ERTRAC

EPoSS
European Technology Platform on Smart Systems Integration

SMARTGRIDS

European Roadmap Electrification of Road Transport

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LIST OF ACRONYMS

Acronym	Meaning
AC	Alternating Current
ACEA	European Automobile Manufacturers Association (Association des Constructeurs Européens d'Automobiles)
BEV	Battery Electric Vehicle
BHLS	Bus with a High Level of Service
BRT	Bus Rapid Transit
CCS	Combined Charging System
CENELEC	European Committee for Electrotechnical Standardisation
CH4	Methane
CHAdeMO	"Charge de Move" - trade name of a quick charging method for BEVs delivering up to 62.5 kW of DC via a special electrical connector
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide equivalent
DC	Direct Current
EARPA	European automotive research partners association
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EEGI	European Electricity Grid Initiative
EGCI	European Green Car Initiative
EGVI	European Green Vehicles Initiative
EITI	Extractive Industry Transparency Initiative
EPoSS	European Technical Platform on Smart Systems Integration
ERA	European Research Area (EU and Associated countries)
ERS	Electric Road Systems
ERTRAC	European Road Transport Research Advisory Council
ESCI	European Smart City Initiative
EU	European Union
EUCAR	European Council for Automotive Research & Development
EV	Electric Vehicle
EVE IWG	Electric Vehicles and Environmental Informal Working Group
FCEV	Fuel Cell Electric Vehicle
FCH-JTI	Fuel Cells and Hydrogen Joint Technology Initiative
FEV	Fully Electric Vehicle
FMS	Fleet Management System
G2G	Grid to Grid
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ICT	Information and Communications Technologies
IEA	International Energy Agency
IEC	International Electrotechnical Commission

ISO	International Organisation for Standardisation,
ITS	Intelligent Transport Systems
kg	Kilogram
km/h	kilometers per hour
kW	Kilowatt
kWh	kilowatt-hour
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LEV	Light Electric Vehicle
MaaS	Mobility as a service
mph	miles per hour
NdFeB	Neodymium Iron Boron
NEDC	New European Driving Cycle
NOx	Nitrogen Oxide
NVH	Noise Vibration Harshness
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PLEV	Plug-in Light Electric Vehicle
PM	Particulate Matter
cPPP	Contractual Public-Private Partnership
PWR	Power-to-Weight Ratio
PWT	Powertrain
R&D	Research and Development
REX	Electric Range Extended Vehicle
R&I	Research and Innovation
SRA	Strategic Research Agenda
TCO	Total Cost of Ownership
TCU	Total Cost of Use
TEN-T	Trans-European Network – Transport
UBA	German Federal Environment Agency (Umwelt Bundesamt)
UF	Utility Factor
ULE	Ultra-low Emission
UNECE	United Nations Economic Commission for Europe
V2G	Vehicle to Grid
V2I	Vehicle to Infrastructure
V2X	Vehicle to anything
Wh/km	Watt-hours per kilometre
WHO	World Health Organisation
WLTP	Worldwide harmonised Light vehicles Test Procedure
WPT	Wireless Power Transfer
WTW	Well-to-Wheel
ZE	Zero Emission

1. INTRODUCTION

Mobility is on the verge of tremendous changes and will rely more and more on electrification. The most **important factors** for this imminent change are:

- the need to accelerate efforts to tackle climate change, coupled with an increasing public concern for air quality, especially in cities,
- increasingly strong regulations in terms of CO_2 and pollutant emissions, set by the European Union and other public authorities worldwide, coupled with the ambition to reduce dependence to fossil fuels and accelerate the use of renewable energies,
- a global economic environment with competing American, Asian and European industries in search for growth and to get technology leadership,
- significant progress in electric motor, power electronics and battery technologies and energy efficiency of the electric powertrain,
- public incentives to support the market take-up of electric vehicles, and growing availability of charging infrastructure,
- new interesting mobility offers for leasing or sharing EVs,
- newcomers in the automotive industry entering the market with newly designed EVs,
- enhanced use of electrified 2/3-wheelers (e.g. pedelecs and scooters) for inner city traffic,
- potential and impact of connectivity and automation.

This context has led to an **increased awareness of the public for Electric Vehicles**, though not yet accompanied by significant large numbers of sales. But the real market take-up for EVs is expected to emerge in the coming years. Car manufacturers invest massively to make electric vehicles an industrially viable and cost competitive product. This will lead in the next five to ten years to a noticeable change in the automotive portfolio. An exemption of this observation is the increased use of power assisted bikes called pedelecs which are sold in increasing numbers. The use of pedelecs and electric scooters can contribute positively to the challenge of urban mobility.

However, there are still persisting technical shortcomings that require more research and development activities in the years to come. In order to keep pace with the worldwide competition, there is a need to accelerate knowledge generation, in particular in the transformation of technology into reliable and cost effective products. These requirements are a necessity to obtain market success and competitiveness.

The **European Roadmap on the "Electrification of Road Transport"**, published jointly by the European Technology Platforms **ERTRAC, EPoSS and ETIP SNET**[1], provides background information and R&D&I roadmaps for the electrification of the different vehicle categories. It has been the major source of recommendations for the projects funded by the European Green Cars Initiative in FP7, followed by the European Green Vehicles Initiative in Horizon 2020. The task of the roadmap is to set the scene, give clear objectives, and list the milestones that require funding or policy action at European level.

This is the 3rd edition of the document, an update of the last publication from 2012. It extends the outlook until 2030, such that it can serve as an input for the strategic discussion about the next Framework Program.

[1] ETIP SNET was created in 2016 and is replacing and enhancing the scope of activities of the former ETP Smartgrids, going beyond the power sector.

The **main objectives** of the updating process were the following:

- take into account the above-mentioned major changes in the policy and industrial environment,
- start from the customer expectations regarding the performance and utility of electric vehicles,
- consider the role of road vehicles electrification for Europe's industrial competitiveness, in particular the opportunities and risks from the international competition,
- enlarge the focus from passenger cars only to 2/3-wheelers and both smaller (L-category) and larger (buses and trucks) vehicles, i. e. commercial vehicles,
- support the consultation process of the European Green Vehicles Initiative PPP upcoming Work Programs with expert assessment and forecasts.

With some of the milestones of the previous roadmap versions being passed, achievements are being reviewed and new objectives are set. In particular, a new milestone entitled "Re-designed electrified road transport meeting the requirements of the future connected society" is introduced for 2030. The recommendations for research and development topics are summarised in the following **four comprehensive "big initiatives"** in view of user acceptance categories, being range, cost, charging speed, added value, and mobility options:

Operation system dependent EVs in the urban environment

Sustainable electrified long-distance trucks and coaches

User-friendly affordable LEV/EV passenger car + infrastructures

No compromise electric urban bus system

This roadmap contributes to the long-term vision formulated in the Strategic Research Agenda (SRA) of the involved European Technology Platforms, with ERTRAC addressing the 2020 societal challenges of Road Transport, EPoSS being focused on ICT and smart systems as key enabling technologies, and ETIP SNET focusing in the transition towards a reliable and sustainable European electricity system with very high shares of renewable. Beyond its relevance for the consultations of the European Green Vehicles Initiative cPPP, the roadmap is also the basis for setting research priorities in the European Commission's Strategic Transport Research and Innovation Agenda (STRIA), as well as for the "Smart Mobility" chapter of the Joint Undertaking on Electronic Components and Systems for European Leadership (ECSEL).

The roadmap is also addressed to national authorities, as an offer of reference and promotion of coordination between local, national and European activities.

2. SCENARIOS FOR ELECTRIFICATION IN ROAD TRANSPORT

2.1. General Expectations

2.1.1. Societal Aspects, Needs and Challenges

Decarbonisation and emission reduction from road transport are the main drivers for the electrification of vehicles, (xEV). The envisaged European CO_2 fleet emission limits for 2025[2] and 2030 already require a massive market introduction of partially electrified vehicles (REX, PHEV) or full EV's (BEV, FCEV). Further, local or regional air quality regulations such as potential zero emission zones will drive demand for these vehicles.

The ambitious targets set by European Union in energy efficiency, GHG domestic emissions reductions and the share of renewable energy in 2030 will result into a substantial reduction of GHG from the electricity sector, which in turn will increase the benefits that electrification of vehicles can provide now to air quality and action against climate change. Electrification of road transport will significantly contribute to the improvement of air quality on the one hand and climate protection on the other hand only if the electricity used is from low carbon / carbon neutral sources, (solar, wind, hydro, geo thermal). Hence, any introduction of electrification of cars and trucks has to be matched with a reduction of fossil energy used within European electricity production. In this roadmap, it is assumed that electricity (or hydrogen) will be provided on an increasingly CO_2-neutral basis.

Electrified mobility means different things to different people. Public authorities seek air quality improvement and climate action, as well as reduction of inner city traffic in general. Consumers expect no less flexibility or reliability; fleet operators need reliability and competitive running costs. Although the introduction of xEVs is primarily driven by either interests of legislation (such as the Euro 1-6 limits placed on ICE), or particular advantages for the users and operators (see other chapter), incentives help seed first xEV fleets which in turn provide real world practicality for users, OEMs and infrastructure providers.[3] This is important as it ensures Europe produces technologically advanced mature products, competitive with global producers at the time of stronger market demand.

The underlying technology of xEVs has gained sufficient maturity to begin a shift in mobility, but it requires a much higher level of maturity to become broadly acceptable and usable for mass markets. While electric mobility technology is becoming more mature and cost-neutral compared to ICEs, it is questionable whether it can be decisive especially if oil prices decrease. This is particularly the case for regions with non-financial incentives.

It is expected that urban and suburban transport will be the major application for the pure battery electric vehicle, at least within the short and medium term, and the possibilities of e-two/three-wheelers for transport of goods and people are sensible. The challenge of the BEV goes beyond urban mobility, though. Intercity and cross-border driving as well as applications in the truck and bus domain should be kept within the focus of R&D as technological solutions that meet all of these requirements still come with a higher price tag and usage limitations when compared to conventional vehicles.

[2] International Council on Clean Transportation. EU CO_2 emission standards for passenger cars and light commercial vehicles. 2014.

[3] Incentives will play a significant role in driving uptake of EV's in Europe. A EU co-funded project, I-CVUE (http://icvue.eu), supported by Intelligent Energy Europe has been initiated to establish the influence of incentives and policy upon EV uptake. Further to this, I-CVUE intends to establish correlation between incentives and regional conditions

2.1.2. User Needs and Expectations

Broad and in-depth analyses and considerations have been carried out in the past regarding the expectations of the consumers and fleet operators regarding electric vehicles[4]:

- Prices as low as todays ICE driven vehicles or at least vehicles with TCO competitive to those as of today
- Range, reliability, durability and re-sale value of electrified vehicles similar to conventional vehicles
- Range adapted to specific use cases
- Usage comfort as good as the state of the art ICE-powered vehicles (availability, "re-fueling" time and possibilities, passenger comfort, transport volume)
- Safe parking and infrastructure for two-wheeler fleets also with direct connection to charging facilities

It must be kept in mind that pure electric vehicles probably will never replace conventional vehicles, as they exist today, keeping the same universality with driving ranges up to 1000 km and refilling times less than 5 minutes. **Successful electric vehicles are not made by simply replacing the internal combustion engine with an electric motor**. Freedom of individual mobility is achievable with these vehicles but will have to adapt to more specific use cases in order to accommodate for these limitations. Users will accept some drawbacks if other advantages overcompensate for these – e.g. access to zero-emission zones or preferential parking for xEV, ease of charging, and driving comfort such as quiet acceleration. Common European-wide legislation of this nature may accelerate market take up.

New concepts such as MaaS will play an important role to compensate for drawbacks, and mobility services such as e-Bikes can offer alternatives.

Some advantages may also be achievable through synergies of the electrification with the connectivity and automation of vehicles. These are not necessarily exclusively linked to xEV but will certainly provide particular benefits for the users of such vehicles (e.g. easy access to charging infrastructure, optimisation of driving routes and minimisation of energy consumption). Automated electric vehicles that are integrated into sharing systems would additionally be able to better match mobility supply and demand, and manage the charging process on their own, i.e. park themselves after the driver leaves the vehicle and automatically be re-charged with wireless charging systems or other such systems that could be automated and standardised. **Connectivity is an essential prerequisite** for such innovative systems that would allow the driver to end the shared session without actually being in the vehicle. However it should also be kept in mind that it requires the availability of appropriate infrastructures that come at a price.

