major tier one cities, but are finding a market in the smaller urban areas and in rural applications.

India

L-category vehicles are treated the same as cars for air pollutant emissions purposes. Bharat Stage IV standards for two- and three- wheelers were applied to all type approvals from 2016 and for all models from 2017 (Ricardo, 2016), (Ministry of Road Transport and Highways, 2014), (Ministry of Road Transport and Highways, 2015). Similar to passenger cars, Stage V will be skipped and Bharat Stage VI will be implemented for all new vehicles from 2020 (Ministry of Road Transport and Highways, 2016). They are applicable nationwide, and the Indian Drive Cycle will be used. There has also been some dilution of the longevity requirements for emission control systems.

5.4.1.2 E-mobility trend

The e-mobility trend reflects the shift in powertrain technology towards electric powered engines. This trend is largely driven by environmental regulations in the context of growing CO_2 emissions and significant air quality problems in major urban centres around the world. For L-category vehicles in particular, electrification is usually a response to city-level policies (e.g. restrictions and bans on the use of ICE vehicles) and trends associated to M-category vehicles to a certain extent.

The transition towards electric vehicles has been fostered by announcements regarding the phase-out of ICE vehicles in several countries[23] or the setting of targets for the sales of electric vehicles. These policies generally target M1/N1-category vehicles (and are described in detail in Appendix A.4) and it is as yet unclear whether they will also apply to L-category vehicles but it could be assumed that such policies will generally assist in the technology development and cost reductions required to make e-mobility commercially viable, including in the L-category segments. Meanwhile, at the city level, cities in China have also banned or restricted the use of ICE two-wheelers. Cities acting in tandem with or in isolation from national measures are likely to be major forces in the drive to phase out ICE vehicles, and in contrast bring in xEVs (ICCT, 2017).

Measures may be restrictive (banning various categories of ICE vehicle as described above) or seek to stimulate the alternatives. Around the world, attempts to stimulate the xEV segments have been based largely on incentives that seek to compensate in some ways

[23] India, China, and France, the UK, Germany and the Netherlands in the EU

for the perceived and actual performance limitations of those xEVs. There is a growing industry consensus that purchase price parity with ICEs will be achieved by around 2025-28, at least for some types of M-category vehicle. It is expected that some L-category vehicles may be able to reach cost parity well before this due to their lightweight nature and relatively simple construction.

Another issue to consider is how far petrol and diesel subsidies (direct and indirect) will be removed. Falling fuel prices in the wake of the 2008-9 financial crisis resulted in many countries reducing or removing direct fuel subsidies (India and Malaysia were key examples; but Brazil did not follow this trend). Globally ICE fuel subsidies are thought to amount to at least US$500 billion in 2013 (IGC, 2016). Ultimately, the removal of such subsidies will create market space for e-mobility alternatives, including those from the L-category segment.

As a result, a growing number of traditional L-category manufacturers are including EV models in their product portfolios and have announced plans to introduce a range of additional models in the near-medium future, whilst other completely new entrants are seeking to capitalise on what they see as an untapped market for their zero emission products. This has been made possible due to declining battery costs enabling OEMs to build an improved portfolio of vehicles, which are affordable and offer acceptable ranges (electrek, 2017) (Business Insider UK, 2016). Table 5.2 lists some of these plans that demonstrate the expected progress towards e-mobility in the L-category vehicle sector in the markets of interest.

The powered two-wheeler market offers some interesting possibilities in scooters (for regular commuting) or large models designed more for long-range touring. However, there is likely to be strong competition from China for both finished vehicles and for components. China is already leading production and sales of electric L-category vehicles, in particular in the electric scooter and LSEV sectors. The established car manufacturers in China are also a leading presence in terms of electric mobility (see for example BYD), but have not yet ventured into the L-category segments.

Table 5.2: OEMs' plans regarding e-mobility

Market	Manufacturer	Plan	Time horizon	Source
EU	Zero Motorcycles	Entered EU market	2015	(The Manufacturer, 2015)
EU	BMW	Electric bike, BMW C evolution, unveiled	2016	(electrek, 2016)
EU	Vespa	Introduced the electric model, Elettrica	2017	(techradar, 2016)
US	Victory Motorcycles	Introduced an electric motorcycle, the 2016 EmpulseT	2016	(revzilla, 2016)
US	Harley Davidson	To produce an electric motorcycle	2021	(plugincars, 2016)
Japan	Honda	Started selling an electric scooter	2010	(live mint, 2010)
Japan	Yamaha	To set up production of	2012	(EV World, 2011)

Market	Manufacturer	Plan	Time horizon	Source
		electric scooter in India		
Japan	Honda	To produce an electric-powered version of the Super Cub	2018	(New Atlas, 2016)
Japan	Honda and Yamaha	To collaborate in the production of electric motorcycles	Medium/Long-term	(Car and Bike, 2016)
India	Tork Motorcycles	Produced India's first electric motorcycle, T6X	2016	(Car and Bike, 2016)
India	Hero Electric	Launched the Flash e-scooter in India	2017	(Planet Custodian, 2017)

Regarding quadricycles in the EU, several quadricycle vehicles produced in France (the VSP category) use (Japanese Kubota) diesel engines. The diesel engines may be deemed unsuitable in the future, especially in urban applications where the (non-French) growth prospects are probably greatest. The need to transition to electric traction is thus a major concern for the sector. There is an EU Light Electric Vehicle Association (LEVA) that is beginning to campaign for such a transition, while the EU FP7 Programme funded research into e.g. lightweight structures for such vehicles (E-Light, n.d.). The current H2020 project RESOLVE builds on this work (RESOLVE, n.d.) and includes both Piaggio and KTM as leading L-category producers in the EU.

One potential area of interest in the medium term is that of fuel cell L-category vehicles. Small fuel cells are already extensively used in certain applications e.g. warehouse fork-lift trucks. These smaller 'commodity' fuel cells are an order of magnitude cheaper than the specialist large fuel cells developed by automotive OEMs for M-category vehicles (e.g. Toyota Mirai; Honda Clarity), and could be adapted for L-category vehicle use as is seen in the Riversimple Rasa. At present such developments are constrained by fuel supply: a suitable infrastructure is lacking.

The e-mobility trend will have important implications not only for the costs of producing L-category vehicles in the future but also for material demand given the different composition of an electric vehicle to that of a conventional ICE vehicle. This will be further developed in the section on the impacts of environmental trends on the competitiveness of EU manufacturers.

5.4.1.3 Lightweighting trend

L-category vehicles are already lightweight compared with mainstream M-category cars, whilst environmental standards are less well developed for L-category vehicles, and so the pressure to reduce weight is less: the powered two-wheelers have a good power to weight ratio and are thus relatively efficient; the quadricycles are in any case regulated by weight among other measures, and are therefore already relatively lightweight. There are some notable exceptions however: first, traditional bicycles are greatly enhanced by the addition of battery electric power for a modest weight and cost penalty; second, some of the forming processes for non-steel materials, especially with regards to various plastics or tubular aluminium, are technically efficient at relatively small scales of production. Hence lightweight materials may be attractive to manufacturers for reasons of scale appropriateness as much as weight reduction, albeit with significant cost considerations. Within the constraints described above, it is to be expected that weight reduction strategies found in M-category vehicles will be emulated in some of the L-category sub-segments, but with some differences.

In respect of the M-category vehicles, and especially for those produced in the EU, it is notable that the materials innovations tend to be found first and foremost in the 'prestige' manufacturers that have the brands with sufficient market power to withstand premium pricing. For the EU L-category sector, the question lies in whether lightweight technologies and materials can be supported by the market, given the relative position of the brands concerned and the relative additional cost of such technologies. As described above, it is not certain that powered two-wheelers need significant weight reduction technologies in many cases. Whilst some of the motorcycle brands such as KTM appear relatively strong in global terms (so may be able to charge a premium and recover additional costs associated with lightweight strategies) and this will assist in the use of such lightweight technologies and materials, others such as Aixam may find this more difficult. Nevertheless, the likely transition towards increased penetration of electric traction may exacerbate lightweighting concerns, as weight reduction is an important consideration in optimising the size and cost of the powertrain (as demonstrated in the BMW i3), so the drivers for change are likely to become stronger. This will be further developed in the section on the impacts of environmental trends on the competitiveness of EU manufacturers.

5.4.1.4 Impacts of future developments in environmental regulation and policies on the competitiveness of EU manufacturers

Strict environmental regulations for L-category vehicles in the EU have ensured that in terms of powered two-wheelers at least, EU-designed and manufactured products are acceptable in markets around the world, and that conversely such regulations have ensured that sub-standard products have not been able to enter the EU market and undercut EU-based manufacturers. Such regulatory protection is also supplemented by issues around brand, image and lifestyle that non-EU competitors have found difficult to emulate (other than Japan).

Indeed, at present the threat to EU L-category producers from those based outside the EU appears limited. The period of time when Japanese motorcycles displaced EU production has declined, and it seems unlikely in the short term that this sort of threat will be replicated with the Micro Commuter concept that has seen some trials in Japan. Similarly, imports from China or India seem unlikely at the moment, but are likely to be more important in the powered two-wheeler segments (electric and combustion engine) and in the electric four-wheel segments in the future.

In terms of the EU internal market, there may be an emergent gap for EU L-category manufacturers to produce commuter vehicles with zero emissions, seating perhaps two people and having restricted performance (notably with regard to top speed). Part of this gap may be filled by electric bicycles, but otherwise there is likely to be growth in demand in the electric L-category segment. The main concerns here for EU manufacturers in the medium term (i.e. 5-10 years from now) are two-fold. First, countries in Asia may become sources of low-cost imports for the powered two-wheeler segments. Second, the overall thrust of policy in China appears to be one of seeking leadership in electric vehicles, and not just in terms of M-category vehicles. Here China has a unique regulatory proposition, and it may enable Chinese manufacturers to be 'ahead of the game' in world markets, as well as assisting in protecting those producers from imports. In this respect, and given the strength China has in terms of access to Lithium and rare metals, along with the relatively low-cost manufacturing base, it is to be expected that the EU L-category may be vulnerable to imports from China in the medium term.

With regards to EU L-category manufacturers' export markets, the EU industry can probably continue to prosper in the higher-value, higher technology powered two-wheeler applications. However, as production of the smaller powered two-wheelers is increasingly decentralised into the major Asian markets (Thailand; India; Indonesia; Malaysia; etc.), those markets may develop an increased production capability in these sectors and could become significant sources of imports into the EU in the medium term.

In terms of quadricycles, the L-category vehicle segment thus far is comprised largely of 'islands' in which both production and consumption are organised, whilst differing international product category definitions and regulations make it difficult for global products to be designed. This means that the export opportunities for EU L-category vehicle manufacturers are few, but equally at present the threat of imports from Chinese LSEVs, US NEVs, or Indian auto rickshaws is negligible. It is also notable that the EU market for L-category four-wheel vehicles is small and apparently declining, and that the use of diesel engines in vehicles of this type is under threat. It is notable that even Japanese kei-class cars have struggled to obtain market share in the EU given this lack of demand.

The future of the EU quadricycle segment is not reducible to policy directed at that segment alone, but is also likely to be shaped by developments that apply to the M-category vehicles and the wider strategies adopted with respect to smart mobility in urban areas in the EU. Many European L-category vehicles currently use small diesel engines. Large scale regulation of diesel and petrol engine LDVs, at national or city level, could open up new opportunities for the L-category segments with electric traction, providing that suitably low-cost components and systems could be developed. The EU automotive 'ecosystem' innovation network generally is very strong, and directing this capacity at the L-category segment to take advantage of the market space created by the regulation of M-category vehicles represents a significant market opportunity within the EU for EU manufacturers.

Impact of electrification of L-category vehicles

Whilst battery packs and associated systems have clear environmental advantages over traditional ICE drivetrains, they tend to add weight relative to an ICE solution, add cost and reduce performance expressed as range, top speed and carrying capacity. There are some advantageous performance attributes that should not be neglected, for example with much reduced noise, vibration and harshness (NVH) concerns, more linear acceleration, greater stability due to the lower centre of gravity, the ability to recharge at home or at work, or at a leisure destination, without the inconvenience of handling petrol or diesel fuel pumps. Nevertheless, the result of electrification is a rather different set of product attributes, which may need to be presented to the market in different ways and perhaps through different business models. The development of xEVs in the L-category sector therefore poses some significant challenges, on top of the likely future erosion of the L-category and M-category markets by e-bikes, as discussed above. Whilst this is at present a relatively minor phenomenon, it could be much more significant in the future, presenting a threat unless traditional L-category manufacturers keep pace with innovation.

The e-bike sector could also be much more difficult to defend against foreign competitors using regulatory controls, particularly in the face of China which has a powerful advantage in the e-bike segment, benefiting as it does from economies of scale and a low-cost manufacturing base. Indeed, one area where China has a potentially significant cost advantage is in the supply of lithium for EV battery packs. Global demand for Li-ion batteries in a wide range of applications is able to be met by current supply, but only by a small margin and Chinese producers are in a very strong position in that market. This, added to existing labour cost advantages, may assist Chinese producers of L-category electric vehicles to be very competitive on a global basis. In addition, China now has a strong machine tool sector, and is price competitive on most commodity materials such as steel. This means that the design and construction costs for L-category vehicles (both e-bikes, but also LSEVs) is likely to be well below that of the equivalent in the EU, even if the quality of finish is not so high. A second area of concern is with the supply of rare earth metals for electric motors, where again China has a strong position in a market that at a global level is very tight. Such metals are particularly scarce in the EU, which already has to import more than 90% of requirements. The majority of imports come from China (European Commission, n.d.), presenting a geo-political market risk that could constrain production in the EU in the future, or could lead to substantial cost increases.

With respect to Lithium batteries and related technologies, the EU can develop its own capacity – a process that is currently underway at the major OEMs in the M-category and some of their major suppliers. However, it is not possible for the EU to achieve similar progress with rare earth supply, so it is likely to be a strategic concern in the future.

Nevertheless, it is assumed that most e-bikes and LSEVs currently in the market in China would not pass existing EU safety requirements, and that in many cases major re-engineering would be required to enable them so to do. However, the sheer variety and volume of output in these segments will allow rapid learning economies and scale economies, while technology transfer from M-category vehicles may enable the rapid introduction of designs that can meet EU legislative requirements.