2.1.3. A change from "one vehicle fits all" mentality

Modern conventional vehicles are designed and developed for the decathlon and can usually be used for multiple purposes. Hence from the perspective of design-for-purpose these vehicles are over-engineered. With the development of new urban mobility concepts and integrated solutions (also due to better connectivity and potential automated driving) vehicles may be designed and

[4] Internation Energy Agency. Deployment strategies for hybrid, electric and alernative fuel vehicles

built in a more specific way for dedicated usage models. A certain degree of adaptability would be needed for cases where the usage model would change, but also since the implementation of needed infrastructure (for the optimal use of the specific vehicles) and smart technologies in the urban areas might not be on the same time-plan everywhere. New vehicle architectures should lead to flexibility and modularity in order to ensure urban-readiness even if vehicles are delivered to different urban areas, which may all have unique aspects that need to be considered. The trend to specific purpose designs may support the possible rise of L-category vehicles and e-bikes for urban solutions. This also has to be further reduced by the use of lightweight materials.

An additional trend that must be considered is that vehicles are now becoming an extension to the highly connected society of people's life style. This new dimension of "**personalisation**" can be observed with cars that are now launched or presented at CES in Las Vegas as well as Frankfurt Motor Show.

2.1.4. Charge points and Governmental Responsibility

Charging is a crucial topic for the success of electrification and is most often neglected. Instead pure battery electric vehicles are pushed to compete with ICE one-on-one, where refilling takes place around once every week. With the right mix of infrastructure, electric vehicles could be competitive with vehicles powered by internal combustion engines, but with the added dimension of refilling comfort. Daily e-charging would mean that drivers never have to stop at filling stations in the future; charging would be done daily at home or at work or at public or commercial parking areas (shops, motorway rest areas, etc.). Charging comfort in general would strongly benefit the use of PHEVs to help ensure that they are operated in electric mode in urban areas as much as possible but overcoming the range anxiety issue in case of longer trips where the availability of (and access to) suitable charging facilities are uncertain. With a sufficient charging infrastructure (e.g. mode 1 charging for scooters and LEVs) the use of low range scooters could also be promoted in cities.

Regulatory efforts for the re-charging of xEV's have already been initiated. The EU has made steps towards the creation of EV re-charging infrastructure with Directive EU 2014/94/EU[5]. This provides an obligation on member state governments to expand the network of charging points (CP), as the number of vehicles in service grows. National governments must be monitoring trends in xEV take up closely and ensure the public CP networks are developed in advance of xEV's sales trends. National/local authorities have a big challenge assessing the need for the CP public network early enough to have it in place to meet the needs of the market uptake, or support the market uptake. Implementation of public CP-networks is generally much slower than the acquisition of EVs although there are many private operators in the market (but with different conditions for public access to their facilities). There is a great uncertainty in where to locate the CPs so that they can be used as much as possible, and even today it is not ultimately clarified who pays for the infrastructure as different business models exist from public to private financing and from user accounts to free facilities.

[5] European Comission. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. 2014.

Even where suitable charging facilities exist, the lack of knowledge as to their location, availability, plug type, price and access/payment conditions by users remains a disincentive, particularly for people driving outside their own city or region. Therefore ICT solutions to guide and inform drivers, including the option to book and pay for charge points in different places (interoperable across different suppliers and across national borders) will be an important part of the solution. Already EV charging roaming providers exist to address this solution and work is underway to link these to build a truly European network.[6]

2.1.5. Charging needs for the long range BEV

Combined with fast, i.e. high-power, charging capacities, pure EVs would be able to serve longer range needs. Price parity in premium brands may even be reached within five to ten years. Take-up is however still expected to require a system of user incentives as the market tests out these new vehicles. Increased generally exceptional use of EV's for longer journeys requiring rapid charging on route may translate into a need for high numbers of CP's and grid level power, especially when these exceptional journeys occur at the same time, e.g. in the holiday season or in connection with sporting events. The cost of charging solutions to cope with these exceptional peaks in localised power demand will need to be considered by authorities and CP providers if the BEV is to prevail. Even though a high number of charging points will be needed in the long run, the exact elasticity of the numbers still remains uncertain. Germany, e.g., has seen strong growth in EVs over that last four years, although the number of public charging points as essentially nearly constant over the years (Figure 1)[7].

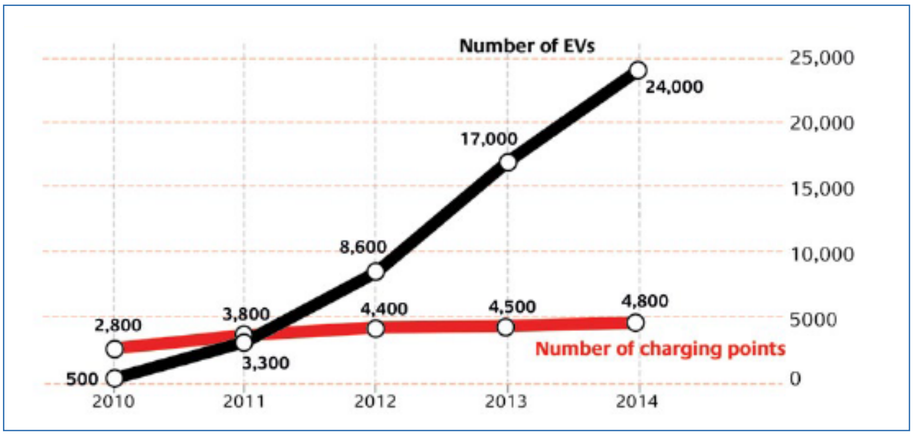


Figure 1: Growth of EV fleet compared to the number of charging points in Germany

REX Vehicles with smart GPS connected charging strategies (to distribute the load) may appear as a **more cost effective and practical solution**, and BEV's being preferred in urban scenarios. However, as there is no guarantee that these vehicles will actually be plugged in, their contribution to environmental goals may thus be in question. Connected systems might be an enabler for some electrified powertrain topologies like REX which sometimes struggle currently to provide users uninterrupted performance on longer trips. Using integrated GPS with topology mapping could enable SMART REX systems, which manage battery charge to suit the journey ahead with a preset level.

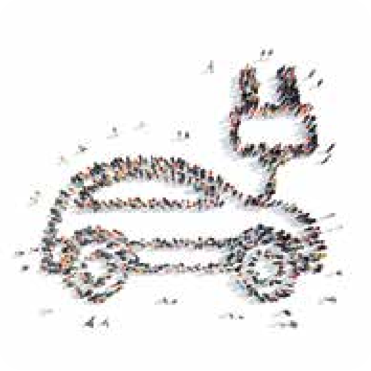
[6] NeMo project: http://nemo-emobility.eu.
[7] German National Platform for Electric Mobility. Progress Report 2014 – Review of Pre-Market Phase. 2014.

2.1.6. Heavy Duty Commercial Vehicles/L-Category Vehicles

Despite an increasing usage of other modes like rail and maritime, freight and non-urban public transport will continue to have a reliance on roads. It is therefore important that also for trucks and coaches an alternative to current state of the art ICE powertrains is developed. Advanced ICE's and disruptive thermal propulsion systems and fuels (Power to liquids or gas), novel hybrid systems with next generation lightweight ICE and simplified powertrain components or GPS / topology connected REX systems may offer viable solutions. Electric Road Systems (ERS) using e.g. a catenary for power supply while driving may evolve for heavy-duty road transport. The necessary equipment is currently under development and testing in a small number of sites in Sweden and Germany[8, 9] , however it remains open whether interoperability can be achieved, user acceptance arises and high up-front infrastructure investments can be justified. Research in the area of heavy-duty vehicle powertrains for long-haul operation need to tackle the challenge of demonstrating electrification solutions in combination with range-extending technologies, that show achievable improvements in cost and efficiency without significantly increasing packing dimensions or increasing the weight of the overall powertrain.

L-Category vehicles with optimised hybrid and electric powertrains will also provide an opportunity for freight applications, as "last mile" delivery and small logistics especially in the urban environment. In this segment LEVs in commercial applications have attractive TCO values if equipped with batteries, which are designed for the range best for the special use case.

2.1.7. Public education



Public education initiatives should be considered to raise awareness through a variety of media channels. It has been observed that acceptance of electrified mobility increases dramatically after initial usage of the electric vehicles. Vehicle sharing could be an icebreaker in this respect. Specific requirements for these vehicles may be realised within the scope of vehicles designed specifically for urban use as previously mentioned. Local incentives have proven to have impact in Japan[10] and the US[11]. OEM's must consider user concerns in their R&D programs upfront in order to improve the value proposition of the EV.

[8] Sia-Partners. Insight - Electrified Road Freight Transport. 2016.
[9] Mov'eo. PVI WATT system, an electric 12m bus with unlimited autonomy in test at the Nice airport. 2014.
[10] Ahman, Max. Government policy and the development of electric vehicles in Japan. Energy Policy. 34, 2006, 4.
[11] Vehicles, State Efforts Promote Hybrid and Electric. http://www.ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx#fl. [Online] 2015, assessed 2017/02/20.

2.2. EU Climate and Energy Framework – Impact and Benefits

The EU Climate and Energy Framework is the basis for emissions reduction in all sectors including transportation in Europe[12]. The framework states an objective of reducing GHG emissions in the EU from all sectors by 80 to 95% by 2050 compared with 1990 levels. This target also sets out boundaries for the transportation sector which is further defined in the Transport White Paper[13] which was issued in 2011. The latter document states the objective to reduce the GHG emissions from the transport sector by 60% by 2050 compared to 1990 and by 20% by 2030 compared to 2008 levels. In 2014 targets for 2030 were announced as follows:

At least
40% cuts
in GHG emissions
(from 1990 levels)

At least
27% share
for renewable
energy

At least
27% improvement
in energy
efficiency

Source: European Commission. A policy framework for climate and energy in the period from 2020 to 2030. 2014.

As part of the package of measures to keep the European Union competitive as the clean energy transition is changing global energy markets, the European Commission in 2016 published four strategies to accelerate clean energy innovation[14] including electro-mobility and a more integrated urban transport system.

2.3. ETPs' Perspective (on electric mobility)

ERTRAC's Strategic Research Agenda advocates a systems approach to reductions in CO_2 emissions from transportation where the vehicle and the fuel (energy) contribute a part of the overall reduction potential. Contributions also come from infrastructure improvements, logistics and mobility services. Within the vehicle category there are contributions not only from the propulsion and energy side but also from other aspects related to the vehicle body rather than the powertrain, such as aerodynamics, weight, size, friction, tires etc. Within the evolution of the transportation sector the expectation is that fossil-based fuels will dominate the energy pool for road transport until 2030[15] and, even on the longer time horizon (2040+), the road transport energy supply mix will be composed of four main sectors: oil based fuels, natural gas, renewable liquid fuels and electricity, itself mostly produced from renewables. Whilst electrification is vital for the future and the efficient utilisation of renewable energy, it will penetrate the powertrain sector progressively.

[12] European Council. Conclusion - 2030 Climate and Energy Policy Framework. 2014.
[13] European Commission. White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. 2011.
[14] Accelerating Clean Energy Innovation. COM (2016) 763.
[15] ERTRAC Roadmap on "Future Light and Heavy Duty ICE Powertrain Technologies"

EPoSS in the "Transport and Mobility" chapter of its updated Strategic Research Agenda points out that Europe must leverage its long-lasting and distinctive know-how to develop further ICE technology as efficiency improvement and emissions reduction may come from the massive adoption of advanced electronic controls systems and e-actuators. However, this approach will be increasingly complemented by progressive electrification of powertrains and energy storage systems through more R&I to achieve more optimised and affordable solutions. Important synergies and technological transfers are envisaged, from x-EV architectures and powertrains for cars, buses and trucks to avionics, where there is an emerging demand for e-aircrafts for short distances with a high potential, but also with connected and automated driving.

ETIP SNET aims to plan and prioritise R&I activities for the best possible integration of the electricity markets, networks and systems with those in the other energy-intensive sectors, especially transport and heating. For example in the electricity distribution system, network planning and optimisation tools linking with energy market design and urban planning tools will be needed to optimise the location of the charging stations and the development of the electricity network. Powerful new information and communication systems will be needed to build on smart meter and smart grid but also traffic data to best plan and operate the energy and transportation systems. ICT tools will be also needed to make the best use of the inherent flexibility offered by EVs both when charging and in Vehicle-to-Grid (V2G) applications. This is addressed in functional objective (FO) D6 (Infrastructure to host EV/PHEV – Electrification of transport) of the ETIP SNET R&I roadmap with a specific KPI (Increased network hosting capacity for EVs).

At transmission level, demand response and storage solutions including the impact of transport system electrification for off-peak hours, and their use in system balancing should be investigated. Methodologies and tools to assess the impact of the transition towards a new model for a European energy system (heat, transport, gas, and electricity) will also be needed. These needs are addressed in two different FOs, T11 (Demand response) and T14 (Interaction with non-electrical energy networks).

Additionally, the ETIP SNET points out that the development of EVs will be beneficial to the development of cost-competitive multi-service stationary battery energy storage systems and as the consequence to the improved operation of the electricity grids.

3. BENEFITS, CHALLENGES AND TECHNOLOGY POTENTIALS OF ELECTRIFICATION

This chapter covers many of the benefits and challenges associated with the implementation of electrified mobility. It also explains some of the technological capabilities, details and limitation in order to understand more about the background relevant for technology roadmaps. At some points in the descriptions, bridges will still be made to the expectations of users, since even the best technical solutions need to satisfy the user's needs and expectations.

3.1. Emissions and Energy Efficiency

The **most important driver** for electric mobility (beyond climate protection) is the ability to operate locally emissions free, contributing to the air quality in cities, and with less noise. Although it should be reminded that noise reduction benefits from electrified vehicles are limited to up to 30 km/h[16] (at constant speed).

The 2016 EEA Report on Air Quality discussing the impacts of local emissions like NOx and particles caused by (among others) road transportation in Europe gives a good overview of air quality and consequences resulting from poor air quality. The growing population of EVs in the longer term can make a contribution to improving air quality as long as power generation itself is low emission in the urban region.

The real climate benefit comes with the increased use of renewable energy sources. Generally, regenerative energy will be mostly available in the form of electricity. Electric vehicles are particularly attractive since they represent vehicles that offer the most efficient use of regenerative energy. On the other hand, it should be noted that although electric vehicles are more efficient, the CO_2 emissions are strongly dependent on the electric power mix, used for battery charging. The evolution of CO_2 emissions of battery electric vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV) and comparison to the conventional power train is shown in Figure 2 and described in much detail in the Annex. As the actual EU electricity power mix presents an increased use of renewable energy sources, the benefit in terms of total CO_2 emissions is already very important in the EU (BEV 2016 EU-28 Mix represents the emissions of a BEV in 2016, if the electric power is delivered by the actual mix of the EU power production etc.)[17]. This does not reflect efficiency improvements in the vehicle itself, but in the effective combination of cleaner power used by the efficient vehicles. Further expected improvements in vehicle efficiency themselves can contribute both to improving user acceptance in terms of range, but especially as a direct benefit to the major target of CO_2 reduction by 2030.

[16] Dudenhöffer, K. and Hause, L., Sound Perception of Electric Vehicles. Research Acoustics. 114, 2012.
[17] European Commission, EU energy in figures – statistical pocketbook 2016, 2016.

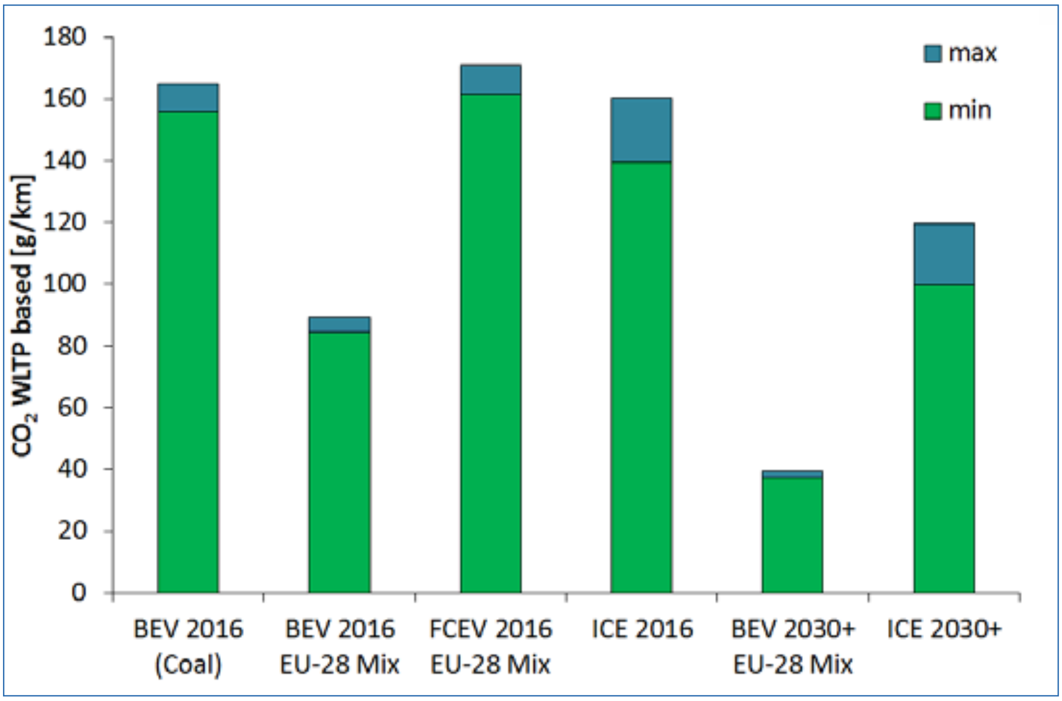


Figure 2: Evolution of CO_2 emissions in grams per km of battery electric vehicles (BEV), fuel cell electric vehicles (FCEV) and comparison to the conventional powertrain (ICE) for coal-based electricity generation and for the EU-28 mix[18]. WLTP-based. Minimum type approval CO_2 emission WLTP for ICE in 2016 and 2030 are 103 g/km and 73 g/km, respectively due to migration factors from WTW analysis.

3.2. Range and cost

Increasing range capability of electric vehicles remains a high priority, as previously mentioned, in order to increase user acceptance and win the broad mainstream market especially in comparison to conventional vehicles and current existing usage models of these vehicles. It is important to keep in mind, however, that increasing driving range supplied by the electro-chemical energy stored in the battery can only be achieved directly by increasing the size of the battery. Increasing the size of the battery increases the "installed" energy storage capability at an increased cost and increased size and weight. This in turn has an impact on the vehicle efficiency itself. To double the range means nearly to double the battery size and weight. The analysis in Figure 3 shows how efficiency drops as battery weight goes up. Another possibility would be to improve the overall system efficiency (especially in representative driving cycles), but in some operating modes over 90% efficiency has already been achieved, or to drastically reduce weight and thus save absolute energy consumption. Although this approach is viable and must be further pursued, it requires much more effort to make modest increases in the driving range.

On the other hand battery prices are still expected to fall with increasing production numbers according to scale economies. So an open question remains, if the vehicle manufacturers would put these savings in more range capability to get a higher performance premium EV or into reducing cost of the vehicle and leave the existing range the same in a user friendly EV concept (see chapter 4.1).

[18] If the energy used is purely from renewable primary resources, the CO_2 emissions for BEV and FCEV vanish to zero.

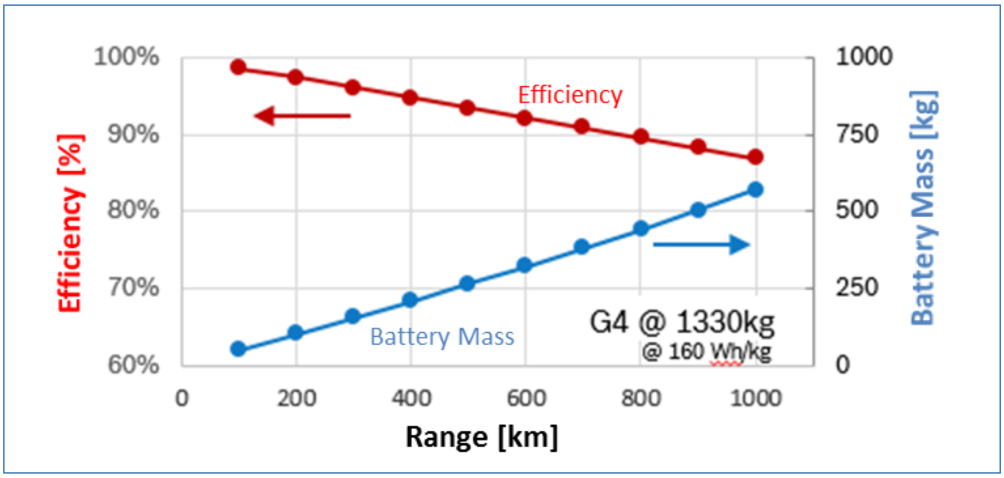


Figure 3: Adding battery weight decreases efficiency, which was revealed by an internal analysis based on G4 Vehicles (Golf class).

In the end, a **three-way relationship exists**: Keeping range low may slow market uptake but is an effective measure to keep the costs lower. Lower range could be compensated by improving charging comfort. Increasing vehicle weight (assuming the range demands are larger than the ability to reduce the weight of the battery) decreases vehicle efficiency as shown in the figure above. It may be the market pressure that finally forces vehicle manufactures to favor increases in range at the cost of the other two variables.

Beside BEVs extended driving ranges can also be achieved with PHEVs, although the distance driven might not be completely powered by electricity and with FCEVs, which already reach ranges of 500 km.

In the past, range has been a strong marketing instrument. However, this could change when especially urban users start adopting new mobility models that are supported by connectivity and integrated solutions. Competitive long-range inter-urban travel may be offered with trains or planes and vehicles waiting and warmed for them at both ends of the journey. Additionally, lightweight L-category vehicles in combination with sufficient charging infrastructure could also be an alternative solution to reduce energy consumption and thus the weight cost of batteries. This can lead to competitive TCO values in regards to ICE powered vehicles also for private use.

3.3. Charging technology and Infrastructure

Convenient and reliable re-charging has already been identified as one of the most important aspects to increase user acceptance of electric vehicles, but is most often neglected. One clear challenge is to provide appropriate charging capabilities to urban dwellers that often have to rely on overnight street parking and limited garage spaces in high-density populated city areas. Municipalities aim long-term to reduce the number of vehicles in cities and are reluctant to electrify a high number of parking spaces with bulky or unsightly charging stations that often do not fit easily in the townscape. These users will have to rely on quick-charge capabilities or charging during the day at work. Additionally, there is the possibility to promote this means of charging with incentives due to the potential usage in vehicle-to-grid applications.

The **following aspects** are of particular interest from the user's perspective:

Charging is different from filling up the tank every one or two weeks. It is the possibility of picking up a little bit of a charge wherever the user goes, just like a smart phone, and hence needs to be as convenient as possible. This leads logically to wireless charging, or (wall-) boxes with the cables permanently attached to the box so the user only has to deal with one plug.

High(er)-power charging (AC up to a limit and DC beyond that) for long(er) distance journeys or situations requiring just enough energy to get home. Rapid chargers installed at current filling stations (that have evolved at locations where there is a need for them) may be one good solution. However, charging duration at peak usage times may create a risk of long waiting lines for the charging stations to become available. Additionally, this might also create some issues regarding the grid capacity.

Finally, **integrated solutions** may be attractive especially when looking at future possibilities and technologies in homes. Classic low-power wall boxes are already common, but advanced solutions should consider low-power charging using the same DC-connector that is used for high-power. The rationale for this is explained below in the section on vehicle to grid.

Fundamental differences in charging technology are the cable solutions compared to wireless solutions. Wireless charging is a promising complementary charge solution to be added to the conventional conductive one and likely to spread as a basic element of the city infrastructure, especially for bus station/stop applications. Wireless charging technology is also being treated by standardisation committees.

3.4. Fast Charging, V2G and Urban charging solutions

Fast charging has not clearly been defined to date since it can include AC charging up to a certain power (43 kW), but requires a DC connection for power levels beyond that power. There are discussions of power levels even up to 300 kW. This may or may not be a practical solution when considering the cables and connectors involved and the need for additional standardisation. Impact on the vehicle electrical architecture would have to be considered as well as the effects on battery lifetime using such high levels of power. Even at this level of power it would take 10 minutes to charge the battery to give the vehicle 300 kilometers more range (assuming just above 15 kWh/100 km consumption). If the charging goes into de-rating to protect the lifetime of the battery, then charging times could triple. It is still uncertain if 30 minutes charging time for 300 kilometers of driving range would be acceptable. Waiting times on motorways during peak vacation driving times could be very risky, as well as the load on the grid at these node points.