On the other hand, the growing market in China may represent an opportunity for EU producers, but the price competition will be extremely difficult to meet. There is an expectation that powered two-wheelers will increasingly be battery electric, with the EU industry focusing on high-performance, quality and design to justify premium pricing.

With regards to quadricycles in particular, at present the main 'unique selling proposition' for quadricycles in the EU lies with the ability of users to drive the vehicles with restricted licences or no licence at all, primarily because of the very limited performance of the vehicles. Existing quadricycle designs could be fitted with batteries and related powertrain components in the future. However, to do so would make them both much heavier and also much more expensive. At present these vehicles are about at price parity with several small M-category cars, so the risk is that the adoption of electric powertrain will make them prohibitively expensive compared with the mainstream competition. Moreover, as is evident with the Renault Twizy, a more radical redesign of the product overall, in a deliberate attempt to capture the benefits of electric powertrain, can yield some interesting and novel vehicles, but again they are relatively expensive.

It is also worth noting the weight aspect of the L-category sector, with defined mass as key cut-off points. While the battery pack is excluded from the weight calculation, it is not clear whether other innovative systems such as fuel cell vehicles, those using flywheels, those using compressed air, or indeed other technologies will be penalised by the weight limits. Hence, a key issue for policy makers is to consider how regulations can be designed that enable the market acceptance of radical innovations. It is notable, for example, that a radical product design such as the Riversimple Rasa that combines a fuel cell with an ultracapacitor in a carbon fibre body can delivery very low carbon emissions per distance travelled, and zero toxic emissions at point of use, but at 550 kg is too heavy to count as an EU L-category vehicle. Moreover, the emergence of a future 'ultra-compact' electric vehicle segment in Japan, or of a substantial LSEV segment in China could pose substantial competitive challenges in the future. As China seeks to formalise the LSEV segment, there may also be a growing search for export markets, potentially posing an additional threat in the quadricycle sector, although initial competition is likely to be in third markets, including Africa.

Impact of lightweighting of L-category vehicles

The impact of lightweight technologies and materials on the competitiveness of the EU L-category segment is likely to be important, but less profound than the impact of electrification. Weight reduction may be a more useful and therefore prevalent strategy in the quadricycle L-category segments, rather than in the powered two-wheeler segments.

The two aspects are of course related, with lightweighting being key to maintaining the performance of L-category segment vehicles as electrification proceeds, particularly for quadricycles. Generally, lightweighting is held to add cost, but in so far as it allows reductions in the (expensive) battery pack and associated powertrain costs, weight reduction strategies can pay for themselves. Additionally, weight reduction involving non-ferrous metals may increase longevity or the ability to design vehicles for module refurbishment and recycling. Hence there are secondary competitive benefits that can potentially be derived from the adoption of lightweight technologies that will work to the competitive advantage of existing EU producers.

The EU has a strong scientific and engineering base in terms of the use of advanced materials, but is less well represented in terms of the production and supply of those materials. Lightweight materials tend to be energy-intensive in production, and hence tend to be migrating to those global locations where initial energy costs are lower (Middle East, Russia), or where renewable energy sources may be used (Brazil, US), or where a strong manufacturing capability exists (e.g. Japan has traditionally had a strong position in the carbon fibre precursor area). Hence there is a concern that the import cost of advanced materials may reduce the competitiveness of the EU L-category sector compared to its international rivals.

While it is the case that lightweight materials will add to the per-unit costs of L-category segment vehicles produced in the EU, the ability to follow premium positioning strategies around the world may insulate the EU somewhat from this issue. Indeed, this premium positioning absolutely depends upon continued innovation both technically and in design terms. Given economic growth rates and the distribution of income in many key markets such as China, Brazil, India and so forth it is reasonable to expect that there is an emergent affluent middle class able and willing to afford the purchase of both M-category cars and other vehicles, and that these consumers will continue to have aspirations for brands of established reputation from 'prestige' locations and incorporating advanced lightweighting, as illustrated by the premium pricing of EU L-category brands in markets such as China and India. However, the market space for premium L-category vehicles is likely to be relatively limited, so for products such as scooters the demand for EU imports incorporating lightweighting in other countries is unlikely to be strong.

As discussed, the lightweighting trend is most relevant to the quadricycle segment, where many of the material alternatives to stamped and welded steel are suitable at lower volumes than is normal for break-even in the case of steel. This could be an advantage to the EU quadricycle segment which may struggle to compete with a high-volume, low-cost, commodity approach to the segment that might emerge out of the Chinese LSEV segment.

5.4.2 Safety trends

Safety regulations aim at improving road safety for both drivers and other road users by preventing accidents from occurring altogether but also reducing the consequences in the event of one. L-category vehicle users are classed as vulnerable road users, being as they are particularly exposed to serious danger in the event of a crash – thereby making safety measures aimed at L-category vehicles all the more important.

Regarding the vehicle itself, L-category vehicles are subject to a number of regulations in the majority of the markets analysed. Regulations tend to mandate specific safety features ranging from passive features (to protect the road users in the event of a crash) to active features (to avoid accidents in the first place). The latter are increasingly linked to developments in CAV technologies which help prevent accidents by minimising human error and improving driving.

The next sections provide more detail on the safety regulations set by the six markets relevant to this study and how these are likely to change in the future. Technology trends such as CAV are also discussed for all markets given their role in providing active safety features. This section concludes with a discussion on the impacts of these trends on the competitiveness of EU L-category vehicle manufacturers.

5.4.2.1 Safety regulatory and policy trends in the different markets

Similarly to M-category vehicles, world reference regulations in road safety for L-category vehicles are developed by the United Nations Economic Commission for Europe (UNECE or ECE). This body, which includes the EU, individual EU Member States but also countries in North America and Asia, manages the UN transport conventions and agreements on technical requirements and international traffic rules (UNECE, 2016). Within the UNECE, the World Forum for Harmonization of Vehicle Regulations (WP.29) provides a platform for the development of a harmonised regulatory framework for vehicle safety but also environmental performance, as described in Box 5.1.

Box 5.1 – UN Framework for vehicle safety and environmental performance

The UN regulatory framework is based on three UN agreements administered by WP.29. For this study, it is worth considering the scope of the 1958 and 1997 Agreements:

- The 1958 Agreement includes UN Regulations which contain provisions for vehicles, their systems, parts and equipment regarding safety and environmental performance. It specifies performance-oriented test requirements and the procedures for type approval, conformity of production and mutual recognition of type approvals. Regulations are updated often to reflect technical developments. The contracting parties do not have to adopt all the Regulations annexed to the Agreement but if they decide to apply one, they must issue approvals in line with the Regulation and mutually recognise the approvals issued by other contracting parties which adopted the Regulation.
- The 1998 Agreement encompasses the United Nations Global Technical Regulations (UN GTRs) which also specify performance-related requirements and test procedures but do not include provisions for type approvals and their mutual recognition.

Sources: (UNECE, n.d.), (OECD, n.d.)

Through WP.29, the EU has been at the forefront of general safety regulations for L-category vehicles in regards to items such as lighting, tyres, and braking systems and for those that specifically apply in regards to electric versions.

Japan and South Korea are also active participants at the WP.29. These countries, as well as the EU, tend to adopt the safety regulations developed at the UN level. Relevant UN Regulations for L-category vehicles include regulations on lighting and light-signalling devices (Nos. 3, 19, 20, 37, 38, 50, 56, 57, 74, 76, 82), on tyres (No. 75), braking (No.78), on controls, tell-tales and indicators (No. 60), and on rear-view mirrors (No.81), among others (Erario, 2008).

On the other hand, the US follows its own approach and sets the US Federal Motor Vehicle Safety Standards (FMVSS), which are also widely recognised (Deloitte, 2013). The standards specific to L-category vehicles are summarised in the relevant sub-section below. It is worth noting the US is only a contracting party of the 1998 Agreement. China and India have only recently developed legislation to improve road safety for L-category vehicles and are far behind the other countries considered here. Both countries are also only contracting parties of the 1998 Agreement.

Compared with M-category cars, safety regulations for L-category vehicles are not as well developed, comprehensive or universal. There is relatively limited scope for the mandating of passive or active safety systems on traditional motorcycles, or other powered two-wheelers. It is worth noting however, that many of the safety features aimed at M-category vehicles are aimed at protecting vulnerable road users (VRUs) such as L-category drivers. This is expected to be particularly relevant with the advent of advanced active safety features related to CAVs, for example through the addition of certain cooperative intelligent transport system (C-ITS) services aimed at protecting VRUs, such as intersection safety services and VRU protection.

It is also important to recognise that safety can be more than regulatory compliance. An illustration of this is the Renault Twizy. In this L-category vehicle the designers considered the use of four wheels as adding both to the practical aspects of safety, but also to the psychological comfort it afforded to occupants. In addition, the Twizy was designed to give the driver an eye level equivalent to that of a standard car, while the floor-mounted battery pack provides for greater lateral stability. Moreover, the Twizy features a cockpit design akin to a motorcycle helmet and thin windscreen pillars to aid visibility. The Twizy also comes with a frontal airbag for the protection of the driver, and a four-point harness for the driver, while the rear passenger gets a traditional three-point harness. To meet impact requirements the Twizy structure is of tubular steel, with thermoplastic panels.

The sub-sections below provide more detail regarding safety regulation for L-category vehicles in the markets of interest.

European Union

For L-category vehicles, Regulation (EU) No 168/2013 defines the procedure for the approval and market surveillance of L-category vehicles. It entered into effect from January 2016 and replaces the repealed Directive 2002/24/EC and other Directives, with a new

Directive and four Delegated Acts (Vehicle Certification Agency, DfT, n.d.), including Regulation 3/2014 on Vehicle Functional Safety Requirements (RVFSR) and Regulation 44/2014 on Vehicle Construction Requirements (RVCR)[24].

Among other requirements, Regulation (EU) No 168/2013 mandates the fitment of automatic dipped-beam headlights to increase vehicle conspicuity and enhanced ABS (anti-lock braking system) for two-wheel motorcycles (with engine capacity above 125cc) only (Council of the European Union, 2012). For motorcycles with engine capacity below 125cc the manufacturer can choose to incorporate ABS or Combined Brake Systems (CBS). These are only two examples of safety features mandatory for L-category vehicles. Others are provided in EU Regulations 3/2014 and 44/2014 (supplementing 168/2013). Any UN Regulations to which the EU has acceded form also requirements for the EU type-approval of a L-category vehicle and are listed in the Regulation (EU) No 168/2013 or in the delegated acts.

As part of the EU Roadworthiness Package, heavy motorcycles with engines over 125cc can be subjected to compulsory inspections from 2022 (Council of the European Union, 2014). Member States might be exempted from this if a suitable alternative is proposed. Stakeholders suggested that some Member-States already have this in place (e.g. Italy). The regulation is expected to ensure cleaner, more environmentally friendly vehicles but also maintain safety performance over time. In addition, the increased frequency of inspection can stimulate renewal of the fleet. Stakeholders noted that motorcycles tend to be inspected at a lower frequency than LDVs.

The European Commission has also commissioned a study to assess the development of additional functional safety and vehicle construction requirements for heavy on-road quadricycles (L7e-A) (Transport Research Laboratory, 2014). This sub-category was introduced by Regulation No 168/2013. Currently, these vehicles do not have to comply with as many safety standards as the LDVs, although they can be used as substitutes. The study assesses whether additional safety standards for this sub-category are necessary and if this is the case, which requirements should be made mandatory. The study recommended the further assessment (cost benefit analysis) of several safety features for 'car-like' heavy on-road quadricycles, including braking, frontal, side and pedestrian impact, safety belt anchorages and seatbelt reminders, among others.

EU regulations on L-category vehicles distinguish between those that have normal seats, and those that are 'straddled' like a motorcycle. In principle, such differentiation may enable rules regarding, e.g. the wearing of helmets, to be decided – though in practice such rules vary across EU national jurisdictions, as do rules regarding licencing age and qualifications.

The EU has been instrumental in shaping the adoption of harmonised UN regulations with regards to many of the detailed requirements of EVs (UN Reg. 136 (UN, 2016)). Such requirements cover, for example, vibration resistance, thermal shock and cycling, mechanical shock, fire resistance, short circuit protection, overcharge protection, over discharge protection and over temperature protection (InterRegs, 2015). In the majority of cases the requirements of the draft Regulation were identical to those specified by ECE 100.02 for M-category vehicles. However, in certain instances, the requirements were tailored to specifically suit the design, construction and use of L category vehicles. The draft Regulation was submitted to the World Forum for Harmonisation of Vehicle Regulations (WP.29) at its 166th session in June 2015, where it was formally adopted. Official publication of the final version of ECE 136 was in early 2016.

United States

The safety performance of L-category vehicles in the US are regulated by the Federal Motor Vehicle Safety Standards (FMVSS). These US Federal regulations define design and performance requirements for motor vehicles and establish the minimum safety level for vehicles produced, sold and imported into the US. Among the regulations that comprise

[24] The other Delegated Acts include Regulation 134/2014 on Environmental and Propulsion unit Performance Requirements (REPPR), and Regulation 901/2014 on Administrative Requirements (RAR).

FMVSS, key standards which apply to L-category vehicles (more specifically, motorcycles, mopeds or motor driven cycles, including three-wheeled vehicles) include legislation on lamps, reflective devices and associated equipment (FMVSS No. 108), on brakes (FMVSS No. 106, 116, and 122), on tyres (FMVSS No. 119, and 120), on Motorcycle Controls and Displays (FMVSS No. 123), on rear view mirrors (FMVSS No. 111), among others (NHTSA, n.d.). There is no information on recent updates to legislation specific to L-category vehicles.

Japan

Regarding L-category vehicles, safety standards tend to follow UN Regulations. As a contracting party of both the 1958 and the 1998 Agreements, Japan can choose to adopt the Regulations and GTRs annexed to these Agreements. Recently, the MLTI has issued new regulation for the mandatory fitting of ABS for motorcycles (with engine capacity below 125cc) and ABS or CBS for mopeds (with engine capacity between 50 cc and 125 cc), which follows UN Regulation no.78 (MLIT, 2015) . It will apply for new types from October 2018 and for all new vehicles from October 2021.

South Korea

South Korea also follows legislation developed at the UNECE level as a signatory of the 1958 and 1998 Agreements. The Ministry of Transport is assessing the inclusion of the L6/7e categories into the Korean Motor Vehicle Safety Standard (KMVSS).