Another aspect may support the widespread use of standard low-power connecting points to the grid. There is much talk and discussion about vehicle-to-grid (V2G) and using these capabilities to buffer energy and possibly support stabilising the grid. This requires however, that the vehicles are actually connected to the grid whenever possible. Vehicles primarily relying on fast charging are only briefly connected and hence cannot be considered. In this case, some of the following issues must be considered:

1. Are the vehicles attached to the grid when peak power occurs and would the batteries help shave the peaks?
2. Are there sufficient parking spots with sufficient connection capabilities that enough power is available during peak production or peak load?
3. Who is willing to pay for the additional equipment needed in the vehicle to make them grid-capable?
4. Are users willing to make the effort to connect to the grid even if they do not require energy? Always connected?

V2G may suit long stay car parks at transport hubs such as airports or train stations, or at work, where rapid charging will be less critical and permanent connection to the CP essential for V2G. This is also most likely to conform with user's behavior since employees would probably not be willing to leave the office to unplug and move the vehicle after charging has been completed.

3.5. Smart homes

Vehicle-to-grid has already been discussed with certain skepticism in the previous section, but **smart homes may offer new attractive technological solutions in this area**. Consider an intelligent home or workplace with photovoltaic solar panels on the roof and storage batteries in the basement or garage. This system would be most efficient if power was left in the DC domain and only converted to AC when needed in that domain. It would be theoretically possible to connect the vehicle to DC domain by means of the DC connector, but in a low power mode. From the home perspective, the vehicle's battery would be treated like the other storage batteries as long as the vehicle is connected to this network.

It is now technically feasible to implement DC networks in homes especially since many electricity consumers in the home are actually DC devices that are powered using inefficient AC/DC converters.

It may become more common in the future to keep the energy to remain in DC domain as long as possible and avoid conversion losses from DC to AC and back again. This could also serve as a solution for the transport hubs previously mentioned or connections at the office. However, it is unclear how power would be monitored to allow accurate billing and power management. This may create a need for ICT solutions with vehicle monitoring software. The vehicle would remain in control of the charging process, but ICT would support the overall implementation and monitoring of the amount of energy flowing back and forth (by means of the vehicle). An additional aspect to consider with respect to vehicle to grid is the need to avoid vehicle 1 discharging to re charge vehicle 2 next door.

3.6. Cost of technology and economies of scale

A strong lever for cost reduction, in general, is the microeconomic principle of scale of economies. These principles apply also to the development of electric vehicles and infrastructure, whereby high fixed development and machinery cost are spread over a large number of manufactured pieces thus allowing for lower prices. As many players, both vehicle manufacturers and suppliers, are providing goods and services to a relatively limited market, the principles of scale economies are not yet applicable and significant scale economies that are typical in the industry are not expected on the short term. Any means of supporting the growth of scale economies should be supported, though such as well-planned incentives, as seen in Norway, can be one strong instrument for supporting the growth scale by means of improving market pull. Norway had a goal of 50,000 vehicles, as the Norwegian "contribution" to scale economies. But, even more important than reaching the number, was the development of a "model" to demonstrate that even the current vehicles with limited range (compared to conventional vehicles) are acceptable and usable in the Norwegian Market, given that the country has put significant effort into developing the boundary conditions.

On the other hand, it is very important not to attempt to artificially creating scales by attempting to increase production and neglecting the market demands.

Furthermore, developing additional advanced technology such as connected services that intend to make electric vehicles more attractive need to be well thought out since these additional services may run the risk of making an expensive vehicle even more expensive and for the user less attractive in the end. Unless specific to electric vehicles, such features or services should also be developed and proven with existing standard vehicles to profit as early as possible from scale economies and successively adapt for use with the electric vehicles.

Mobile navigation systems are a good example of how scale economies and strong competition in consumer electronics can make such high tech systems affordable for the mass market. In the early phase of market uptake, before scale of economies has been reached and vehicles are still expensive, **connectivity and automation may play an important role particularly for electric vehicles in new mobility schemes such as car sharing and specific fleet applications**. In these cases, the business model becomes the dominating decision factor. It may be of strategic value to artificially support business models for a designated period of time in well-planned initiatives that are intended to evaluate the effectiveness of the instrument technology push. This is beneficial for maintaining technology leadership, gaining knowledge regarding user acceptance early on, as well as developing the market base.

3.7. Value chain

There is **no doubt** that the innovative area of electrification offers new opportunities for both the classic supply industry as well as new players. Shifts in the value chain are expected over the coming years at least until the mechanism of scale economies begins to apply. While it is probable that new players will try to substitute existing ones due to new vehicle architectures associated with the flexibility of electrification, this, however, often runs the risk of an oversimplified view of the competitor arena, especially for start-ups. Systems and components that have a strong dependency on the scale production may end up with suppliers that already have high production capabilities. Technologies and components that have low market-entry barriers run the risk of a high number of competitors and hence a strong market fragmentation. This could be inhibitive for standardisation that is needed as a further pillar in reducing the cost of electric vehicles. At the same time, modularity would be beneficial in supporting scale economies since single modules could be produced in high numbers and fit wherever interfaces are standardised, but comes with an effort and cost for overhead. Integrated solutions utilise synergies with the solution and thus also minimise the number of interfaces.

In the on-going dynamic phase that is expected for at least the next 10 years there should continue to be room for “small” players with innovative solutions. These players should be further supported in order to challenge existing supply chain structures to improve the overall competitiveness of the European supplier industry.

3.8. Four Big Initiatives

Based on the expectations, challenges and potentials of electric mobility described above, the following four thematic domains have been defined to describe coherent sets of research and innovation needs:

Operation System dependent EVs in the urban environment	Non - compromise electric urban bus system
User-friendly affordable EV passenger car + infrastructures	Sustainable electrified long-distance trucks and coaches

The technology roadmaps in chapter 5 thus follow this scheme and establish four initiatives related to it. **The background of these initiatives or thematic areas is briefly sketched here**.

⦿ OPERATION SYSTEM DEPENDENT EVs IN THE URBAN ENVIRONMENT

The success and the rate of market penetration of EVs will strongly depend on the degree of usage and perceived suitability for usage of these vehicles in urban areas. Several cities have launched programs towards zero emission passenger cars and commercial vehicles. Even if the final goal is a 100% pure electric inner city transport, a ramp-up phase is needed and meaningful. This could be achieved via hybrid vehicles with rather limited electric range and plug-in hybrids which could already cover most electric range requirements towards full battery or fuel cell electric vehicles.

Managed fleets of electric vehicles can ease many of the issues that are hurdles for the mass adoption of electric vehicles, like e.g. limited range and inconvenient recharging. Also, the ongoing introduction of more and more connected as well as automated vehicles will have a very strong impact also on EVs in the urban environment. Range requirements, durability, reliability and recharging of shared EVs – as personalised automated mass transport – will result in much different requirements than individually and privately owned vehicles – including modified legislative frameworks.

In order to achieve a market penetration as fast as possible, research is needed to further improve the whole operation system of EVs in urban areas. **The activities have to focus on those topics with highest contribution to the achievement of 2030 targets**:

Vehicle technologies	Infrastructure technologies	Traffic system technologies
Lightweight & highly efficient city vehicles (passenger cars, L-category and commercial vehicles) with high impact on the reduction of specific energy consumption per person/ton-kilometer and competitive cost	Easy-to handle charging technology incl. vehicle-infrastructure interface with high impact on minimal effort for and best use of infrastructure	Control of traffic flow by means of connectivity, IoT and automation with high impact on best use of urban space, vehicles and charging infrastructure

⦿ USER-FRIENDLY AFFORDABLE EV PASSENGER CAR + INFRASTRUCTURE

In order to establish EV passenger cars as the preferred means of private transport, EVs have to fulfill in the future also all expectations of the user of "classic multi-purpose vehicles" in all kinds of environments and usage profiles, but also in consideration of the physical limits mentioned in section 2.1. Hence, this second initiative should foster a fast EV roll out on broad mass market level. A significant increase of acceptance of EVs can come only via further and significant cost reductions and elimination/limitations of range disadvantages compared to other propulsion technologies as previously discussed. Hence, major research efforts are needed in the near and longer future regarding batteries with significantly improved high energy density batteries and further improvements in efficiency. Such research offers the advantage of multiple synergetic uses for all kinds of xEVs. However, also improvements of all other components of electric powertrains are as important and relevant for achievement of high market penetrations.

The broad spectrum of activities needed can be grouped as follows:

Disruptive steps in battery technology development	Significant advancements of e-powertrain technology	Best use of connectivity
Simultaneous improvement of energy and power density considering minimal costs, best durability and optimised system performance, such as high-power charging capability, will eliminate most hurdles for mass market introduction	e-motors, power electronics, charging system etc. with high impact on powertrain efficiency as well as reduced needs raw materials and rare earths	Energy efficient control of EV operation (vehicle powertrain, passenger comfort, traffic flow, charging and energy management) with high impact on the integration of EV in the traffic environment

◉ NON-COMPROMISE ELECTRIC URBAN BUS SYSTEM

Quite challenging but, if successful, very effective regarding air quality improvement in cities is the fast introduction of electric urban bus systems in order to replace current Diesel-engine based buses. Whereas the basic electric propulsion technology for such vehicles is available (from existing trolley buses), fast charging and energy storage on board need to be addressed in upcoming research activities. Further, not only the component and system costs but also total costs of ownership (TCO) have to be reduced significantly in order to be competitive. Finally, also energy efficient operation of these buses by means of connectivity has to contribute to minimising TCO.

The following thematic areas with potentially high impact are identified:

Battery technology for heavy duty applications	High efficient vehicle & propulsion systems	High efficient and fast charging
Achievement of very high reliability and CV-type-specific long durability as needed for buses are a prerequisite for electric bus systems and thus have a direct impact on the elimination of hurdles for market introduction transport and general operation	Improvement of efficiency of all main and auxiliary systems has a direct impact on energy/operational costs and, thus, minimise TCO	Energy supply (charging technology) and interfaces for fast charging with high impact of costs for infrastructure

Improved operating interfaces and optimal use of electric bus system	Reliability and public acceptance
Best use of bus services with double impact on TCO for operators and cost/ comfort for customers	are key elements to achieve the necessary TCO and regular service operation

⦿ SUSTAINABLE ELECTRIFIED LONG-DISTANCE TRUCKS AND COACHES

The challenge of carbon-neutral long distance road transport (medium and heavy duty, trucks and coaches) should be tackled in parallel regarding most efficient technologies in order to minimise the energy needed to be stored on board for the designated route as well as CO_2-free or CO_2-neutral energy sources (electricity and fuels for renewables including power-to-liquid and power-to-gas). A technology-neutral approach should allow the consideration of all kind of “energy converters” (e-motors and generators, internal combustion engines, fuel cells), “energy buffers” (batteries) as well as “energy interfaces” (fast charging and electric road systems). Benchmark in view of efficiency, performance and costs (TCO) has to be the “classical” heavy duty powertrain, but in combination with most advanced technology elements and sustainable, CO_2-neutral fuel. Also the potential to reduce local noxious emissions should be considered.

Following the considerations above, **most relevant fields of improvements needed and with highest impact** are in the field of electrification:

Efficiency of propulsion system	Charging and electricity infrastructure	CO_2 free or CO_2-neutral energy sources
Highly efficient e-powertrains also in conjunction with ICE and incl. auxiliaries that help to minimise the energy demand for freight transport and general operation	with a direct positive impact on TCO for operators of vehicle fleets and infrastructure	High efficient power-to-liquid and power-to-gas with impact on secure & efficient supply of energy for road freight transport

Connectivity and logistics	Reliability
Continuous improvement of freight logistics towards an optimised, most efficient transport system by eliminating inefficient transport processes	as it is a key element to achieve the necessary TCO and regular service operation, and public acceptance has to be investigated

R&I actions needed in order to achieve the contributions listed above will be elaborated in terms of milestones and content in the subsequent chapters 4 and 5.

4. MILESTONES

By setting ambitious milestones, the dedicated objectives and the overall timeframe of a roadmap are defined. Thus, milestones are the basis of any roadmap. The way towards achieving these milestones strongly depends on the vehicle categories and projected usage, and is thus detailed in chapter 5 where roadmaps for each of the four big initiatives are outlined before specifying the individual goals. Tasks necessary to reach the milestone targets are described. In this chapter, the technology goals for electrified passenger cars, L-category vehicle and commercial vehicles are described, the milestones are reviewed and further extended, and projections for the deployment of electric vehicles in Europe are presented.

To reach such ambitious milestones, major research efforts (see chapters 3.8 and 5) are vital in the near and longer future regarding batteries, charging, propulsion, costs.

4.1. Electrified passenger cars

The 2012 version of this roadmap was focused on electrified passenger cars only, and based on two technology paths which can be expected to develop at comparable pace:

FULLY ELECTRIC VEHICLE

Around 2030 EVs are expected to see tremendous evolution, concerning i) the vehicle technologies (battery, drivetrain components, energy management), ii) the industrialisation (dedicated platforms, standardisation, high volumes), iii) the charging infrastructures (availability, roaming) as well as iv) the usages thanks to a wide use of information communication technologies (trip planning, car sharing, autonomous drive). At that time it is possible to distinguish two types of EVs marketed, i.e.:

User friendly affordable EVS	These vehicles, in the A/B/C segments, will present a more optimised range/cost solution enabling a better market penetration and then a very big impact on urban pollution and GHG reduction. The range of 250 km under standard European procedure[19] (~180 km in day to day average usage) will be well adapted to urban/suburban use. Such vehicles would need to have an expected retail cost[20] in the same order of magnitude as their ICE-based equivalent. The major challenge will be to achieve significant cost reduction of the battery and propulsion systems. Their TCO[21] should be favourable, as compared to conventional vehicles, but will be highly dependent on national and local government's policies (transportation energy taxes, city centre driving ban, infrastructure support and cost of electricity); the development of these vehicles supports the first one of the big initiatives, operation system dependent EVs in the urban environment.

[19] To better highlight technology improvement and provide more accurate technology comparison along the time schedule, all the consumption and range data are expressed according to the already existing NEDC procedure. For the EV cases, a 30% correction factor, based on existing products analysis has been used to highlight actual use performances on vehicle range.

[20] All retail price comparisons are made assuming a gasoline equivalent conventional vehicle (dynamic performances and equipment), no incentives for EVs and PHEVs cases and battery included for EVs.

[21] TCO evaluation does not consider vehicle resale.

Higher performance EVS	Such vehicles in the C/D/E segments will maximise the performances offered, providing at least 700 km on a single charge. These vehicles will remain more expensive to buy, especially because of the high amount of battery capacity on board, i.e. massive improvements of battery cell and system cost and significant performance improvements in terms of energy density and high-power charging of energy batteries will be required. The development of these vehicles supports primarily the second of the big initiatives, **user-friendly affordable EV passenger car + infrastructures**.

The expected performance goals for these two electric vehicle categories are summarised in table 1 with 2020 being the starting point relevant for research.

Case considered	EV 2016	EV 2020		EV 2030	
Hypothesis	Existing	User friendly affordable	Higher performance	User friendly affordable	Higher performance
Energy consumption (Wh/km)[22]	140	130	135	115	120
Range (km)[21]	250	250	500	250	700
Battery total energy (kWh)	35	33	68	29	84
Battery Li-ion cell gravimetric energy density (Wh/kg)	160	> 180	300	> 330	500[23]

Table 1: Hypothesis for EVs.

⦿ PLUG-IN HYBRID ELECTRIC VEHICLE

By 2030 PHEVs will be proposed on the one hand for their very low fuel consumption and GHG emission and on the other hand as one of the market responses to potential city centre driving bans. Such vehicles could provide up to 150 km of pure electric range with no or minimal compromise in dynamic performances in that mode. However, as previously mentioned, the challenge is to ensure that the vehicles are actually charged and driven in electric mode when operated in urban areas that require this mode. Full electric ranges beyond 50 kilometers should also bring concepts like REX into the discussion.

[22] To better highlight technology improvement and provide more accurate technology comparison along the time schedule, all the consumption and range data are expressed according to the already existing NEDC procedure. For the EV cases, a 30 % correction factor, based on existing products analysis has been used to highlight actual use performances on vehicle range.

[23] Best performances expected for post Li-ion technologies.

Weighted gasoline consumption under standard European procedure4 will lie between 0.45 to 0.65 L/100 km (10 to 15 gCO_2/km). It is important to be noted that in use PHEV fuel consumption will be weighted between CD[24] and CS ones. Therefore the weighted value will be highly connected to the way the vehicle will be charged from the grid, indeed its liquid fuel consumption will lay between 0 (daily use lower than the all-electric range and night charge) to values close to 3.0 to 4 L/100 km (70 to 90 gCO_2/km) for long trips or no battery grid recharge. Retail extra cost of such vehicle would still be in the order of 2,000 to 3,000 €, which again requires massive progress in the area of significantly reducing the cost battery cells and systems. The development of these vehicles supports both the first and the second of the big initiatives, **operation system dependent EVs in the urban environment, and user-friendly affordable EV passenger car + infrastructures**.

The expected performance goals for the plug-in hybrid electric vehicle categories are summarised in table 2.

Case considered	PHEV 2016	PHEV 2020	PHEV 2030
All Electric Range (km)[21]	50	Up to 100	Up to 150
Dynamic performance in EV mode	Urban/suburban performance	Urban/suburban performance	Full performance No compromise*
Retail extra cost (€)[22]	~3000 to 10 000	~3000 to 6000	~2000 to 3000
Consumption under standard procedure (L/100 km)[21]	1.5 to 2.0	0.8 to 1.0	0.45 to 0.65
CO_2 emission under standard procedure (g/100 km)[21]	35 to 50	20 to 25	10 to 20
Battery total energy in (kWh)	~8	~15	~20

Table 2: Hypothesis for PHEVs.

4.2. Electrified L-Category Vehicles

L-category vehicles (in particular two and three wheelers and light quadricycles) are very suitable for electrification because of their small dimensions and lightweight, which means low energy consumption and consequently lower battery cost. In particular, electrified L-Vehicles can play an important role in urban areas where they can contribute to decongestion of traffic and relief for pressure on parking. Range and cost are main open issues for technology development and market penetration. In urban area usage, real autonomy is less important, nevertheless customers are more inclined to electric vehicles that do not need to be constantly recharged. However battery sizes adopted specifically for the urban use case can lead to attractive TCO values also for private use. Nowadays there are only pure electric vehicles in this category, with a few examples of hybrid solutions. By considering L-category vehicles, this roadmap is aimed at increasing the attractiveness of vehicles by the reduction of costs and the improvement of the functionality of use, which means appropriate range, shorter recharging time and recharging comfort (mainly depending on infrastructures). The development of these vehicles supports primarily the first one of the big initiatives, **operation system dependent EVs in the urban environment**.

[24] CD: Charge depleting
CS: Charge sustaining

4.3. Electrified commercial vehicles

This roadmap now also considers both trucks class N2 (3.5 to 12 tonnes) and class N3 (more than 12 tonnes) and buses class M2 (lower than 5 tonnes) and class M3 (more than 5 tonnes) distinguishing the following **four categories**:

Trucks and vans for urban transport	Trucks for long-haul transport	City buses for urban transport	Inter-urban buses and coaches for long distance travel

The technology path is dependent on the intended use of the vehicles. Commercial vehicles are often custom-built to meet specific needs concerning load and operation which results in a large variety and low production volume of different vehicle configurations. Plug-in hybrids and full electric vehicles are well suited for urban and regional operation where charging and dynamic power transfer infrastructure can be developed to an integrated transport system. Longer distance and heavier transports are more suitable for conventional hybrids, plug-in hybrids (enabling pure electric drive e.g. in urban sections of the trip) and possibly dynamic power transfer due to the physical limitations of on-board electric energy storage.

The pathways for the four categories are described in detail in the following.

TRUCKS AND VANS FOR URBAN TRANSPORT

The operation of vehicles for urban transport is characterised by transient loads with high-power peaks for acceleration with low loads in slow traffic and at standstill. The electric urban truck will contribute to energy efficient, emission free and low-noise goods transport solution through pure electric drive. The size of the energy storage will be dependent on both the size of the vehicle and the charging strategy bridging from large storage to medium for overnight charging to opportunity charging at logistic centres. The total cost of ownership should be comparable to the ICE truck although the initial cost may still be higher, due to the lower cost of maintenance and fuel prices, assuming the price for the electric energy does not rise further and the diesel prices stay approximately constant.

The plug-in distribution truck will have both an electric energy storage and ICE, less dependent on charging infrastructure and need less time for charging. It will provide higher energy efficiency compared with conventional distribution trucks and the possibility of limited emission free and low-noise transport through pure electric drive and high performance recuperation. The introduction of electric urban trucks is supported by the deployment of a charging infrastructure, which probably includes strategically located fast charging points, potentially shared in some cases with public transport vehicles. Such introduction may be favored thanks to non-emission free vehicle ban from city centers and special opportunities for operators (night delivery). Milestones for electrified urban trucks will in many respects follow similar milestones as for city buses with the difference that urban freight transport is usually not bound to transport line operation, but still also have a home base for overnight parking and charging. Higher voltage (e. g. up to 1500 Volt) on-board vehicle power networks may advantageous to fulfil the requirements on these vehicles in terms of low-speed torque and efficiency. The development of these vehicles supports both the first of the big initiatives, operation system dependent EVs in the urban environment.

⦿ TRUCKS FOR LONG-HAUL TRANSPORTS

Heavy trucks for long-haul transport (40 tons, 80 km/h) have an average energy consumption of 1500 Wh/km. Long-haul operation is characterised mainly by almost steady-state operation for longer periods combined with peak power demand during acceleration and uphill with low-speed operation through urban areas, in terminals and in highway congestion situations. Introducing electric hybrids could open up a more flexible and future CO_2 neutral operation of trucks for long-haul transportation. However, although battery technology holds great promise for passenger cars and light vehicles the outlook for long-haul transports is very different. Introduction of electric hybrid vehicles and later also plug-in hybrid vehicles using static fast charging and/or dynamic power transfer (ERS) have the potential to shift energy supply, energy efficiency and decrease emissions for long-haul road transport. Total cost of ownership needs to be comparable to the ICE long-haul truck (although the initial cost may still be higher). It is also of key importance to ensure that payload potential will not be affected negatively when introducing any electrification technology. Hence it is important to understand how to introduce electrification into the logistics system to improve the overall long-haul transport system.

The introduction of dynamic power transfer systems (e.g. electric road systems) could likely start as a closed system (point to point transports) where system boundaries are predetermined and the transport needs of operations can be anticipated. The next challenge will be to define all interfaces (including signal exchange interfaces) in order to test dynamic power transfer systems with multiple actors on transportation corridors and highways. In addition, it should be noticed that installation of ERS would have to cover wide sections of the highway network in order to guarantee availability, convenience and beneficial business cases to the users and hence the timely generation of revenue, i.e. this would reveal any inherent weakness in appropriate business models and public acceptance.

As previously mentioned in section 2.1 research in the area of heavy-duty vehicle powertrains in general need to tackle the challenge of demonstrating electrification solutions in combination with range-extending technologies that show achievable improvements in cost and efficiency without significantly increasing packing dimensions or increasing the weight of the overall powertrain.
The development of these vehicles supports primarily the fourth of the big initiatives, **sustainable electrified long-distance trucks and coaches**.