China

There is limited information on safety regulations for L-category vehicles in China. With regards to quadricycles, China has decided to recognise the LSEV segment but it is not clear at this stage whether there will be a safety regulation regime put in place for these vehicles.

It is also worth noting that China is once again considering a ban on electric bicycles for safety reasons, with a primary focus on the tier one cities (Forbes, 2016), (BIKE Europe, 2016). It is not yet clear how such a ban could be enforced given that there are some 200 million e-bikes in circulation in China and that this is a major source of income for China's e-bike manufacturers, and given that previous attempts at bans have failed.

India

Bikes and scooters are expected to be mandated to have automatic headlamp on (AHO), similar to daytime running lights in cars, from 2017. There is also a plan from the road transport ministry to work on a standard that requires the fitment of a device which emits a sound to alert people in the vicinity of an accident.

A notification from the Ministry of Road Transport and Highways (MoRTH) issued in 2016 requires two-wheelers with an engine displacement above 125cc to be equipped with ABS by 2018. In the case of two-wheelers with an engine displacement less than or equal to 125cc, manufacturers can choose to install either ABS or CBS (autocar, 2016).

Stakeholders are of the opinion that India has similar regulations as the EU but with a delayed implementation.

5.4.2.2 Connected and autonomous vehicles technology trends

Connected and autonomous vehicle (CAV) are a recent trend which is expected to revolutionise the automotive sector.

As vehicle design is optimised and passive safety options are exhausted, the development of CAV will be essential to bringing additional safety benefits and reducing accidents altogether by minimising the role of human error in accidents and improving driving.

In order to achieve this, regulations and policies that enable autonomous vehicles are essential to allow its rapid development. A lack of appropriate regulation can not only limit the trialling of this technology on public roads required to achieve technological progress, but also undermine the conditions for its future commercialisation (if for example a driver is required to be in control of the vehicle).

According to the European Association of Motorcycle Manufacturers (ACEM), C-ITS may play a more important role than full autonomy in achieving safety improvements in the EU, in the near-medium term. Through the use of C-ITS, it may be possible to address one of the largest causes of injuries and fatalities for L-category drivers, namely collisions with M-category vehicles. Research shows that one of the most frequent human errors in accidents is the failure of other road users to see powered two-wheelers within the traffic environment, due to a lack of driver attention, or temporary visual obstructions. This problem could be addressed by enabling non-powered two-wheeler drivers to receive a 'motorcycle approaching indication' (MAI) or, in the case of an emergency situation, a 'collision warning' message. Such a form of 'digital conspicuity' of powered two-wheelers would result in a higher level of safety for riders. The most important factor here is the timely detection of L-category vehicles by M-category and other vehicle types.

It is essential therefore that L-category vehicles are not overlooked when EU-level coordination and design activities concerning the successful deployment of C-ITS to EU infrastructure and other vehicle types are considered. The motorcycle industry is therefore taking an active role in ensuring that L-category vehicles are central to the deployment of C-ITS. On its side, the European Commission has also included vulnerable road users (VRU) protection as one of the core Day 1.5 C-ITS services to be adopted as part of its C-ITS strategy.

It should be noted that ITS applications on powered two-wheelers will depend largely on developments in the automotive sector, due to the lower economies of scale and the higher fragmentation in the L-category segment. At the same time, it will not be possible to simply carry over technology from M-category vehicles to as further research and adaptation will be required. To this end, in the Memorandum of Understanding signed in March 2014, ACEM members pledged to have at least one L-category model on the market with C-ITS technology (as standard equipment or as optional equipment) by 2020. Rapid developments in the US are thought by ACEM as likely to provide important technology to motorcycles in order to improve safety of vulnerable road users. ACEM members are also undertaking research on the eCall system for motorcycles (ACEM, 2016) .

Autonomous control of two-wheelers is more problematic. When considering automated driving, introducing a partly automated driving control function on a motorcycle is complicated, as a result of the leaning behaviour of powered two-wheelers, the accurate positioning within the lane boundaries, and due to the fact that the automation systems intervene in the vehicles' longitudinal and lateral control, which would affect the stability of the vehicle. Due to the design characteristics of a motorcycle, the vehicle and the rider form together an integrated system. While conceptually possible, market deployment of autonomous two-wheelers seems unlikely in the near-medium term.

Even the deployment of certain semi-autonomous systems (e.g. ADAS) for powered two-wheelers will depend greatly on acceptance by riders, which is a challenge considering the riding dynamics of a two-wheeler, which requires full control of deceleration, acceleration, speed and direction. For other systems such as automatic braking, problems also exist since, contrary to cars, the intervention of an automated system in the dynamics of the driving system (e.g. automatic actuation of the brakes) could impact handling and potentially lead to loss of stability/control.

Finally, Human-Machine Interfaces (HMI) represent a significant challenge. While car manufacturers are able to offer a complete set of HMI solutions (driver attached with a seat belt, air bag, activators, integrated systems), the powered two-wheeler industry depends on the collaboration with other market players, such as clothing and helmet manufacturers. This makes the systems and the overall process much more complicated.

For the quadricycle category on the other hand, autonomous technologies may be more likely, although this would need to be balanced with the ability to bear the additional costs of such technology on these relatively inexpensive vehicles compared to M-category vehicles.

Nevertheless, some CAV technologies are being applied into two-wheel vehicles, although these are more aimed at convenience and journey optimisation. A good example of the way in which design may evolve and incorporate such technologies is the Ford concept e-bike MoDe: Flex shown in 2015 (engadget, 2015). The bike is linked to a smartphone app which can provide information on weather, parking availability and even the owner's level of fitness to plan routes. In the case of e-bike sharing schemes, smartphone apps can also be used to unlock a bike and, when tracked via GPS, these apps can also be used for billing of usage and for notification of where the bike has been left.

5.4.2.3 Impacts of future developments in safety regulation and policies on the competitiveness of EU manufacturers

Regarding L-category vehicles, existing safety regulations help to protect the EU industry from low cost competition from markets with lower standards, such as China and India. However, with the majority of markets planning to align themselves with the UNECE world reference regulations, other regulations may be required to ensure that the EU maintains its regulatory lead in this area, for example regulations related to the inclusion of C-ITS technologies or eCall. Conversely, the EU should be well-equipped to access most external markets given its regulatory lead and ability to meet regulatory standards in key export markets such as China and India.

Longer-term it may be that an overhaul of regulations is needed to allow for dynamic safety systems akin to those on autonomous cars, and for passive systems using innovative structures such as carbon fibre reinforced plastic to manage impact energies differently to steel.

Impact of CAV technology on L-category vehicles

In the M-category segment, Germany has been at the forefront of legalising the use of autonomous vehicles up to NHTSA level 4 (i.e. short of vehicles that absolutely lack a steering wheel or other driver controls). Cars such as the current generation Audi A8, launched in May 2017, are designed to capitalise on this legislation. So, while the initial impetus for autonomous cars came from the US (supported by military applications and initiatives by 'tech' firms in Silicon Valley such as Uber, Google, etc.), it is apparent that the EU automotive industry is catching up fast. While the policy impetus has largely been justified on the basis of reduced road traffic deaths and injuries, for the major OEMs the attraction is more related to premium product positioning and associated brand values. The main areas of concern are with 'handover protocols' to define under what conditions and in which ways a driver can cede control to the car, and hence what activities the driver may be allowed to undertake while the car is under autonomous control. Still, the attraction for the M-category manufacturers is one of selling the advantages to the driver.

As an illustration, Volvo has stated the intention to produce autonomous vehicles for the luxury market, with the 'Autopilot system adding US$10,000 to the cost of the car. According to Hakan Samuelsson, CEO at Volvo Cars the idea is:

"To make a car even more premium, one of the most interesting things is a full autopilot…Not a supervised version, but really the one that you can sit back and watch a movie or whatever. That will make the premium car even more premium." (Bloomberg, 2016).

The story is somewhat different for the L-category segment, with much higher accident and fatality rates and significantly lower pricing levels leaving less room for expensive CAV technology innovation. With regards to competitiveness impacts, there are two main areas of concern for L-category manufacturers in the EU: the direct and the indirect consequences of CAV technology.

In direct terms CAV technologies can be fitted to many L-category vehicles, including those with two-wheels, to improve their appeal and safety to consumers. Connectivity technologies alone are unlikely to be a differentiator, but the way that CAV packages are deployed, marketed and integrated into the vehicles will be significant – with C-ITS safety features likely to be at the forefront of improved consumer appeal. Indeed, the adoption of CAV technologies will assist in two main respects. First, there is likely to be a safety benefit for occupants and other road users. The reduction in collisions may have further implications for the reduction of impact-related expenses and insurance premiums. Second, CAV technologies will make the vehicles more attractive and functional to users by e.g. assisting in navigation around urban areas or in streaming video services.

Given their lower overall revenues however, it is unlikely that many manufacturers in the L-Category segment will be able to afford the full cost of developing their own CAV systems, and so partnerships with suppliers seems the likely route forward. A key concern here is the proliferation of more or less bespoke systems by both OEMs and suppliers (including new entrants such as Google) in a competitive race to secure the market and to control the customer relationship. This could be further complicated by the use of smartphone-based systems to deliver certain elements of connectivity and CAV, which may result in the customer interface being controlled by a party other than the vehicle manufacturer. The outcomes of this process are far from certain, but one likely outcome is that large amounts of R&D spending will be lost when there is a rationalisation of the available systems on the market (Bloomberg, 2017). Overall, there is therefore a threat to the competitiveness of the EU L-category industry if these risks are not carefully managed.

In indirect terms the longer-term question is whether the widespread adoption of CAV technologies will enable the use of mixed vehicle types on existing infrastructures and / or the reduction in the use of passive safety systems. At present this prospect is unlikely but if the vast majority of road-using vehicles are fitted with collision avoidance systems there may be a reduced need for (heavy) passive systems to absorb impact energies. In turn the reduction in passive safety systems may reduce weight, and hence fuel / energy consumption. Overall, this could lead to lower manufacturing costs and higher performance of the vehicles, thereby helping to improve profitability (assuming that market prices remain constant) and the overall competitiveness of the EU L-category industry.

The applicability of CAV to other global L-category vehicle markets is debateable. In markets such as India the vast majority of road traffic deaths and injuries occur to people that are not in a vehicle, but are vulnerable road users. Certainly, powered two-wheelers are also vulnerable road users, and an important consideration in road traffic mortalities in much of Asia for example, but the chaotic road conditions may preclude the successful deployment of autonomous car safety systems. Therefore gaining a significant advantage in CAV in the EU market may not provide any significant benefit to EU manufacturers in accessing these developing markets in the near-medium term.

5.5 Conclusions on the EU L-category vehicle industry

The ambitious regulatory environment in the EU has helped and continues to help both protect the internal market from low cost competition from markets with lower standards as well as maintain access to foreign markets, with EU vehicles being accepted worldwide. This holds particularly for the two-wheeler sub-segment where competition is more intense. Supplemented by strong brand image, new technology and lifestyle features on which EU OEMs capitalise, EU powered two-wheeler production is internationally recognised as a high-value, high-technology offering, being able to compete in the premium segments globally. In the light two-wheeler market, EU manufacturers are also able to compete on the global scale, through localised production and low cost, branded designs. The market for quadricycles, on the other hand, is less-well defined globally and as such this fragmentation has helped protect the EU market but also presents limited opportunities to export EU production.

In particular, the EU is leading in the setting of progressively stricter pollutant emissions regulations but lags behind China regarding CO_2 emissions/fuel efficiency policies directed at the L-category segment. In fact, China is the only country to have mandated fuel economy standards for these vehicles, whilst city-level pollution control policies have led to the rapid emergence of a vast e-bike industry. Regarding safety regulations, the EU has a very stringent regulatory framework but the trend towards regulatory convergence in this area will require further regulatory ambition (e.g. associated to C-ITS) if the EU wishes to remain in the lead.

All in all, EU OEMs are expected to continue to prosper in the higher-value, higher technology powered two-wheeler applications, although the production of smaller vehicles is likely to continue to be localised in order to benefit from lower labour costs. The regulatory environment could be the driving force for increased innovation in the segment, creating opportunities for EU OEMs to grow but also posing significant risks if not strengthened, for example through the introduction of low-cost Chinese e-bikes in the EU market. Table 5.3 below provides an overview of the opportunities and threats faced by EU OEMs in the L-category market given the current and expected market, regulatory and technology trends.

Table 5.3: Opportunities and threats faced by EU OEMs in the L-category market

Opportunities for EU OEMs	Threats to EU OEMs

• To develop innovation networks:
   o OEMs will need to keep pace with innovation
   o Likely to establish new relationships within and beyond the confines of the traditional L-category vehicle segment
• Take advantage of trend towards smaller vehicles in the EU due to growing congestion issues in urban centres
• Benefit from the growing global market and increased sales value of the L-category vehicle segment
   o Price competition difficult to meet but could focus on high performance, quality and design to justify premium pricing
• Benefit from growing product-service system market around the provision of Mobility-as-a-Service
	• Threat to EU OEMs is limited at present
	• Vulnerable to low-cost imports from China and India in the medium-term
	   o Due to low labour costs, easy access to materials and strong environmental regulatory framework in China
	   o Stricter safety regulations in the EU have protected the internal market from low-cost imports to-date, but these will need strengthening to maintain the regulatory barrier
	• Significant risk of regulatory shocks in China and India:
	   o Banning of ICE two-wheelers from city centres
	   o Advent of high-volume, low-cost manufacturers of two-wheelers (e.g. e-bikes)
	• Weaknesses in terms of materials:
	   o Increased use of certain materials for batteries and lightweighting
	   o Lack of sources in the EU likely to affect balance of payments

6 CONCLUSIONS AND RECOMMENDATIONS

A number of key conclusions emerge from the analysis, as described below.

In the baseline, the EU tends to have the highest production costs amongst all the markets for all vehicle segments, with few exceptions. The EU also has one of the most ambitious regulatory environments over time and therefore the **difference in production costs between the EU and the other markets is expected to shrink as regulations in these markets converge to EU levels**. This effect is further reinforced as labour costs in these countries, and especially in China and India, also increase relative to EU labour costs. Nevertheless, EU costs are expected to remain the highest until 2050 which points towards other underlying structural issues, such as overcapacity and labour relation issues. As concluded from the analysis of the cost breakdown, the EU is characterised by high levels of indirect costs when compared to other markets, which explains in large part the persistence of the EU's higher costs compared to the other markets analysed.