⦿ CITY BUSES

Bus fleets are ideal for electrification as buses are normally in operation 10 to 18 h/day and energy charging infrastructure can be installed in a very cost-efficient way in existing bus depots or at dedicated bus stops. City buses have an average energy consumption in the range of 1000 to 1500 Wh/km for a 12 meter, and 2000 to 2500 Wh/km for an 18 meter bus; this consumption does not include the power drawn from on-board auxiliaries (in particular for heating / cooling the passenger area) which are usually running up to 18 hours and can even lead to a 50% higher energy consumption. The operation is characterised by many stops and relatively low average speeds resulting in transient loads with high power peaks for low-speed acceleration and wide use of breaking energy recovery. The electric bus will contribute to energy-efficient, emission-free and low-noise passenger transport solution through pure electric drive. The size of the energy storage system will be dependent on the charging strategy bridging from large storage for only overnight charging, up to small when charged also at end stations (opportunity charged), at bus stops, or by dynamic charging. The Total Cost of Ownership must be comparable to the ICE bus with higher initial cost but then lower cost of maintenance and fuel prices. It is highly dependent of the utilisation of the infrastructure and could be cost neutral on operations similar to BRT or BHLS. Already today TCO are shown to be comparable to the diesel one with the exception of the infrastructure costs and continuing challenges to significantly reduce battery costs. Plug-in or hybrid buses have an increased availability by combining pure electric drive with an ICE, less dependency on charging infrastructure and less time needed for charging. They present higher energy efficiency compared with conventional diesel buses and the possibility of limited emission-free and low-noise passenger transport through pure electric drive mode. They still depend on an ICE either as propulsion engine or range extender. The energy consumption and the long operating time require solving a trade-off between energy storage versus charging strategies and degree of hybridisation (e. g. PHEV or REX). A bus charged only during the night would require dedicating an important share of his load capacity for the battery-pack, de-facto reducing the passenger capacity. On the contrary, a bus with smaller energy storage would need to perform high-power fast charging during the service (for example at the bus terminal), de-facto limiting the flexibility of the bus network design. The development of these vehicles supports primarily the third of the big initiatives, **non-compromise electric urban bus system**.

⦿ INTER-URBAN BUSES AND COACHES

The operation of inter-urban buses is characterised by few stops and a constant average speed higher than city buses. The electric bus for inter-urban operation will need either a larger energy storage which is charged at end station or a smaller energy storage which is opportunity charged, charged at bus stops and/or dynamic power transfer (ERS), or a competitive hybrid solution as mentioned above. The total cost of ownership is dependent the investment cost due to the amount of batteries required and accordingly on the utilisation of the infrastructure. The plug-in or hybrid buses have an increased flexibility by combining pure electric drive with an ICE, less dependent on charging infrastructure and less time needed for charging. This technology would provide higher energy efficiency compared with conventional buses depending on the actual load profile and the possibility of limited emission-free and low-noise passenger transport through pure electric drive. The development of these vehicles supports primarily the fourth of the big initiatives, **sustainable electrified long-distance trucks and coaches**.

4.4. Detailed milestone descriptions

Looking back to the first roadmaps done in 2009, the first step to implement electrified mobility was based on the adaptation and conversion of existing vehicles into plug-in hybrid and electric cars. Beyond demonstration and field operational tests, first vehicles and fleets were evolving for niche applications like, e.g. taxis, car sharing systems, delivery services and other captive fleets. Standards for safety, data communication and billing were developed, along with testing activities and actions for raising public acceptance. At the same time breakthroughs were reached in terms of better understanding of underlying technologies and principles.

For the years 2012 and 2016 the following milestones were set:

COMPLETED MILESTONES

MILESTONE 1: Adaption of existing vehicles (2012)

MILESTONE 2: 2nd Generation updated powertrain (2016)

The expected performance of the electric vehicles for these two (and the 2020 and 2025 milestones of the previous version) was described in terms of six categories (energy storage system, drivetrain technologies, vehicle system integration, grid integration, transport system integration and safety). The 2012 milestone has been successfully passed, whereas the 2016 milestone properly describes the status quo.

Currently, a second generation of EVs with increasing longevity, reliability and battery power as well as consumer-friendly design and functionality support the acceleration of the market ramp-up. A majority of consumers remain tentative, since the cost is still much too high and limitations of range and charging infrastructure make these vehicles appear less convenient than conventional cars. The European technological standard CSS was agreed on a charging plug standard in the year 2015, paving the way for a European e-mobility infrastructure. Whereas the market volume of electrified passenger cars is still rather low, but scaling up, the electrification of buses and trucks is still in an early stage. Several projects set up test lines in cities as well as test sections for ERS. The offer of L-Category vehicles has quite increased in the last years but the market growth has been limited.

Until 2030, the following three milestones related to the focus of this document, electrification of passenger cars, can be identified.

UPCOMING MILESTONES

MILESTONE 3: Mass production of passenger cars and scaling up of HDV electrification (2020)

⦿ PASSENGER CARS

Mass production of dedicated plug-in hybrid and electric vehicles may be initiated in Europe. Especially, purpose-designed EVs raise acceptance of a majority of consumers. A lower battery weight at higher capacity will have positive effects on the energy consumption as previously shown in section 2.1. The mass production of lightweight constructed cars goes hand in hand with this, but still faces economic challenges. It will be essential that highly integrated and relatively cost efficient electrical motors and power electronics, highly efficient and cost effective thermal solutions and particularly batteries, the most crucial component, are on the market. Only this will make the vehicles sellable with moderate subsidies. The infrastructure for grid integration may be expected to provide on a broad scale advanced levels of convenience through e.g. contactless and (given the availability of appropriate power lines and batteries) quick charging at high efficiencies in urban testing areas. Bidirectional energy flow between the vehicle and the grid has great potential to develop to an interesting option for EVs. First applications of automated driving functions as well as connectivity solutions increasing energy efficiency and thus range find entrance in the premium and middle class segment.

⦿ L-CATEGORY VEHICLES (LV)

L-Category Vehicles will also benefit from battery improvement in terms of cost and energy density. Component integration and mass production will allow powertrains to become cheaper and smaller, enhancing the positive characteristic of electric LVs, however, adoption to urban use cases is necessary to get affordable TCO numbers. Differently from cars and vans, the use of removable/swappable batteries will be more widespread. Probably no plug-in hybrid will be developed, but rather full electric solutions. L-Category Vehicles will share positively the same recharging grids and facilities, including bidirectional energy flow and the use of the cloud for safety and sharing.

⦿ CITY BUSES

There will be a relatively small series of electrified buses in production with an adaptation of existing platforms to pure electric propulsion driven vehicles. First development of new vehicle platforms adaptable to the different possibilities in terms of alternative fuels and charging mode are available. Particularly, auxiliaries will be optimised to reduce energy consumption. Various charging concepts are already displayed through demonstrations and interactions between vehicle (OEM), infrastructure (energy supplier) and bus depots (operators). First standards of automatic charging and signal interfaces for charging services will be in place. Bus operators have prepared bus depots and bus routes with standardised charging infrastructure and extend the number of bus routes for e-bus deployment. Demonstrations of various charging concepts of vehicle and infrastructure will result in draft standards of charging interface for automatic charging and signal interface for charging services (OppCharge). Especially buses used at airports to transfer passengers from the terminal to the planes are an ideal demonstration platform since short distances are travelled and parking at the terminal is always at the same spot. An alternative development path may arise from trolley buses.

⦿ LONG-DISTANCE TRUCKS AND COACHES

Concepts for hybridised long-distance trucks and buses from logistics and coach operators meeting both society and business demands will be available. Their operation will be based on dynamic power transfer or static fast charging which will be shown in demonstrators dedicated for long-distance trucks and coaches. Cost competitiveness has to be confirmed by holistic studies. Full/hybrid electric long distance trucks and coaches may follow for selected applications.

MILESTONE 4: Fully Revised Electric Vehicle Concept (2025)

⦿ PASSENGER CARS

The exploitation of the full potential of electric vehicles regarding energy savings and reduction of environmental impact requires not only "electrifying" the conventional car concept, but to totally revise the automobile concept starting from the level of the electric and electronic architecture. This should lead to synergies that enable improvements in various technology fields (e.g. batteries, vehicle weight, software and sensor-networks for automation and connectivity etc.) which could lead to step changes in energy efficiency, usability and cost. Hence, the achievement of this major innovative step will greatly contribute to the maturity of EVs and PHEVs and reducing compromises in recharge time, comfort, and with a range acceptable for many usage needs.

The **3rd generation electric vehicle** is envisioned to feature innovative zero emission drive train systems enabled by distinctly improved energy recovery and batteries with V2G and fast charging capabilities. Especially contactless charging may be an available alternative for more comfort and widely standardised charging while driving may be demonstrated on dedicated routes. DC-charging should also be available in smart homes. The deployment of EVs will be accompanied by educational initiatives and campaigns. By 2025 the majority will be fully aware of the abilities and benefits of EVs. Moreover, the learning effect leads to the insight, that EVs for special purposes do not need large battery packs when charging infrastructure and fast charging allows a convenient daily use, e.g. for commuting within suburbs and city centres.

⦿ L-CATEGORY VEHICLES (LV)

Electric LV (in particular two and three wheelers and light quadricycles) will be designed to enhance every advantage that the electric drive can offer. In this step, there will be new concepts aimed at reducing energy consumption by weight reduction, tire improvements, and even strong integration of mechanical and electric/electronic parts into vehicle structures. Battery swapping could be a common solution and good alternative for personal mobility and urban logistics applications where batteries have been right-sized and hence sufficiently light and compact to enable this approach. Vehicle sharing will be one attractive application for electric L-category vehicles and their use will be one of the valid alternatives in seamless transport systems.

⦿ CITY BUSES

The production portfolio of electrified city buses is enhanced and the buses have been improved regarding to weight, costs, energy demand, efficiency etc. Standards for automatic charging and information exchange have been established. Bus operators largely increase the number of deployed electrified buses and gather further experiences out of them.

⦿ TRUCKS FOR CITY DISTRIBUTION

There will be commercially available plug-in distribution trucks from major OEMs with various performance levels. Full scale demonstration of electrified distribution truck networks will take place in multiple locations. Standards will be available for automatic charging and for information exchange.

⦿ LONG-DISTANCE TRUCKS AND COACHES

Integrated transport solutions with selected logistics stakeholders will be demonstrated for different use cases at several corridors and countries in Europe. Dynamic power transfer, static charging pilots dedicated for long-distance trucks and coaches (kW capacity, number of charging locations, km ERS installed, etc.) will be checked for feasibility and plug-in/full/hybrid electric long distance trucks and coaches will be deployed for selected applications (range, payload, etc).

MILESTONE 5: Redesigned electrified road transport meeting the requirements of the future connected society (2030)

⦿ PASSENGER CARS

By 2030 an automobile paradigm shift will lead to synergetic effects of automation, connectivity and electrification. The adaption of the car to new mobility models with specific purpose profiles will influence the shape, interior and performance features. Active safety mechanisms enabled by automation functions allow the application of lightweight construction, and thus less material use and lower weight. This would increase energy efficiency, and provide either longer range or ensures better affordability at same range due to reduced battery cost. Energy-efficient and environmentally friendly post-Lithium batteries as well as safe hydrogen-powered drive trains will support these trends. The EVs can be fully-integrated in the grid, and so are the second life battery storage systems. Charging while driving should be tested on highways, although research is needed on the resource demands that would be needed including a holistic environmental impact. The hydrogen infrastructure spans a growing network, benefiting from connected driving solutions and route planning. The consumers will be fully aware of automated EV benefits.

⦿ L-CATEGORY VEHICLES (LV)

Fully connected electric lightweight vehicles will be perfectly suitable to a world of automated city cars. Due to different characteristics, L-category vehicles would not be as automated as cars but they will be connected as well and safe to use. New technology for batteries will be sprung towards electric lightweight vehicles.

⦿ CITY BUSES

Bus operators have converted a big part of their fleet to electrified buses assuming that economic targets have been met and in consideration of procurement cycles. The second generation of improved electrified buses is introduced to the market, and there are full interactions between vehicle and infrastructure (energy and net management).

⦿ TRUCKS FOR CITY DISTRIBUTION

Charging infrastructure is available from multiple suppliers including services/information exchange possibilities.

⦿ LONG-DISTANCE TRUCKS AND COACHES

Given that the need for infrastructure investment has been brought in balance with business cases and society needs, electrified logistics pilots could be in operation at several locations and corridors throughout Europe, and integrated in flexible energy systems combining the potential of dynamic road systems and flexible road-side charging locations (e.g. at Highway truck-stops), also to support auxiliaries. Furthermore, flexible multi-technology modular vehicle architectures with on-board energy management are developed to be able to handle renewable fuel & electricity transfer with different combinations of ICE, electric motor, transmission in hybrid drivetrains, chassis, and energy storage containers for renewable fuels.

4.5. Deployment of electrified passenger cars

The future market penetration of EVs and PHEVs depends on a multitude of factors including technological developments and breakthroughs, policy support, deployment of charging infrastructure, production capacity, future customer needs for mobility and their acceptance of new technologies, and economic parameters such as vehicle production cost, vehicle TCO and energy prices. Based on the interplay of these factors, several forecasting exercises have been carried out during the last years. The incertitude in quantifying the abovementioned factors results in a wide range of options as can be seen in Figure 4.