The analysis also revealed that the production costs of ICE vehicles are anticipated to increase continuously up to 2050, whilst the costs of BEVs and FCEVs decrease to 2050, given the increasing costs of emission control and other (e.g. safety) technologies on ICE vehicles, against a backdrop of significant learning effects related to the costs of BEVs and FCEVs through time. The change in the production costs of PHEVs is not as clear, depending on the vehicle segment, but in general terms their costs tend to increase for larger vehicles.

This is particularly valid for the luxury cars as the safety features expected to be mandated for this vehicle segment in the latter modelling years are more stringent and thus imply higher costs, which, combined with the cost of the emission control technologies, offset the cost reductions associated with learning effects from the production of PHEVs. Overall, **the production costs of xEVs tend to reach a point which is lower or close to the costs of producing ICE vehicles (and in particular diesel vehicles) by 2050, particularly for the smaller vehicle segments. This result demonstrates that production cost parity between ICE vehicles and xEVs is due to take place in the medium/long-run, whilst purchase cost parity is anticipated to be achieved much sooner, around 2018-2025. Further measures (including regulation) to foster the uptake of xEV powertrains will be key to accelerate this process**.

As costs increase due to progressively tighter regulation, profit margins also tend to go down in all markets. Profit margins are relatively low in the baseline in the EU for all vehicle segments and as such the increase in costs effectively leads to higher prices (in order to maintain the minimum profit margin set at 2%). In other markets, profit margins tend to be higher in the baseline and as such there is more scope to absorb the cost increases and maintain prices at a stable level, although profit margins also suffer in these markets. Specifically in the luxury vehicle segment, it will generally be possible to produce alternative powertrain vehicles at the same price as their ICE counterparts in these markets, which supports the EU OEMs' strategy of producing and selling high-technology branded vehicles in these markets. The same occurs in the entry-level vehicle segment in China, which makes China especially attractive for OEMs to sell xEVs profitably. The mid-range passenger cars and LCV segments, on the other hand, are more competitive (i.e. profit margins are generally low in all markets) and as such average profit per vehicle tends to be higher in the EU in the long-run than elsewhere, as prices in the EU tend to be higher.

The analysis also demonstrates that the **transition towards more stringent regulation including the advent of e-mobility, tends to benefit the EU**. Whilst the initial impact of tougher regulation is reduced profitability (average profit tends to go down by 2030), average profit tends to recover and increase in the medium/long-run compared to 2030 (although not beyond the level observed in 2017 in the majority of the cases). This is associated with the relatively low profit margins for both ICE vehicles and xEVs: as the sale of more expensive vehicles rises, they contribute to increasing average absolute profit levels in the EU, despite continued low margins. Conversely, for countries which have higher profit margins initially on ICE vehicles, the shift to xEVs leads to lower margins and decreasing average profit levels for the whole period analysed. Note that this assumes vehicle demand remains constant and profit margins remain at the minimum level of 2%. All of this contributes towards **a gradual levelling of the playing field between the EU and other markets through time**, as regulations become stricter across the globe.

The timing of the shift towards more stringent regulation and the electrification of powertrains also seems significant in determining the future profitability of OEMs in the EU. The scenario analysis revealed that the situation in which very ambitious regulation is implemented earlier in the EU is the most beneficial (scenario 3). Despite the cost increases associated with increased regulation from 2025, cumulative profits are the highest of all scenarios for this gradual approach towards regulatory leadership by 2030, since the low profit margins characteristic of the EU market contribute to further increased prices, especially those of xEVs, which in turn result in higher average profits as the penetration of xEVs rises over time. These benefits do not consider the significant potential benefit from **an ambitious regulatory environment in the EU protecting the internal market from foreign competition.** Indeed, the internal market sensitivity analysis demonstrates that EU OEMs could capture a higher share of the EU market provided foreign OEMs from countries where regulation is not as tough as in the EU cannot comply with the higher regulatory requirements in the EU. This could represent a substantial increase in profits for EU OEMs of about €29 bn cumulatively between 2030 and 2050 as estimated in scenario 2. Clear additional benefits are foreseen when considering the impacts of externalities such as reduced CO_2 emissions, pollutant emissions and accidents. Compared to a situation in which the share of xEVs remains low until 2050, CO_2 emissions are expected to reduce by about 235 Mt which is equivalent to €21.5 bn savings in 2050. A reduction in accident rates of 5% could also deliver benefits in the order of €7 bn annually.

Scenario 5, on the other hand, represents the situation which would occur if regulations were frozen at their 2020 levels; the results from this scenario show the opposite effect, namely a reduction in costs after 2020 due to the regulatory freeze, accompanied by lower profits over time compared to the baseline given the lower prices (and constant, low margins) commanded by these vehicles. For the period analysed (2017 – 2050), cumulative profits are slightly positive but the decrease in profits observed does not account for the potential significant erosion of EU OEMs' market shares both at home and abroad due to the lower regulatory ambition in the EU in this scenario.

Finally, the EU's strategy in leading the setting of progressively more ambitious legislation for environmental, pollutant emission and safety standards, as set out in the various scenarios and analysed in this study, gives EU OEMs a strong advantage when responding to regulatory shocks in foreign markets such as China. This study assessed such a scenario in China, where in this case, EU OEMs are expected, due to the EU's regulatory lead over other markets, to be able to capture significant market share at the expense of OEMs from other countries where regulation is not as stringent as in China and the EU. In this scenario, these foreign OEMs cannot maintain full access to the market due to their failure to comply with the increased Chinese regulations in time, resulting in significantly higher expected revenues and profits for EU OEMs in this market (approximately €183-€1,073 bn in additional revenues cumulatively between 2030 and 2050 and €82-€100 bn in additional profits cumulatively). This scenario is particularly relevant given recent news about China considering to toughen its planned zero emission mandate in the relatively near future.

The baseline and scenarios also have important implications for future materials demand, albeit with different magnitudes. **Higher penetration of xEVs in the market in the future will require access to scarce raw materials such as lithium, cobalt and manganese to be used in the production of batteries for these powertrains.** The increase in demand for these materials can lead both to a situation of strong resource scarcity and dependency on the small number of extracting and producing countries, many of which are politically unstable, thereby posing a potential supply risk in the future. It is therefore important that the EU maintains access to these materials and diversifies its supply of resources as much as possible. Technological improvements and associated R&D in the EU focusing on alternative material mixes for batteries will also be an important step in this direction. Finally, recycling of materials and the circular economy has an important role to play in minimising these issues. Other materials that will see a growth in demand include composites and light alloys, both of which will contribute towards lightweighting in all powertrains – however these materials tend to have a strong domestic supply within the EU and do not suffer from the same external dependency issues. Nevertheless, maximising recycling rates for these energy-intensive materials will help to minimise both their cost and their environmental footprint in the future.

From a wider economy perspective and when considered in isolation, the implementation of progressively more stringent regulation is expected to slightly reduce GDP, private consumption and to some extent employment in the EU. When taking into account the role of regulation in protecting the internal market and reducing transport externalities (CO_2 emissions, air pollutant emissions, accidents) however, the outlook is much more positive, with a significant swing towards positive GDP impacts in particular – thereby demonstrating that more ambitious regulation can have a positive impact on the wider economy.

The negative impact of regulation is linked to the effect on private consumption. As the costs of regulation increase, manufacturers are assumed to pass these costs on to consumers via higher prices (in order to maintain the minimum 2% profit margin assumed). In turn, this results in lower disposable income for consumers to spend on other goods and services in the economy, which ultimately has a negative impact on the economy. The model shows that the negative impacts on employment reduce over time and the change relative to the baseline becomes positive by 2050. At an industry level, the increased regulation scenarios benefit those sectors directly linked to the automotive industry, and in particular those involved in the supply chain for batteries and power electronics, given the increase in demand for these technologies due to an earlier and stronger shift to e-mobility. Note however that this tends to lead to an increase in imports in these sectors, given the relatively strong position of the Asian markets in supplying these products, compared to the EU. Other traditional automotive supply industries are negatively affected as demand for their products decreases, such as the steel industry, whilst lower disposable consumer income also has a negative impact on unrelated industries, as described previously. Demand for energy generation is positively affected as a greater proportion of transport energy is derived directly from electricity, whilst **oil imports are significantly reduced**, helping to improve the EU's energy independence.

When considering the full impacts of regulation on the internal market however, the small negative impacts on GDP described above become very positive. This sensitivity analysis performed on scenario 2 considers the situation in which non-EU OEMs are partially excluded from the internal market as they are not able to comply with the higher regulatory level. Stricter regulation also brings about strong benefits in terms of reduced transport externalities. **The early electrification of powertrains in the scenarios is responsible for larger savings in CO_2 emissions which result in important benefits regarding climate change prevention**. In addition, **other local pollutant emissions are anticipated to fall and their associated health impacts are thus minimised**. **These benefits are associated with the lower fuel consumption which also contributes to reducing imports into the EU and reducing the external dependency of this commodity**, as described above. On the other hand, electricity use increases and the sources of energy used for this can impact the final outcome on CO_2 and pollutant emissions, although the overall impact is strongly positive. Accident rates will also be reduced with stronger regulation, bringing about significant socio-economic benefits in this area as well. Finally, it is also worth considering the **benefits of establishing domestic battery production in the EU**. The analysis shows that the continued import of batteries (assuming no domestic production) can be detrimental to GDP and employment. This illustrates the importance of supporting the development of the EU industry associated with e-mobility.

From an economic perspective, stricter regulation that jumps to the highest regulatory level in one go in 2030 (scenario 2) is the most beneficial to the EU economy, delivering aa positive impact on GDP from 2025 onwards (increasing GDP by about 0.5% in 2030 against the baseline)**, when considering the impacts on the internal market** (not accounting for the quantification of external benefits: savings in CO_2 emissions are expected to account for €34-€58 bn cumulatively between 2020 and 2050; nor taking into account the benefit of developing domestic battery production capacity: if all batteries were to be imported into the EU, this could represent €24 bn in additional imports in 2050, which is expected to have significant negative impacts on GDP and employment)**.** Conversely, the scenario in which regulation is implemented gradually to overshoot the current level (scenario 3) entails the worst overall performance across the four main scenarios considered from an economic perspective, despite bringing the highest socio-economic benefits. Note that the scenarios also fail to quantify the impacts of regulation on innovation and the opportunity for OEMs to differentiate their products and possibly charge higher premiums – this is a potentially significant secondary benefit that should also be noted.

The higher regulatory ambition demonstrated by scenario 2 shows significant additional benefits when considering a possible future regulatory shock in China, in which the EU is able to capture additional market share from other OEMs which are not able to fully comply with the increase in regulatory stringency. When combined with scenario 2, the China case illustrates the benefits for the EU economy from the additional opportunities afforded by an overall stricter regulatory environment. The model concluded that, **in the China case, scenario 2 reinforces the positive impact and leads to a higher increase in GDP relative to the baseline** (GDP is expected to increase over time and reach 0.23% above the baseline in 2050 in the high scenario, or about €800 bn cumulatively between 2020 and 2050)**.** This is associated with the **additional EU exports and revenues accrued to the EU OEMs in China which occurs in addition to the socio-economic benefits and internal market benefits described previously.**

All in all, a situation in which regulation matches the most stringent global standards from 2030 in one go (scenario 2) represents the least extreme situation, resulting in the most positive impacts for the home economy of all the scenarios considered. In the event of a regulatory shock occurring in an overseas market, it can enlarge the positive impacts for the OEMs operating in that market. It is also important to take into account the additional benefits regarding lower CO_2 and other pollutant emissions and reduced accident rates, their associated impacts on health and climate change as well as the reduced dependency on foreign oil. All of these contribute towards a broadly positive picture with regards to progressively more ambitious regulation.

6.1 Key conclusions from the analysis of the Tier 1 supply industry

6.1.1 Impacts of a 100% EV transition

The impact of a full EV transition on the automotive industry supply chain is mixed. Historically, OEMs led most innovations and contracted suppliers to produce parts they needed. However, in the future suppliers may compete, or even outpace OEMs in terms of innovation, particularly new-entrant high-tech specialist suppliers. Those with strong exposure to the e-mobility megatrend (e.g. Continental or Valeo) are likely to outperform industry growth, whereas those with large ICE vehicle businesses (e.g. Faurecia and Schaeffler) are likely to underperform. Fewer parts per vehicle reduce the need for servicing and maintenance which will affect dealerships and spare parts suppliers, and the 'new entrant' semiconductor (e.g. Infineon, NVIDIA, Intel) and electronics and software providers (e.g. 'electronic giants' such as LG, Panasonic and Samsung) will be the primary beneficiaries of the rising electronic and digital content in EVs, putting margins and market shares of traditional suppliers under pressure.

OEMs and traditional Tier 1 suppliers are working aggressively to catch up, but adapting to rapid technological changes while keeping prices competitive will be a major challenge for both the traditional automotive industry and technology sector newcomers. Ultimately, the impact on the supply chain of an EV world may be a decreased proportion of value going towards traditional Tier1 suppliers and an increased proportion going to competitive new entrant-suppliers. Partnerships and M&As (mergers and acquisitions) between both sectors seems, in many situations, a likely way forward for many suppliers (and indeed an avenue that is already being pursued by some). Indeed, traditional Tier 1 suppliers will need to further adapt their product portfolios and internal capabilities to the car of the future and at the same time, electronics giants and specialist companies as new entrants in the automotive industry will need to seek access to potential automotive customers. The partnership approach may therefore be a good way to enable Tier 1 suppliers to keep a presence in this rapidly changing industry.

6.1.2 Impacts of high penetration of CAV technology

Within the rapidly evolving automotive industry, autonomous driving capability is likely to become one of the main features of new vehicles offered. This could benefit well-positioned Tier 1 automotive suppliers in terms of a new revenue potential, as well as new technology entrants into the automotive market. However, this could be at the expense of conventional OEMs as business models rapidly evolve and value shifts increasingly from hardware (which may be increasingly seen as commoditised) to software capability.