Although the total number of PEVs in the M1 segment currently only equals a total of 460.000 units[25], its market share in the EU28 has been growing consistently during the last 5 years albeit beginning from a very low basis. It is hence foreseen that after the initial phase of market introduction and towards mass production the number of electric vehicles will be constantly rising: based on current policies 4-5 % market share for new vehicles is envisaged to be achieved by 2020, but appropriate supporting measures may further increase market share up to 8 or 10%, although with some exceptions most European countries are today still under 1%.

Once initial mass production is reached in 2020 **(MILESTONE 3)**, the number of produced vehicles will not saturate since further advancements in technology and production processes are expected towards 2025 and 2030. In fact, as described above, following initial mass production of dedicated vehicles a major innovative step is expected leading to a revised EV system by 2025 **(MILESTONE 4)** and integrated EV's for new mobility models, making full synergetic use of automation, connectivity and electrification by 2030 **(MILESTONE 5)**. Hence the number of produced electric vehicles will continue to increase. The somewhat more conservative scenario, with a focus on achieving CO_2 targets by more efficient and hybridised ICE vehicles foresees a market penetration of 20% for EVs and PHEVs by 2030. Forecasting based on technical breakthroughs resulting in competitive products and mass production as requested by policy makers from 2020 on may results in market shares up to 70% in 2030. As can be seen in Figure 4, many different predictions have been found in literature. However, under similar assumptions of technology development the derived market development is within the same range.

[25] www.eafo.eu

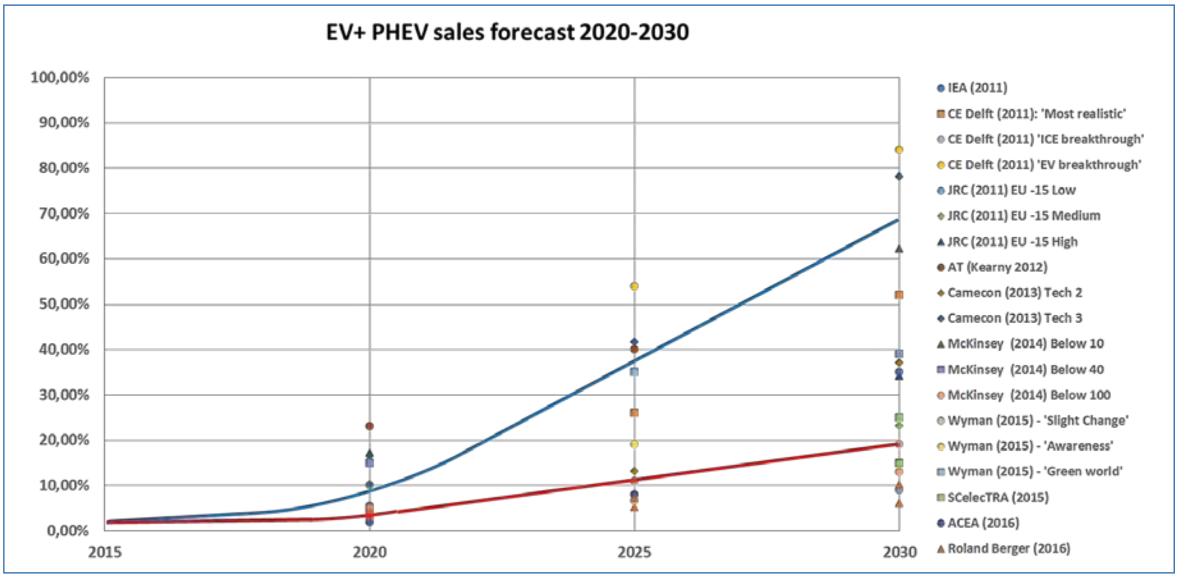


Figure 4: Overview of recent market forecasts for Europe in literature[26], and market share projections for electric and plug-in hybrid vehicles (new sales). Lower curve: perseverant market scenario based on CO_2 targets achieved with a focus on technology improvements and hybridisation of ICE-based vehicles. Upper curve: expected development under assumption of reaching major technological breakthrough for EVs (Battery technology: lowering price and extended lifetime so that by 2020 medium-size PHEV become competitive in partially urban and nonurban transport, and small (urban) FEVs competitive are competitive with their ICE equivalent, resulting in a and mass market uptake).

[26] https://www.rolandberger.com/publications/publication_pdf/roland_berger_integrated_fuels_and_vehicles_roadmap_to_2030_v2_20160428.pdf
http://www.acea.be/industry-topics/tag/category/electric-vehicles
http://www.ertrac.org/uploads/documents_publications/2015 ICE workshop/R Cornubert Oliver Wyman.pdf
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http://cedelft.eu/publicatie/impact_of_electric_vehicles/1153

5. ROADMAPS

Following the definition of milestones, the involved companies and organisations from the automotive and energy sectors agreed on actions to be taken in order to achieve the stated objectives. Roadmaps were drafted for the four dedicated initiatives introduced above considering the fact that the **five biggest hurdles for user acceptance of electric vehicles are, high cost, inconvenient and slow charging, limited range, perceived lack of added value and concerns of limited mobility**. These roadmaps indicate what has to be done and when in order to overcome these hurdles and to move of Europe towards the electrification of road transport.

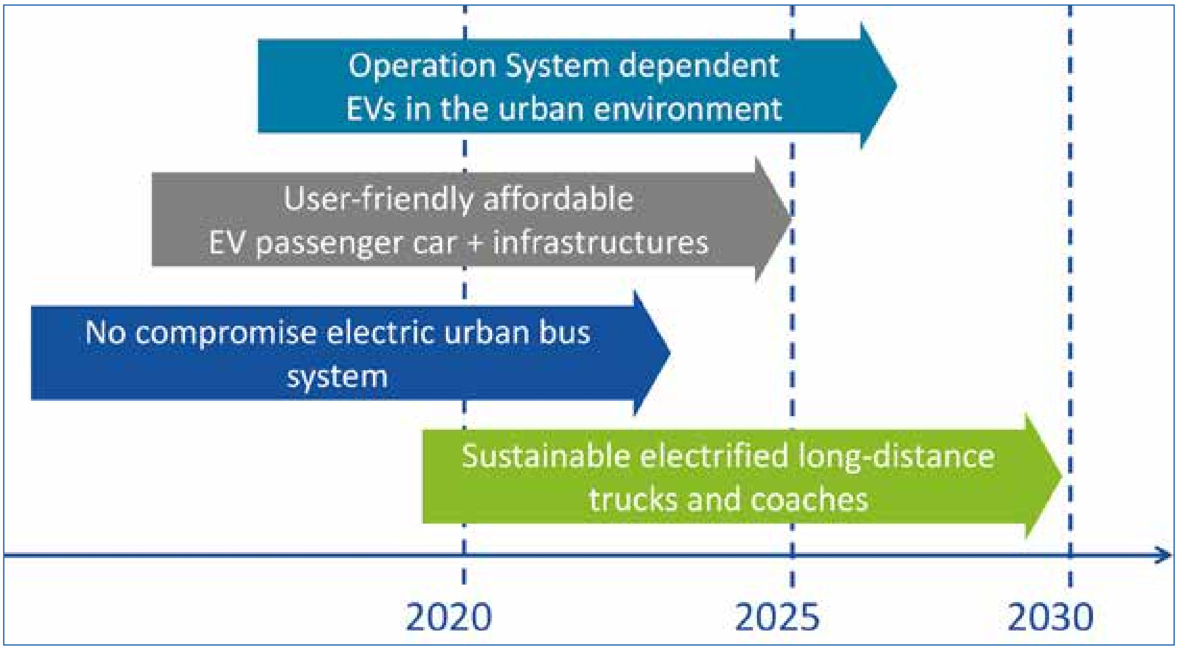
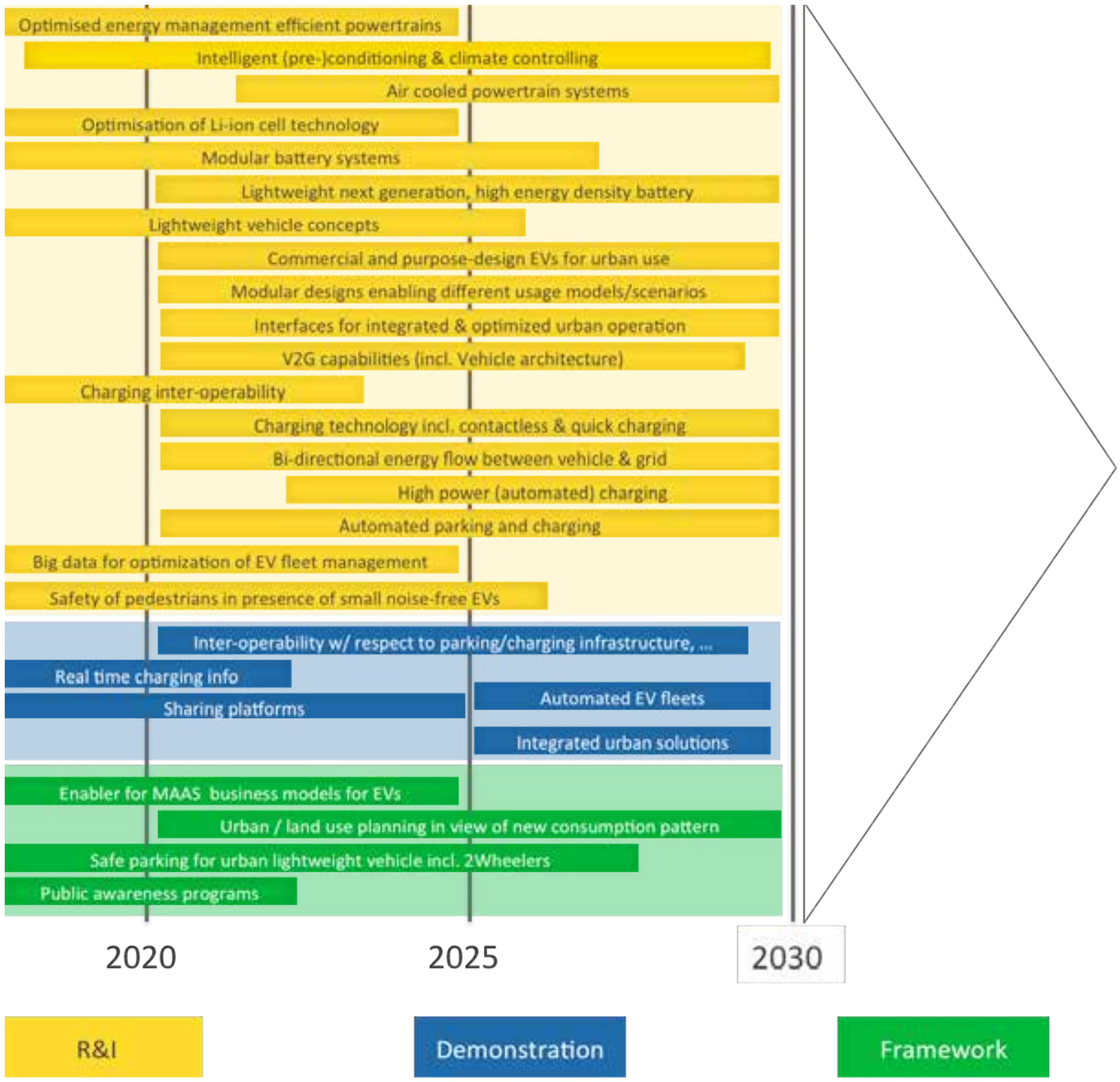