Tier 1 suppliers e.g. Bosch, ZF/TRW, Continental, and Schaeffler will face a range of challenges. They need to maintain a competitive position as high-quality suppliers and decide between two strategic directions: either move upward in the old pyramid structure and expand their offering to meet new demands, thereby potentially displacing OEMs from some areas of specialist hardware supply; or they could shift the focus of their value creation from hardware, to also include increasingly valuable software. The latter is thought to be the best option, meaning in the short term making R&D investments in sensors, devices, and other critical components, and in the long term establishing strong reputations as software, as well as hardware, suppliers.

OEMs and Tier 1 suppliers are aware that they do not have the internal capabilities to continue to succeed on their own in the automotive industry, in terms of software capabilities. As the industry moves further into the world of CAVs, they risk being outpaced by, and surrendering increasing portions of value creation to, third-party providers. In certain sectors, OEMs and Tier 1 suppliers are also facing a race for innovation against new entrant providers, for which they will need to try to remain at the forefront, in order to maintain their market presence. This trend is already being seen in the automotive software sector, especially infotainment, with OEMs and Tier 1 suppliers developing their own systems, but the threat of new entrant players (such as Apple, Google and Baidu bringing this technology to the industry) being high.

Given these potential threats and the limited native capability in these new areas amongst many Tier 1 suppliers, it is unlikely that players will have the full capability to cover all the diverse elements of a connected and autonomous mobility experience across the value chain. As a result, OEMs and Tier 1 suppliers will likely need to consider acquisitions or partnerships to provide end-to-end connected and autonomous solutions and to maintain market presence if in house product development isn't viable. Whilst it is not possible to know which players will dominate at this stage, future strategic alliances/acquisitions and the choice of core competencies are likely to be key in deciding which incumbent Tier 1 suppliers will have the greatest success in the CAV space. Players that are most likely to seek a part in these partnerships include well-known global technology and software leaders money (e.g. large Silicon Valley players such as Google, Apple, Tesla and Uber), as well as other specialist suppliers with the capability to invest in key new technologies, such as Intel and NVIDIA).

Some players have already acted to gain access to capabilities, technologies, skills and cloud-based platforms: Toyota has invested in Uber; Mercedes, BMW and Audi have acquired Here; GM has invested in Lyft; Apple has invested in Didi Chuxing; Daimler has invested in Mytaxi; VW has invested in Gett; BMW has developed its DriveNow service; Bosch is cooperating with TomTom; and IBM and Cisco are cooperating with Continental. The trend of automotive players developing partnerships is expected to continue, and currently 57% of automotive executives predict opening their software /API to third parties or external software developers (McKinsey & Company, 2015) . As more alliances begin to form however, there is a risk that other players could be left behind.

6.2 Key L-category conclusions from analysis

6.2.1 For EU manufacturers

Despite efforts to achieve regulatory convergence, for example via UNECE, free trade agreements, etc., the L-category vehicle segment is likely to continue to be defined in very different terms in the EU, in the US, in Japan, and in other key markets such as India and China – owing in part to the very different applications of these vehicles in the different markets, as well as current regulatory differences. This feature will both help protect the existing EU industry from imports, but also hinder the scope for the industry to achieve exports.

The EU automotive industry is unlikely to be a passive observer of vehicle concepts that lie somewhere between the bicycle and the car. Neither will much of the EU components and sub-systems suppliers simply rely upon their existing OEM customers to pull forward new projects. Rather, the stage is set for a range of new innovative mobility concepts to be developed by EU L-category manufacturers and for the L-category to be reinvented if sufficient regulatory space is allowed for it so to do. Indeed if, as expected, the EU continues to maintain its regulatory lead in the L-category sector, this will provide an additional driving force for innovation and a significant barrier to entry for foreign-manufactured vehicles.

Existing L-category segment participants will likely play a major part in developing new and innovative products, but this will rely on the creation of new innovation networks and new relationships within and beyond the confines of either the traditional L-category segment or the existing automotive industry. These new innovation networks will help to shape the future of non-car personal mobility in the EU, and in turn define the possibilities for the continued health of the segment for EU manufacturers both within the EU market and in export markets.

As part of these changes, it is to be expected that the L-category segment in the EU will be a beneficiary of wider developments in the automotive industry. For example it is already the case that established automotive suppliers such as Bosch and Continental have used some of the expertise and knowledge gained in the supply of EV systems to M-Category vehicles, to develop a presence in the e-bike segment. Other examples include ZF, which is an active participant in the e-go project in Aachen (for an electric bus) while the bearing manufacturer Shaeffler has shown its own 'micromobility bio-hybrid' (Schaeffler, 2016) and purchased a manufacturer of micro electric motors to build on its 'mobility for tomorrow' strategy.

A technologically-advanced EU L-category industry will be able to develop new markets to maintain and grow its presence in the EU, benefitting from trends such as the switch towards smaller, nimbler and zero emission mobility in city centres. Outside the EU, notwithstanding the market diversity noted throughout this report, EU L-category manufacturers could at least expect to be competitive in non-EU markets at the premium end of such markets for a considerable time to come. Whether vehicles will be produced in the EU and then exported is less certain, there may be strong pressures to localise production in the markets to be served or to form partnerships with domestic incumbents in those markets. However, the continuation and growth of production within the EU is likely to be supported by the fact that the initial market for these new technologically advanced products will be in the EU, and this could serve as a future export platform.

Another significant opportunity for growth exists with the rapid growth of light two-wheeler mobility in markets such as China and India. With existing capacity to produce vehicles and local partnerships in those regions, the EU L-category industry is already well placed, however it is at significant risk of regulatory shocks, such as the banning of ICE two-wheelers from various city centres in China, as well as from the advent of high-volume, low-cost local manufacturers of two-wheelers such as e-bikes. It will be very difficult for the EU to compete in these new markets given its higher-quality but more expensive product portfolio and it may choose instead to focus on higher-value products drawing on its extensive innovation in the EU market.

Regarding the location of production, interviews with stakeholders revealed an important difference regarding the type of vehicles whose production is expected to be relocated and moved closer to local markets. One example is India, where manufacturers are establishing production driven by the low labour costs and the increasing quality of components, progressively meeting expectations regarding environmental and safety trends. Examples of partnerships between European and Indian companies include KTM with Bajaj and BMW with TVS. By relocating production, manufacturers also avoid the high import duties in India and are able to sell their low/mid-end products as a high-end product in the local market. The same vehicles can also be imported into the EU as entry-level or mid-range products, as is the case for the KTM Duke bike. The production of high-end vehicles, on the other hand, is less likely to be delocalised as sales in those markets are expected to be low, targeting only a small and wealthy class which can afford the high import duty. Instead, they are anticipated to remain being produced in the EU and then exported into India and other foreign markets.

6.2.2 For the EU market

There seems to be an appetite at policy level for the use of smaller, more tailored mobility solutions and this, combined with a desire to restrict the access of ICE M-category vehicles from urban areas would suggest that the future market for the L-category segment in the EU should be greater than it is now. Furthermore, as noted elsewhere in this report, the L-category segment varies substantially across major world markets, and hence lacks the homogenous quality of the M-category segment. As such, while many markets outside the EU appear also to have an appetite for developing distinct varieties of L-category vehicle, the resultant diversity of products is likely to reduce the scope for global integration and therefore the threat to the EU market from foreign imports.

Nevertheless, three possible threats to the EU L-category segment seem important as a result of the research undertaken for this report. First and most obvious is the possibility of low-cost imports from markets such as China based upon an adapted and perhaps higher quality version of the LSEV segment vehicles. Second, and less obviously, is the possibility that the Japanese Micro Commuter concept will be developed further. There is a perception that the Japanese vehicle manufacturers were somewhat hampered by the kei class segment in Japan, because investments into this segment could only be amortised in the Japanese market. Similarly, US M-category OEMs may have suffered because cars designed for the US market had limited appeal in other markets. European cars, particularly those in the premium segment, have been accepted by many markets around the world. So, it is reasonable to expect a stronger export push from Japan if the Micro Commuter concept is adopted for the domestic market. Third, the lower and middle value segments of the powered two-wheeler market remain vulnerable to imports from Asia in particular, if appropriate market surveillance is not carried out. Such a competitive threat could undermine overall volumes for both the final assemblers and for suppliers.

Global harmonization of the market definitions of L-category segment vehicles is not a realistic prospect at present and hence regulatory convergence is unlikely beyond some generic safety and emissions concerns.

6.2.3 For the EU economy

Growth in the L-category segment of producers and in the market will have significant economic benefits for the EU economy even if cross-border (i.e. in and out of the EU) trade is likely to be modest in the short term. Protection and nurturing of the segment now will enable the formation of a technologically advanced industry with a global technological lead over its international peers. This modernised L-category industry will be ideally positioned to capture not just the increased sales value of the L-category segment and of new two- and four-wheel mobility concepts, but also what is likely to be a strongly growing product-service system market around the provision of mobility as a service both individually and collectively. This shift into in-use revenue streams will constitute a significant challenge to the industry, as illustrated by the low profitability of existing e-bike sharing schemes and the need for local or state-support for different car-sharing schemes.

Furthermore, the industry has some identifiable gaps or weaknesses that might have economic consequences, notably in terms of advanced materials for powertrains (including batteries) or structural applications (such as lightweight structures). If supply tightens relative to demand then import costs for such materials will rise to the overall detriment to the balance of payments.

Nevertheless, the benefits to the EU economy will flow from both the vehicle manufacturers and also from the EU automotive components and materials industry. Not only will manufacturing operations benefit, there will be jobs retained in high-value activities in research and development in both hardware and software. The EU balance of trade in the automotive sector can be preserved if the right regulatory framework and a supportive R&D environment is provided. Secondary economic benefits might include reduced social costs arising from reductions in the number and severity of road traffic incidents.

6.3 Recommendations for the EC

The conclusions outlined above reveal areas where the EC can play a role to enhance and strengthen the EU automotive industry in the context of disruptive innovations and global trends in regulation. This section identifies key steps the EC could take to ensure the EU automotive industry is best positioned to take advantage of these global trends and ensure it maintains or grows its market share both in the EU and in key foreign markets. It provides recommendations focusing on M1/N1 – category vehicles (section 6.3.1), the supply chain associated to the EU automotive industry (section 6.3.2) and L-category vehicles (section 6.3.3).

6.3.1 M1/N1 – category vehicles

1. *Ensure that the benefits of additional regulation outweigh the additional costs to the EU industry*

The study shows that the increase in stringency of regulation can deliver significant net benefits if certain conditions are observed. The EC can work towards guaranteeing that the additional costs to the EU industry are accompanied by benefits by designing regulation that help both protect the internal market from low-cost competition, as well as engaging in efforts at the international level to design and align regulation, thereby helping the EU industry maintain and expand access to key foreign markets.

As regulation is tightened around the world, securing preferential access to the Chinese and other high-growth markets will be essential to support the viability and profitability of the EU industry. The China case scenarios demonstrate that setting progressively stricter regulation can be advantageous when responding to a regulatory shock in a foreign market. In these scenarios, EU OEMs are expected to maintain full access to the Chinese market and, if supported by activities at the EC level and at the international level, could gain additional market share from other foreign OEMs as EU OEMs are able to comply with the higher stringency of regulation. These scenarios represent €183 - €1,073 bn in additional revenues cumulatively (or €82 - €100 bn in additional profits) for EU OEMs, compared to €100 - €973 bn in additional costs cumulatively. In order to reap these benefits, the industry will need to respond accordingly, by making the necessary investment in order to innovate and adopt the required technologies which will enable them to compete globally.

To ensure a successful response to a regulatory shock, the EC should continue to ensure its regulatory lead and support the industry in maintaining access to these high-growth markets. Recent announcements and global trends seem to validate the likelihood of a regulatory shock happening in China. The country is already implementing stricter regulation: in the air pollutant emissions regulatory framework China 6b already sets limits beyond Euro 6 RDE; in the CO_2 emissions regulatory domain, China is designing an ambitious ZEV mandate and setting a target date for the gradual replacement of ICE vehicles. These events require swift action in the EU regulatory environment accompanied by regular talks with Chinese authorities to ensure EU OEMs are able to maximise opportunities from selling their technologically-advanced solutions into the market.

The strengthening of regulations worldwide can also represent significant risks for EU OEMs in their home market. Until now, the high stringency of regulation has prevented the EU market from being flooded with cheap imports from foreign markets. As regulations tighten in those markets, the EC must continue ensuring that high standards prevent low-cost entrants from accessing the EU market. Increasing the regulatory ambition further in the EU could yield significant additional benefits for the EU automotive industry, by excluding larger numbers of foreign OEMs from the EU market. Indeed, the internal market sensitivity analysis shows that taking the regulatory lead can not only support EU OEMs in maintaining their market share in the EU, but also gain additional market share at the expense of foreign OEMs which are not able to comply with the stricter regulatory level. These scenarios represent approximately €1,429 bn in additional revenues cumulatively (or €29 bn in additional profits) for EU OEMs, compared to €1,400 bn in additional costs cumulatively. Protecting the EU from low-cost, non-compliant options will also be important in protecting the internal market, requiring greater market surveillance to ensure products entering the EU are in compliance with the regulation in place. This could be achieved through revisions of the type approval framework to enforce market surveillance aspects.

2. Help support profitability in the EU automotive industry

The study shows that the profitability of EU automotive OEMs is expected to suffer at first as regulation is tightened. Nevertheless, it is expected to recover over time as vehicle demand is expected to remain unchanged and able to accommodate the changes in prices driven by the investment in new technologies. In order to ensure that increased absolute profits accompany the increase in costs, the EC should work towards supporting continued demand in the EU automotive industry in the future. The mass uptake of xEVs will not only require efforts on the supply side through stricter regulation on CO_2 and air pollutant emissions as assessed in this study, but also support through existing funding mechanisms and cooperation with the European Investment Bank to assist the automotive industry with cost reductions and deployment of infrastructure (as described in more detail in recommendation 3). Demand-side measures will also be key to ensure continued strong demand for these vehicles. At the EC level, these include guidelines on financial incentives and structural funds to some extent.

It is important to note that any increase in absolute profits occurs in a context of very low profit margins today in the EU market. One particular weakness contributing to low profitability in the EU revealed by the analysis lies in the high level of indirect costs that characterise the EU automotive industry. The analysis shows that although average production costs for different vehicle types and drivetrains are expected to converge over time between international markets, the EU remains the location where vehicle production is the most expensive out to 2050, with a large part of this additional cost associated with high indirect costs. There are known structural issues in the EU automotive contributing to these high costs, for example excess manufacturing capacity, high labour costs, etc. To tackle this issue, the EC should support the EU automotive industry as it seeks to reduce its uncompetitive overheads, through ensuring that it is able to effectively streamline manufacturing and increase the use of automation, whilst also supporting it as it seeks to become a global leader in the development of manufacturing 4.0. To this end, the EU can provide financial support to encourage and facilitate collaboration and strategic alliances which help companies share the costs of R&D investments as well as to develop new business models.

On the other hand, the analysis also revealed that high profitability can be attained in foreign markets, particularly in the luxury vehicle segment. This is particularly important considering that markets such as China and India have a high growth potential and thereby represent substantial opportunities in terms of market size and value for EU OEMs.

In order to diversify the source of profits and attain new opportunities, the EC can help the EU OEMs secure access to high-margin and high-growth foreign markets. This will be particularly important in the context of stricter regulatory environments that can pose a risk to EU OEMs if excluded from these markets. The China case scenarios illustrate the benefits of maintaining the regulatory lead which have been described above. Removing barriers to trade and obtaining beneficial trade agreements can also be important to reinforce the presence of EU OEMs in these markets.

3. *Focussing efforts on cost reduction initiatives whilst maintaining ambitious plans for regulation*

The study demonstrates that cost increases are expected due to the advent of disruptive innovations such as e-mobility and CAV technologies. In particular, efforts should focus on reducing the costs of xEVs and addressing the costs associated with CAVs which are due to become significant components of overall costs in the future. The analysis also revealed that the EU industry has considerably higher levels of indirect costs which can also be targeted for cost reductions, as discussed above.

The production costs of xEVs should be a primary target for reductions. The analysis shows that over time their costs are expected to come down as battery efficiency improves. xEVs nearly achieve cost parity with ICE vehicles, especially in the case of the smaller segments but there is still room for improvement. There are areas which could benefit from additional resources for research given the limited native production capability for key technologies such as batteries in the EU. The EC can play a role in spurring innovation and supporting research in these areas. Combined with the measures that support the uptake of xEVs (both supply and demand side), research can further contribute to achieve learning effects and economies of scale as to bring costs down – thereby helping to ensure that OEMs can maintain margins without needing to significantly alter pricing of their products. By seeking enhanced compliance of more ambitious regulation (also via the revision of EU type approval), piecemeal regulatory efforts by local authorities limiting the sales of certain technologies can be avoided, thereby assisting in achieving the economies of scale required to provide additional leeway for cost reduction.

The analysis also shows that higher levels of automation can incur significant additional production costs. Similarly to xEVs, the EC can support research and funding in this area, to ensure that these technologies, which represent very high R&D and future production costs for OEMs, do not place an unmanageable burden on the future costs of vehicles.

By supporting the development of affordable EU capability in both the xEV and automation technology areas, the EC can not only contribute to ease the burden on manufacturers but also support new industries in the EU whose major players are currently mostly based outside the EU. Specific areas where the EC can assist include through Public Private Partnerships (PPPs), where it can support the funding of large scale testing and commercial deployment, via the Important Project of Common European Interest (IPCEI) initiative, and the deployment of infrastructure, with help of the Trans-European Networks (TENs) and the Connecting Europe Facility (CEF). Recommendations on the supply chain are provided in section 6.3.2.

6.3.2 Automotive supply chain

4. Minimise risk from increased reliance on non-native materials linked to e-mobility

The advent of e-mobility is expected to give rise to important impacts on the trade of commodities used by the automotive supply chain. In particular, the increased production and use of batteries and electric motors requires access to scarce materials which are often located in a small number of relatively unstable regions of the world.

To minimise the risks from relying on scarce and non-native materials, the EC should focus efforts on research regarding alternative material mixes for batteries and electric motors, whilst also maximising efforts to recycle these materials within the EU, in order to diversify and potentially reduce material demand from foreign markets. Efforts on material recycling could be included in the activities to implement the Circular Economy Action Plan, which aims at reducing waste and maintaining the value of resources for longer in the economy (European Commission, 2015). Securing reliable primary suppliers will also be instrumental to reducing risks from relying on unstable supplier regions - the EC could look at establishing trade agreements to secure preferential access to these markets.

5. Support the development of a technologically-advanced e-mobility supply industry

The shift towards e-mobility has the potential to significantly reduce the content on vehicles derived from OEMs and traditional Tier 1 suppliers. In particular, much of the traditional automotive industry is poorly-equipped to supply the relatively simple, but highly capital-intensive components such as batteries, or battery management systems, with most of the major global players originating outside of Europe, e.g. in Japan, Korea and the US.

In order to ensure that the EU-made content on xEVs remains high, the EC should seek to support the development of native capability in these crucial technology areas. Initiatives such as its Flagship battery initiative and R&D funding to support the development of these capabilities could go some way towards achieving this aim and securing an ongoing role for the traditional EU automotive industry in the future production of xEVs.

6. Support the development of a technologically-advanced industry associated with CAVs

The developments in CAVs are likely to shift value creation in the industry away from hardware to software capability. This is anticipated to have significant impacts on both traditional OEMs and Tier 1 suppliers which tend to lack capability in software development, but also constitutes an opportunity to capture new revenue if the EU industry is well-positioned. It is worth noting that strong players in this field include global technology and software companies which are mostly located outside the EU (e.g. large Silicon Valley players).

In order to develop a technologically-advanced industry with strong CAV capabilities, strategic cooperation will be required to facilitate the transition towards a redefined value chain. The EC should seek to support the EU industry in this transition and contribute to the development of the necessary native software capabilities, in order to benefit from the potential revenues generated by this growing trend and create a strong industry in this area capable of competing worldwide.

6.3.3 L – category vehicles

7. Given the EU's leading role in global harmonisation, ensuring high standards are followed and supporting other world regions do not "cherry pick" requirements

The EU has been leading discussions at the UNECE level for the definition of increasingly stringent regulation for L-category vehicles worldwide. Its role at the global level has supported the harmonisation of an otherwise fragmented market which has been essential to expand the market opportunities for EU OEMs externally. This is particularly important given that EU market is only expected to grow marginally.

The EC should continue following this approach by ensuring that high standards are followed by other regions in their entirety, so as to avoid further fragmentation of the market. This can be complemented by bilateral dialogues and trade policy activities, which in turn are expected to reinforce efforts at the UNECE level.

8. *Seek removal of barriers to trade in key powered two wheelers markets*

The market for L-category vehicles is only expected to grow marginally in the EU and in traditional foreign markets (Japan, the US). Conversely, the highest growth is anticipated to occur in emerging economies. It is thus essential for EU OEMs to gain access to these markets, in order to further expand their market opportunities.

The EC can play a role in removing trade barriers together with harmonising international standards (as described in recommendation 5), in order to help EU OEMs increase their export opportunities. Other aspects such as patent protection should also be considered to ensure the protection of the EU industry.

9. *Implement market surveillance requirements foreseen in Regulation 168/2013, to ensure fair competition, a level playing field and consumer protection, preventing non-complying products (e.g. low quality products from Asia – mainly China) from entering the EU market [this principle applies also to electric bicycles]*

The biggest threat to EU OEMs in the L-category market arises from low-cost imports from foreign markets such as China and India. Although regulatory requirements are still stricter in the EU, especially those associated with safety regulations, China and India are catching up and exporting increasing volumes of products to the EU market. This will become even more relevant as China in particular exploits its lead in developing e-bikes for the global market. Protecting the EU from low-cost, non-compliant options will require greater market surveillance to ensure the large share of products entering the EU are in compliance with the regulation in place. As such, the EC should ensure that market surveillance mechanisms are implemented as defined in Regulation 168/2013, thereby ensuring fair competition and consumer protection and preventing non-complying products from entering the EU market. This effort should also be extended to M1/N1-category vehicles.

10. *Support research in vehicle technology, for electric L- category vehicles (dedicated batteries and battery management systems)*

Similarly to M1/N1-category vehicles, e-mobility will transform the L-category market. There is a growing trend towards smaller, zero emissions commuter vehicles in the EU, whilst in other markets and particularly in China, a combination of CO_2 standards targeting two-wheelers and the banning of ICE two-wheelers from certain city centres has fostered demand for electric L-category vehicles.

The strength of the EU industry has traditionally been based in design innovation alongside technology innovation. The advent of e-mobility can be an opportunity for EU OEMs to capitalise on these strengths and reinforce their presence in foreign markets dominated by low-cost production. Nevertheless, the EU industry is not currently well-placed in the e-mobility space, with limited native production capability for key technologies such as batteries, battery management systems, etc. The EC can play a role in supporting EU OEMs with their R&D efforts in this area. This is particularly important for L-category vehicles since e-mobility represents a significant cost burden to OEMs whose products start from a low cost base. Nevertheless, it also applies to M1/ N1- category vehicles as addressed in recommendation 3 and the overall automotive supply chain as discussed in recommendation 10.

11. *Support ITS developments targeting L-category vehicles*

ITS developments have focused mainly on M1/N1-category vehicles but the application of these technologies and their impacts should also be considered for powered two wheelers. ITS applications have a high potential to improve the safety of vulnerable road users including those using powered two wheelers. The EC should thus support research on ITS developments that take into account L-category vehicles, in addition to the review of the General Safety Regulation (GSR).

7 REFERENCES

AARP, 2016. *Automatic Emergency Braking Systems Are About to Be Everywhere.* [Online] Available at: http://www.aarp.org/auto/driver-safety/info-2016/automatic-emergency-braking-systems.html#quest1

ACEA, 2015. *Regulation and Competitiveness of the EU Automotive Industry,* s.l.: s.n.

ACEA, 2017. *European Automobile Manufacturers Association.* [Online] Available at: http://www.acea.be/statistics/tag/category/world-production

ACEM, 2016. *The safe ride to the future - The motorcycle industry's commitment to road safety.* [Online] Available at: http://www.acem.eu/images/publiq/2016/The-safe-ride-to-the-future---ACEM-road-safety-strategy.pdf

Allied Market Research, 2016. *Europe Electric Motor Market Report,* s.l.: Allied Market Research.

Anon., 2007. *Limits and measurement methods for the emissions of pollutants from motorcycles on the running mode (CHINA stage III).* [Online] Available at: http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/dqydywrwpfbz/200704/W020120104512013466312.pdf

Anon., 2007. *GB18176-2007, Limits and measurement methods for emissions of pollutants from mopeds on the running mode (CHINA stage III).* [Online] Available at: http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/dqydywrwpfbz/200704/W020120104514001226749.pdf

Anon., 2009. *Regulation 443/2009/EC of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles.* [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0001:0015:EN:PDF

Anon., 2013. *Implementation Regulations of the Atmospheric Environment Act, as Amended 24 May 2013 (in Korean).* [Online].

Anon., 2013. *Regulation (EU) No 168/2013 of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles.* [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:060:0052:0128:EN:PDF

Anon., 2014. *Limits and measurement methods for emissions from motorcycles (CHINA IV), Draft regulation.* [Online] Available at: http://www.mep.gov.cn/gkml/hbb/bgth/201409/W020140928401243501792.pdf

Anon., 2014. *Regulation (EU) No 333/2014 of 11 March 2014 amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars.* [Online] Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0333&from=EN

Anon., 2016. *Corrigendum to Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles.* [Online] Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2016_077_R_0004&from=EN

Argonne National Laboratory, 2007. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model 2, Version 2.7.* s.l.:UChicago Argonne, LLC. as Operator of Argonne National Laboratory under Contract No. DE-AC02-06CH11357 with the Department of Energy (DOE).

Association for the Advancement of Automotive Medicine, 2003. *Benefits of Seat Belt Reminder Systems,* s.l.: PMC.

ATKearney, 2016. *How Automakers Can Survive the Self-Driving Era,* s.l.: ATKearney.

autoblog, 2014. *A window into China's low-speed electric vehicle revolution.* [Online] Available at: http://www.autoblog.com/2014/07/25/a-window-into-chinas-low-speed-electric-vehicle-revolution/

autocar, 2016. *ABS to be standard on two-wheelers in India.* [Online] Available at: http://www.autocarpro.in/news-national/abs-standard-fitment-125cc-wheelers-india-april-2018-16877

Autoevolution, 2013. *ADAC Rates BMW's Pedestrian Protection System as Satisfactory.* [Online] Available at: https://www.autoevolution.com/news/adac-rates-bmws-pedestrian-protection-system-as-satisfactory-video-71109.html#

Automotive News Europe, 2017. *VW to build EV motors at transmission plant in China.* [Online] Available at: http://europe.autonews.com/article/20170704/ANE/170709924/vw-to-build-ev-motors-at-transmission-plant-in-china

Automotive News, 2013. *Japan's Toray buys stake in U.S. supplier Plasan Carbon Composites.* [Online] Available at: http://www.autonews.com/article/20130719/OEM10/130719834/japans-toray-buys-stake-in-u.s.-supplier-plasan-carbon-composites

Automotive News, 2014. *Suppliers bet big, try new techniques to ramp up production.* [Online] Available at: http://www.autonews.com/article/20140519/OEM10/305199964/suppliers-bet-big-try-new-techniques-to-ramp-up-production

Autotrader, 2014. *Trend Watch: Adaptive Cruise Control.* [Online] Available at: https://www.autotrader.com/car-tech/trend-watch-adaptive-cruise-control-227409

bcg perspectives, 2015. *Revolution in the Driver's Seat: The Road to Autonomous Vehicles.* [Online] Available at: https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/?chapter=4#chapter4

BIKE Europe, 2016. *China Bans E-Bike Use in Major Cities.* [Online] Available at: http://www.bike-eu.com/home/nieuws/2016/4/china-bans-e-bike-use-in-major-cities-10126136

Blackrock, 2017. *Future of the vehicle - Winners and loosers: from cars and cameras to chips,* s.l.: Blackrock Investment Institute.

Bloomberg, 2016. *China to Grant Low-Speed Electric Car Producers Legal Status.* [Online] Available at: https://www.bloomberg.com/news/articles/2016-10-17/china-plans-to-grant-low-speed-electric-car-makers-legal-status

Bloomberg, 2016. *Volvo Plans to Offer Fully Self-Driving Car to Luxury Buyers.* [Online] Available at: https://www.bloomberg.com/news/articles/2016-09-29/volvo-plans-to-offer-fully-self-driving-car-to-luxury-buyers

Bloomberg, 2017. *Billions Will Be Blown in Race to Field First Self-Driving Cars.* [Online] Available at: https://www.bloomberg.com/news/articles/2017-07-12/billions-will-be-blown-in-race-to-field-first-self-driving-cars

Bloomberg, 2017. *The Scooter Wars Are Getting Electric in Paris.* [Online] Available at: https://www.bloomberg.com/news/articles/2017-06-15/bosch-enters-paris-electric-scooter-fray-as-diesel-loses-favor

Bosch, 2016. *The eBike market has the wind behind it.* [Online] Available at: www.bosch-ebike.com

British Geological Survey, 2015. *European Mineral Statistics 2009-13.* [Online] Available at: http://bgs.ac.uk/mineralsuk/statistics/europeanStatistics.html

Business Insider UK, 2016. *One dramatic chart shows why electric cars are about to become mainstream.* [Online] Available at: http://uk.businessinsider.com/electric-vehicle-battery-cost-decreases-2016-3?r=US&IR=T

Business Standard, 2014. *Airbag costs will put off new car buyers: Tata Motors.* [Online] Available at: http://www.business-standard.com/article/companies/airbag-costs-will-put-off-new-car-buyers-tata-motors-114112500142_1.html

CAP HPI Consulting, 2016. *EU Commission _ UK Automotive Study on the Pricing and Fitment of Optional Extras to Passenger Cars and Light Commercials.* [Online] Available at: https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/uk_automotive_study_en.pdf

Car and Bike, 2016. *Honda And Yamaha Announce Possible Collaboration For Small Scooters In Japan.* [Online] Available at: http://auto.ndtv.com/news/honda-and-yamaha-announce-possible-collaboration-for-small-scooters-in-japan-1470514

Car and Bike, 2016. *Tork Motorcycles Introduces India's First Electric Bike T6X; Will Be Priced At ₹ 1.25 Lakh.* [Online]

Available at: http://auto.ndtv.com/news/tork-motorcycles-introduces-indias-first-electric-bike-t6x-will-be-priced-at-rs-1-25-lakh-1397927

Casualty Actuarial Society Automated Vehicles Task Force, 2014. Restating the National Highway Transportation Safety Administration's National Motor Vehicle Crash Causation Survey for Automated Vehicles. *Casualty Actuarial Society E-Forum, Fall 2014-Volume 1*.

CEBR, 2015. *Britain's Over-50s Motoristis: A Report for SAGA,* London: Centre for Economics and Business Research Ltd.

CleanRider.com, 2016. *eCooltra launched its electric scooter-sharing in Barcelona.* [Online] Available at: http://cleanrider.com/ecooltra-started-its-electric-scooter-sharing-in-barcelona/

Continental, 2015. *Worldwide Emissions Standards and Related Regulations,* s.l.: s.n.

Cooltra, n.d.. *Our projects.* [Online] Available at: http://corporate.cooltra.com/en/our-projects/

Council of the European Union, 2012. *Motorcycles: new safety and environmental requireme.* [Online] Available at: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/intm/134159.pdf

Council of the European Union, 2014. *Council adopts the roadworthiness package.* [Online] Available at: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/trans/141818.pdf

CR , 2015. *Forward-Collision Warning With Braking to Become Standard.* [Online] Available at: https://www.consumerreports.org/cro/cars/why-forward-collision-warning-and-automatic-emergency-braking-ne

CRU, 2016. *Cobalt: Tightness looms for the new 100,000 tonne market.* [Online] Available at: https://www.crugroup.com/knowledge-and-insights/insights/cobalt-tightness-looms-for-the-new-100-000-tonne-market/

Dagord, C., 2015. *Adventure Riding: exploring beyond pavement ends.* [Online] Available at: https://idratherberiding.com/2015/03/09/what-is-an-adventure-motorcycle/

Deloitte, 2013. *Trends and outlook of the auto electronics industry.* [Online] Available at: https://www.roboticsbusinessreview.com/wp-content/uploads/2016/05/deloitte-cn-mfg-auto-electronic-industry-en-210314.pdf

Deloitte, 2016. *Supplying the future of mobility - Automotive suppliers in the evolving transportation ecosystem,* s.l.: Deloitte University Press.

Detroit Free Press, 2017. *Delphi considers new name and will spin off $4.5-billion powertrain division.* [Online]
Available at: http://www.freep.com/story/money/cars/2017/05/03/delphi-powertrain-spinoff/101237396/

DfT, 2008. *ISA UK: intelligent speed adaptation,* s.l.: DfT.

Drive West Midlands, 2016. *Connected & Autonomous Vehicles: Developing the UK Supply Chain.* [Online]
Available at: https://www.drivemidlands.co.uk/wp-content/uploads/2016/03/Dr-George-Gillespie.pdf

EEA, 2014. *Costs of air pollution from European industrial facilities 2008-2012.* [Online] Available at: https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012

electrek, 2016. *BMW unveils a new electric 'C evolution' scooter with up to 100 miles range.* [Online] Available at: https://electrek.co/2016/09/13/bmw-unveils-a-new-electric-c-evolution-scooter-with-up-to-100-miles-range/

Electrek, 2017. *Daimler unveils its own new battery Gigafactory for electric vehicles,* s.l.: Electrek.

electrek, 2017. *Electric vehicle battery cost dropped 80% in 6 years down to $227/kWh – Tesla claims to be below $190/kWh.* [Online] Available at: https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/

E-Light, n.d.. *Advanced Structural Light-Weight Architectures for Electric Vehicles.* [Online] Available at: http://cordis.europa.eu/project/rcn/97210_en.html

engadget, 2015. *Ford's latest eBike breaks down to fit in your trunk.* [Online] Available at: https://www.engadget.com/2015/06/24/ford-mode-flex-ebike/

EPA, 2009. *Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers,* s.l.: s.n.

EPA, n.d.. *CFR 40, Part 86 - Control of emissions from new and in-use highway vehicles and engines.* [Online]
Available at: https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=0a57ac29b59ade8455648e60e739a181&rgn=div5&view=text&node=40:19.0.1.1.2&idno=40#40:19.0.1.1.2.6.1.13

Erario, A., 2008. *International harmonisation and its effects on road safety.* [Online]
Available at: http://www.pisa-project.eu/downloadables/Workshop_presentations_29052008_Bologna/RoundTable_International_Harmonization_Erario.pdf

ETSC, 2015. *Drink driving in commercial transport,* s.l.: European Transport Safety Council.

ETSC, 2017. *Briefing: Intelligent Speed Assistance (ISA).* [Online]
Available at: http://etsc.eu/briefing-intelligent-speed-assistance-isa/#_ftn4

European Commission, DGs for Energy, for Climate Action and for Mobility and Transport , 2016. *EU Reference Scenario 2016. Energy, Transport and GHG Emissions Trends to 2050.* [Online]
Available at: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

European Commission, 2015. *Benefit and Feasibility of a Range of New Technologies and Unregulated Measures in the fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users,* s.l.: s.n.

European Commission, 2015. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop - An EU action plan for the Circular Economy.* [Online]
Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1453384154337&uri=CELEX:52015DC0614

European Commission, 2016. *SET - Plan ACTION n°7 – Declaration of Intent "Become competitive in the global battery sector to drive e - mobility forward".* [Online]
Available at: https://setis.ec.europa.eu/system/files/integrated_set-plan/action7_declaration_of_intent_0.pdf

European Commission, 2017. *Statistics – accidents data.* [Online]
Available at: https://ec.europa.eu/transport/road_safety/specialist/statistics_en#

European Commission, 2017. *Supporting studies to develop the EU strategy on CO2 and cars.* [Online]
Available at: https://ec.europa.eu/clima/policies/transport/vehicles_en#tab-0-2

European Commission, n.d.. *European Rare Earths Competency Network (ERECON).* [Online]
Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en

Eurostat, 2017. *Transport database, Multimodal data, Road transport safety.* [Online].

EV World, 2011. *Yamaha to Set Up Electric Scooter Production in India.* [Online]
Available at: http://www.evworld.com/news.cfm?rssid=25602

Fleet News, 2014. *AEB 'will save more than 1,200 lives in 10 years'.* [Online]
Available at: http://www.fleetnews.co.uk/news/2014/5/21/aeb-will-save-more-than-1-200-lives-in-10-years-/52453/

Fleet News, 2016. *Safety: Technology to keep your drivers safe.* [Online]
Available at: http://www.fleetnews.co.uk/fleet-management/risk-management/technology-to-keep-your-drivers-safe

Forbes, 2016. *Why Chinese Cities Are Banning The Biggest Adoption Of Green Transportation In History.* [Online]
Available at: https://www.forbes.com/sites/wadeshepard/2016/05/18/as-china-chokes-on-smog-the-biggest-adoption-of-green-transportation-in-history-is-being-banned/#17601437141b

Fortune, 2016. *Tesla plans to buy lithium for Gigafactory from nearby Nevada mine.* [Online]
Available at: http://fortune.com/2015/09/16/tesla-lithium-gigafactory-nevada/

Frost & Sullivan, 2015. *eCall Mandate—A Cost Burden for Car Manufacturers Rather than a Driver for the European Connected Car Market.* [Online]
Available at: https://www.frost.com/sublib/display-market-insight.do?id=294662783

GitaCloud, 2016. *AUTOMOTIVE SPARE PARTS BUSINESS: BUSINESS CHALLENGES AND SUPPLY CHAIN EXCELLENCE STRATEGIES.* [Online]
Available at: http://gitacloud.com/blog/2016/10/11/automotive-spare-parts-business-business-challenges-and-supply-chain-excellence-strategies

Howard, B., 2017. *How BMW weaves, bakes, and builds the carbon fiber 7 Series.* [Online] Available at: https://www.extremetech.com/extreme/209812-how-bmw-weaves-bakes-and-builds-the-carbon-fiber-7-series

IBEF, 2016. *Automobiles.* [Online] Available at: https://www.ibef.org/download/Automobile_December_2016.pdf

ICCT, 2013. *Light-Duty Vehicle Technology Cost Analysis: European Vehicle Market - Updated Indirect Cost Multiplier (ICM) Methodology,* s.l.: FEV.

ICCT, 2016. *Proposed temporary Management regulation for corporate average fuel consumption and new-energy vehicle credits for new passenger cars in China.* [Online] Available at: http://www.theicct.org/sites/default/files/publications/China%20CAFC%20and%20NEV%20credits_policy-update_vF_06102016.pdf

ICCT, 2017. *Cost–benefit assessment of proposed China 6 emission standard for new light-duty vehicles,* s.l.: ICCT.

ICCT, 2017. *Electric vehicle capitals of the world - Demonstrating the path to electric drive.* [Online] Available at: http://www.theicct.org/sites/default/files/publications/Global-EV-Capitals_White-Paper_06032017_vF.pdf

ICCT, 2017. *Proposed fuel-consumption standards for two- and three-wheelers in China.* [Online] Available at: http://www.theicct.org/sites/default/files/publications/China-2-3-wheeler-FE%20_ICCT_pol-update_08032017_vF.pdf

IDTechEx, 2017. *Power Electronics for Electric Vehicles 2017-2027,* s.l.: IDTechEx.

IEA, 2016. *World Energy Outlook 2016,* Paris: IEA.

IGC, 2016. *Low oil prices: An opportunity for fuel subsidy reform.* [Online] Available at: http://www.theigc.org/blog/low-oil-prices-an-opportunity-for-fuel-subsidy-reform/

IHS Automotive, n.d.. *Vehicle Production Forecast, 2017 - 2024,* s.l.: IHS Automotive.

Institute for Transportation & Development Policy and the University of California, Davis., 2015. *A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities Around the World, with Estimated Energy, CO2, and Cost Impacts,* s.l.: Institute for Transportation & Development Policy and the University of California, Davis..

InterRegs, 2015. *New ECE Regulation on Electric Vehicles of Category L Adopted.* [Online] Available at: http://www.interregs.com/articles/spotlight/new-ece-regulation-on-electric-vehicles-of-category-l-adopted-000161

JAMA, 2016. *Motorcycle Market Trends in Japan: Summary of Results of JAMA's Fiscal 2015 Survey.* [Online]
Available at: http://www.jama-english.jp/release/release/2016/160426-3.html

Japan's Ministry of Land, Infrastructure, Transport and Tourism, 2012. *Approval System for New Mobility.* s.l.:s.n.

Kallstrom, H., 2015. *Raw materials – the biggest cost driver in the auto industry.* [Online] Available at: http://marketrealist.com/2015/02/raw-materials-biggest-cost-driver-auto-industry/

live mint, 2010. *Honda unveils all-electric scooter, China in sights.* [Online] Available at: http://www.livemint.com/Companies/fmONt1vUKwuFRNcG7kqx5H/Honda-unveils-allelectric-scooter-China-in-sights.html

livemint, 2016. *One in three households in India owns a two-wheeler.* [Online] Available at: http://www.livemint.com/Politics/Yd2EAFIupVHDX0EbUdecsO/One-in-three-households-in-India-owns-a-twowheeler.html

Lutz, C., Meyer, B. & Wolter, M. I., 2010. The Global Multisector/Multicountry 3-E Model GINFORS. A Description of the Model and a Baseline Forecast for Global Energy Demand and CO2 Emissions. *International Journal of Global Environmental Issues,* Volume 10, pp. 25-45.

Magna, 2016. *News Release - Magna to Build Jaguar Land Rover I-Pace Vehicle in Graz, Austria.* [Online]
Available at: http://www.magna.com/media/press-releases-news/2016/12/01/news-release---magna-to-build-jaguar-land-rover-i-pace-vehicle-in-graz-austria

Marketsandmarkets , 2014. *Automotive Powertrain Market by Position (FWD, RWD, & AWD), Vehicle Type (Passenger Car, LCV, & HCV), Engine Type (Gasoline & Diesel) & Geography (Asia-Oceania, Europe, North America, & ROW) - Industry Trends & Forecast to 2019,* s.l.: Marketsandmarkets.

MarketWatch, 2016. *Want to invest in self-driving cars? Check out the chips.* [Online] Available at: http://www.marketwatch.com/story/want-to-invest-in-self-driving-cars-check-out-the-chips-2016-08-26

McKinsey & Company, 2014. *Connected car, automotive value chain unbound,* s.l.: McKinsey&Company.

McKinsey & Company, 2015. *Competing for the connected customer – perspectives on the opportunities created by car connectivity and automation,* s.l.: McKinsey & Company.

McKinsey&Company, 2016. *Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry,* s.l.: McKinsey&Company.

MEP, 2014. *Motorcycle and moped emission limits and measurement methods - Draft (phase IV).* [Online]
Available at: http://www.mep.gov.cn/gkml/hbb/bgth/201409/W020140928401244889399.pdf

Mercedes-Benz, 2016. *Environmental Certificate Mercedes-Benz E Class,* s.l.: s.n.

MEV, 2015. *Motorcycle emission standards and strengthening the enforcement of the Clean Air Conservation Act (in Korean).* [Online] Available at: http://www.me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=540280&menuId=286

Ministry of Road Transport and Highways, 2014. *Notification G.S.R. 431(E).* [Online] Available at: http://www.indiaenvironmentportal.org.in/files/file/Central%20Motor%20Vehicles%20%2811th%20Amendment%29%20Rules,%202014.pdf

Ministry of Road Transport and Highways, 2014. *Notification G.S.R. 99(E).* [Online].

Ministry of Road Transport and Highways, 2015. *Notification G.S.R. 487(E).* [Online].

Ministry of Road Transport and Highways, 2016. *Notification G.S.R. 889(E).* [Online] Available at: http://morth.nic.in/showfile.asp?lid=2391

Ministry of the Environment, 2012. *Summary of the Future Policy for Motor Vehicle Emission Reduction (The 11th Report).* [Online] Available at: http://www.unece.org/fileadmin/DAM/trans/doc/2013/wp29grpe/GRPE-65-14.pdf

MLIT, 2015. Ministry of Land, Infrastructure, Transport and Tourism. *GRRF Meeting February 2015*, February.

Mundy, S., 2017. *India's motorcycle makers burnish brand credentials.* [Online] Available at: https://www.ft.com/content/8f526d52-1add-11e7-bcac-6d03d067f81f

Munro & Associates, 2015. *BMW i3 Teardown and Benchmarking Study: Reports Summary and Pricing Detail,* s.l.: Munro.

New Atlas, 2016. *Honda plans to produce the EV-Cub by 2018.* [Online] Available at: http://newatlas.com/honda-ev-cub-2018-production/42375/

New York Times, 2014. *Japan Seeks to Squelch Its Tiny Cars.* [Online] Available at: https://www.nytimes.com/2014/06/09/business/international/japan-seeks-to-squelch-its-tiny-cars.html?hp&_r=3

NHTSA (2), 2007. *Review of Technology to Prevent Alcohol-Impaired Crashes (TOPIC),* s.l.: U.S. Department of Transportation.

NHTSA (2), 2009. *Federal Motor Vehicle Safety Standard; Rearview Mirrors,* s.l.: s.n.

NHTSA, 2007. *Electronic Stability Control Systems,* s.l.: U.S. Department of Transportation.

NHTSA, 2009. *The Long-Term Effect of ABS in Passenger Cars and LTVs,* s.l.: U.S. Department of Transportation.

NHTSA, n.d.. *Requirements for Motorcycle Manufacturers,* s.l.: NHTSA.

Nieuwenhuis, P., 2016. *Tackling automotive obesity: L-category vehicle prospects for the UK,* s.l.: Presentation to LowCVP Conference 2016.

OECD, 2015. *OECD Inter-Country Input-Output (ICIO) Tables, 2015 edition.* [Online] Available at: http://www.oecd.org/sti/ind/input-outputtablesedition2015accesstodata.htm

OECD, n.d.. *World Forum for Harmonization of Vehicle Regulations (WP.29) - Executive Summary.* [Online]
Available at: https://www.oecd.org/tad/ntm/43897382.pdf

Öko-Institut, TML Leuven , 2016. *Electric mobility in Europe –Future impacts on the emissions and energy system. Final report of task 2 - Assessing the status of electrification of road transport passenger vehicles and potential future implications for the environment and European energy.* [Online] Available at: https://www.oeko.de/fileadmin/oekodoc/Assessing-the-status-of-electrification-of-the-road-transport-passenger-vehicles.pdf

Planet Custodian, 2017. *Hero Electric unveils Flash e-scooter that you can drive without a license.* [Online]
Available at: http://www.planetcustodian.com/2017/02/08/8898/hero-electric-unveils-flash-e-scooter-that-you-can-drive-without-a-license.html

Plastix World, 2013. *BMW i3: carbon fiber body.* [Online] Available at: http://www.plastix-world.com/bmw-i3-carbon-fiber-body/

plugincars, 2016. *Carmakers' Commitment to Electric Cars: Brand-by-Brand Review.* [Online] Available at: http://www.plugincars.com/carmakers-commitment-electric-cars-brand-brand-review-130155.html

Posada, F., Bandivadekar, A. & German, J., 2013. *Estimated Cost of Emission Control Technologies for Light-Duty Vehicles Part 1 - Gasoline,* s.l.: SAE International.

Posada, F., Bandivadekar, A. & German, J., 2013. *Estimated Cost of Emission Control Technologies for Light-Duty Vehicles Part 2 - Diesel,* s.l.: SAE International.

Quartz, 2017. *China is selling more electric vehicles than the US—and it's not even close.* [Online] Available at: https://qz.com/972897/china-is-selling-more-electric-vehicles-than-the-us-and-its-not-even-close/

RESOLVE, n.d.. *RESOLVE project website.* [Online] Available at: http://www.resolve-project.eu/

Reuters, 2017. *China upholds strict electric car sales quotas despite industry protests.* [Online] Available at: http://www.reuters.com/article/us-china-autos-electric-idUSKBN1941V5

revzilla, 2016. *New developments, new players in the U.S. electric motorcycle market.* [Online] Available at: https://www.revzilla.com/common-tread/the-us-electric-motorcycle-industry-in-2016

Ricardo AEA et al, 2014. *Update of the Handbook on External Costs of Transport.* [Online] Available at: https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf

Ricardo Energy & Environment et al, 2016. *Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves. Service Request 4 to LDV Emissions Framework Contract.,* s.l.: A report for the European Commission, DG Climate action by Ricardo Energy & Environment, TU Graz, TEPR, EC JRC and the University of Cardiff. (Pending publication)..

Ricardo, 2014. *Japan - Motorcycles & Mopeds.* [Online] Available at: http://www.emleg.com/legislation/view/japan-motorcycles-mopeds

Ricardo, 2015. *China - Motorcycles & Mopeds.* [Online] Available at: http://www.emleg.com/legislation/view/china-motorcycles-mopeds

Ricardo, 2015. *South Korea - Motorcycles and Mopeds.* [Online] Available at: http://www.emleg.com/legislation/view/south-korea-motorcycles-and-mopeds

Ricardo, 2015. *US Federal - Motorcycles & Mopeds.* [Online] Available at: http://www.emleg.com/legislation/view/us-federal-motorcycles-mopeds

Ricardo, 2016. *India - Motorcyles & Mopeds.* [Online] Available at: http://www.emleg.com/legislation/view/india-motorcycles-mopeds

Roland Berger , 2014. *Autonomous driving - Disruptive innovation that promises to change the automotive industry as we know it — it's time for every player to think:act!,* s.l.: Roland Berger Strategy Consultants.

Santucci, M., Pieve, M. & Pierini, M., 2016. Electric L-category Vehicles for Smart Urban Mobility. *Transportation Research Procedia, 14,* pp. 3651-3660.

Schaeffler, 2016. *A glimpse of the future: mobility in flux.* [Online] Available at: https://www.schaeffler.com/remotemedien/media/_shared_media/08_media_library/01_publications/schaeffler_2/brochure/downloads_1/micromobility_bio_hybrid_fact_sheet_xxl_de_en.pdf

Shanghai Motor Vehicle Inspection Centre, 2012. *National Standardization Technical Committee - car and motorcycle standards (in Chinese).* [Online] Available at: http://www.smvic.com.cn/smvic/mtcfbxgzdt/1058.htm

Steelmate Automotive, 2017. *TP-70 DIY Tyre Pressure Monitoring System.* [Online] Available at: http://www.steel-mate.co.uk/acatalog/TP-70-DIY-Tyre-Pressure-Monitoring-System-222.html

techradar, 2016. *Vespa has created its first electric scooter.* [Online] Available at: http://www.techradar.com/news/vespa-has-created-its-first-electric-scooter

The Guardian , 2017. *Electric cars may stall without a battery revolution.* [Online] Available at: https://www.theguardian.com/sustainable-business/2017/jul/19/electric-cars-battery-revolution-tesla-volvo

The Guardian, 2015. *Harley-Davidson's reputation as an 'old, white-guy brand' may be its downfall.* [Online]
Available at: https://www.theguardian.com/business/2015/oct/24/harley-davidson-brand-revenue-loss-easy-rider-image

The Hankyoreh, 2015. *Motorcycle Emissions Standards Strengthened from 2017 (in Korean).* [Online] Available at: http://www.hani.co.kr/arti/society/environment/700887.html

The Hankyoreh, 2015. *Motorcycles five-times the polluter that cars are.* [Online] Available at: http://english.hani.co.kr/arti/english_edition/e_national/700967.html

The Manufacturer, 2015. *Zero to hero for electric motorcyle maker Zero Motorcycles.* [Online] Available at: http://www.themanufacturer.com/articles/zero-to-hero-for-electric-motorcyle-maker-zero-motorcycles/

The Telegraph, 2001. *Are you sitting comfortably?.* [Online] Available at: http://www.telegraph.co.uk/motoring/4750094/Are-you-sitting-comfortably.html

TNO and AVL, 2014. *Study on assessing the implementation of Euro 6 light-duty vehicle pollutant emission standards in the EU and benchmark Euro 6 against international emission standards,* Luxembourg: s.n.

TNO et al, 2017. *Euro 5 effect study for L-Category vehicles.* [Online] Available at: https://circabc.europa.eu/d/d/workspace/SpacesStore/13a4bc40-b046-4ac0-b0f8-865fea35c49d/Euro%205%20effect%20study%20-%20final%20presentation.pdf

Transport Research Laboratory, 2014. *CLIENT PROJECT REPORT CPR1821 - Provision of information and services to perform an initial assessment of additional functional safety and vehicle construction requirements for L7e-A heavy on-road quads,* s.l.: Transport Research Laboratory.

TransportPolicy.Net, 2016. *China: Motorcycles: Fuel Consumption.* [Online] Available at: http://transportpolicy.net/index.php?title=China:_Motorcycles:_Fuel_Consumption

Triumph, 2017. *TRIUMPH AND BAJAJ AUTO INDIA IN NEW PARTNERSHIP.* [Online] Available at: http://www.triumphmotorcycles.co.uk/news-and-events/news/global/2017/august/triumph-bajaj-new-partnership

TRL, 2014. *Study on the benefits resulting from the installation of Event Data Recorders,* s.l.: Transport Research Laboratory.

TTAC, 2017. *Government Intervention is Intentionally Killing the Japanese Kei Car.* [Online] Available at: http://www.thetruthaboutcars.com/2017/09/government-intervention-killing-japanese-kei-car/

U.S. Department of Transportation, 2012. *Operation of Neighborhood Electric Vehicles (NEVs) on Roadways with a Maximum Speed Limit of 40 mph (64 kph): Fuel Consumption Savings and Safety Ramifications.* [Online] Available at: https://acquia-dev-nhtsa.dot.gov/sites/nhtsa.dot.gov/files/neighborhood_electric_vehicles.201206.pdf

U.S. Environmental Protection Agency, 2013. *Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles..* [Online] Available at: https://www.epa.gov/sites/production/files/2014-01/documents/lithium_batteries_lca.pdf

U.S. Geological Survey, 2015. *European Mineral Statistics 2009-13.* [Online] Available at: http://bgs.ac.uk/mineralsuk/statistics/europeanStatistics.html

U.S. Geological Survey, 2017. *Mineral commodity summaries 2017.* [Online] Available at: https://minerals.usgs.gov/minerals/pubs/mcs/

UBS, 2017. *UBS Evidence Lab Electric Car Teardown - Disruption Ahead?,* s.l.: UBS.

UN, 2016. *Addendum 135 - Regulation No. 136: Uniform provisions concerning the approval of vehicles of category L with regard to specific requirements for the electric power train.* [Online] Available at: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2016/R136e.pdf

UNECE, 2016. *UNECE paves the way for automated driving by updating UN international convention.* [Online] Available at: http://www.unece.org/info/media/presscurrent-press-h/transport/2016/unece-paves-the-way-for-automated-driving-by-updating-un-international-convention/doc.html

UNECE, n.d.. *WP.29 - Introduction.* [Online] Available at: https://www.unece.org/trans/main/wp29/introduction.html

United Nations, 2017. *World population prospects. The 2017 revision.* [Online] Available at: https://esa.un.org/unpd/wpp/

US EPA, 2014. *Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule: Regulatory Impact Analysis,* s.l.: EPA.

Vehicle Certification Agency, DfT, n.d.. *Motorcycle ECWVTA Framework Regulation.* [Online] Available at: http://www.dft.gov.uk/vca/vehicletype/revised-framework-directive-motorcycles.asp

Weiss, M. et al., 2015. On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. *Transportation Research Part D,* pp. 348-366.

Wells, P. & Lin, X., 2015. Spontaneous emergence versus technology management in sustainable mobility transitions: Electric bicycles in China. *Transportation Research Part A: Policy and Practice. 78,* pp. 371-383.

WHO, n.d.. *Health and sustainable development - Air pollution.* [Online] Available at: http://www.who.int/sustainable-development/transport/health-risks/air-pollution/en/

Winkle, T., 2016. Safety Benefits of Automated Vehicles: Extended Findings from Accident Research for Development, Validation and Testing. *Autonomous Driving.*

Xinhua, 2016. *Policy on low speed electric vehicles: System specifications and public opinion.* [Online] Available at: http://news.xinhuanet.com/auto/2016-04/05/c_128863503.htm

Zimmer, W. et al., 2016. *Endbericht RENEWBILITY III - Optionen einer Dekarbonisierung des Verkehrssektors,* s.l.: s.n.

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