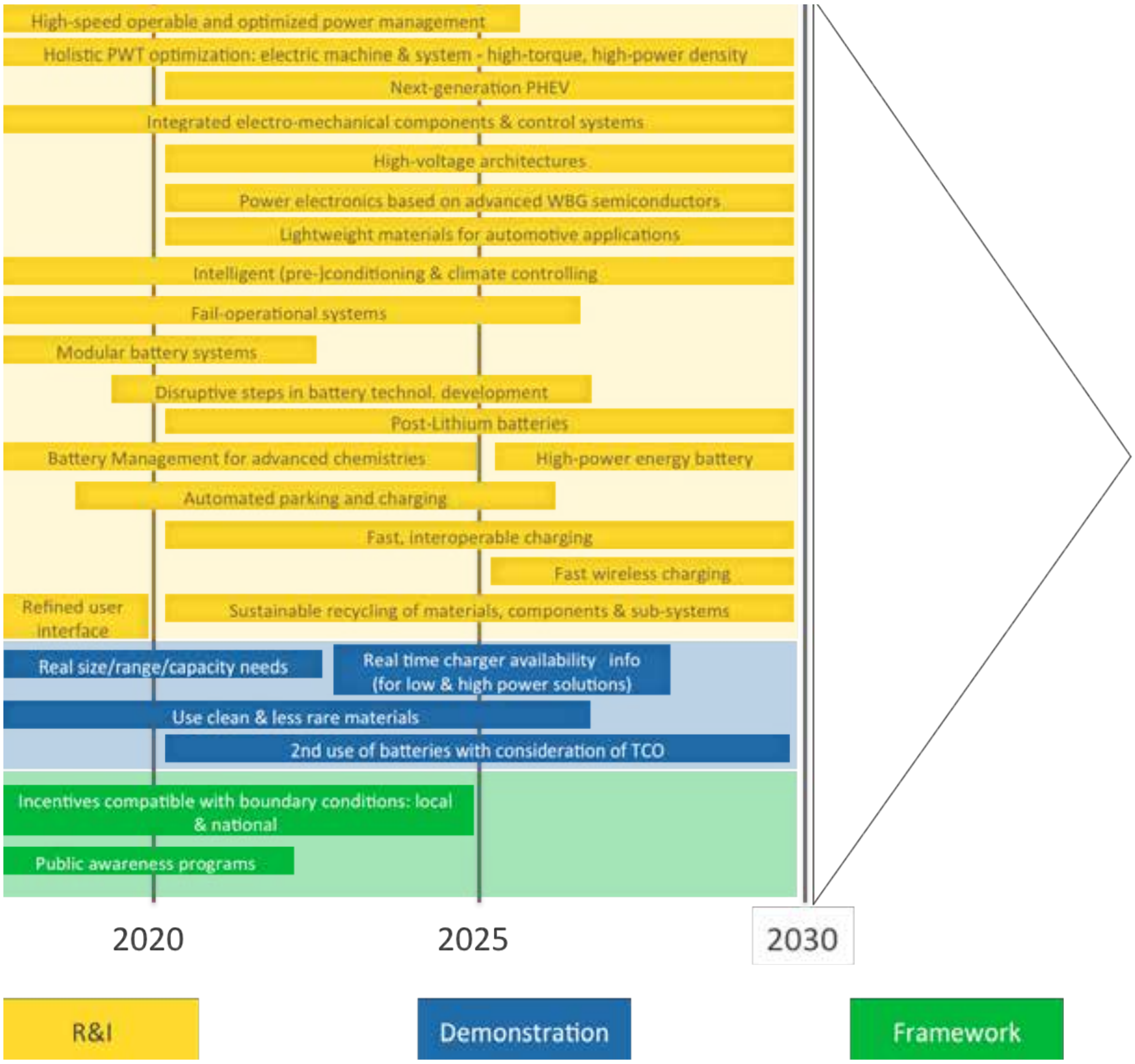
Figure 5: Four big initiatives for the electrification of road transport

The roadmaps indicate phases of R&D, production and market introduction as well as the establishment of regulatory frameworks for each of the initiatives. Focus topics within these roadmaps equal the abovementioned priorities in Energy Storage Systems, Drive Train Technologies, Vehicle System Integration, Grid Integration, Safety Systems, and Integration into the Transport System as a whole (see following figures).

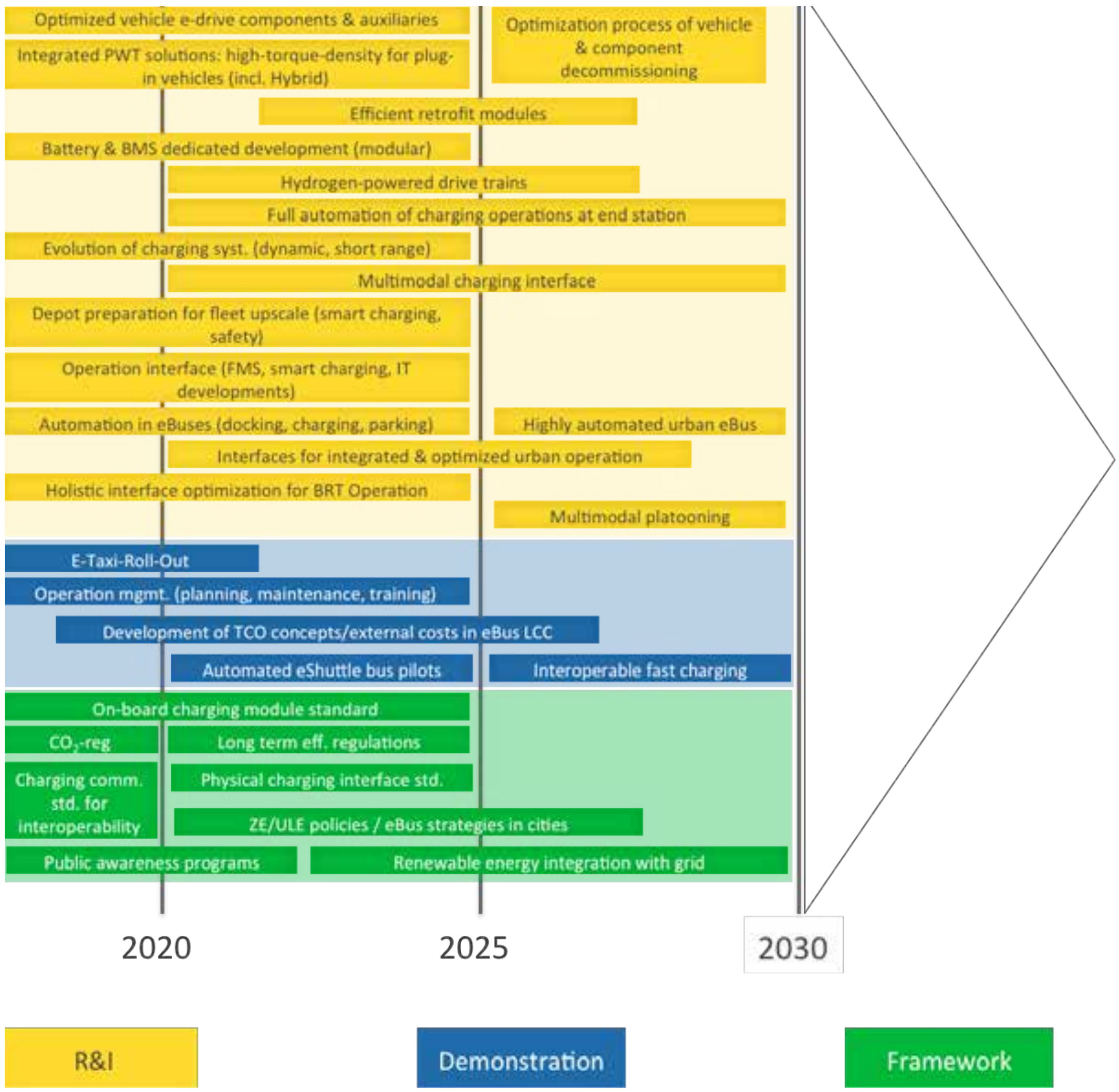
5.1. Roadmap "Operation system dependent EVs in the urban environment"



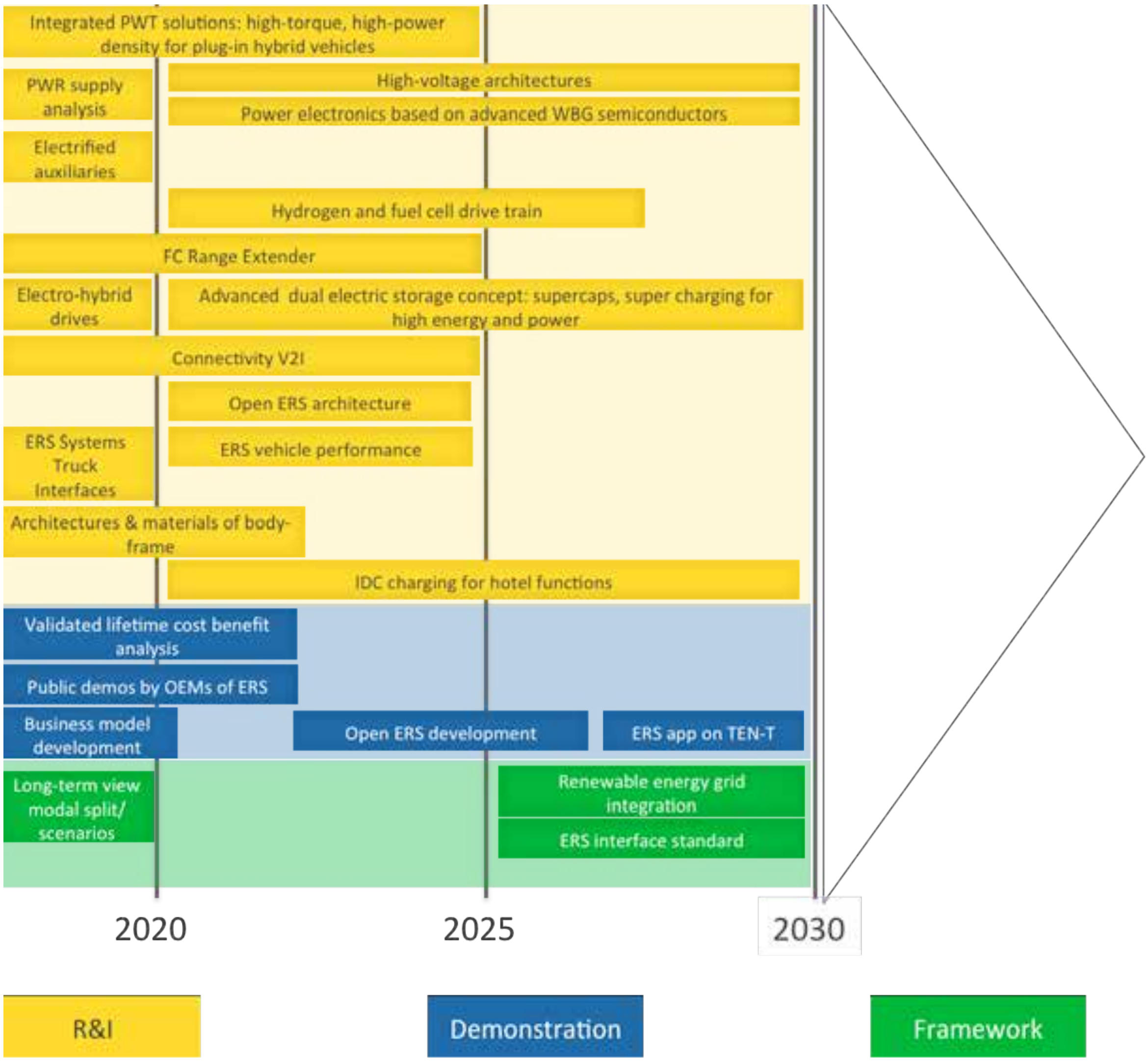
5.2. Roadmap "User-friendly affordable EV passenger car + infrastructure"



5.3. Roadmap "Non-compromise electric urban bus system"



5.4. Roadmap "Sustainable electrified long-distance trucks and coaches"



6. ANNEX

Year	Grid Efficiency	Inverter AC/DC Efficiency	Battery Efficiency (Fast Charge)	Power Electr. Efficiency (DC/DC DC-AC)	Motor to wheel efficiency (NEDC)	Motor to wheel efficiency (WLTP)	Wheel Energy Consumption (Ideal) mid-size car at NEDC Wh/km ****	Wheel Energy Consumption (Ideal) mid-size car at WLTP Wh/km ****	NEDC based Total Consumption of Primary Energy Wh/km	WLTP based Total Consumption of Primary Energy Wh/km	CO2 from electricity generation g/Wh*	WtW CO2 NEDC based g/km	WtW CO2 WLTP based g/km
BEV 2013 Coal based electricity production Range 150km	0,93	0,9	0,9	0,9	min 0,8 max 0,86	min 0,81 max 0,87	120	170	min 206 max 221	min 288 max 310	0,6706	min 138 max 148	min 193 max 208
BEV 2013 **EU 2012** Range 150km	0,93	0,9	0,9	0,9	min 0,8 max 0,86	min 0,81 max 0,87	120	170	min 206 max 221	min 288 max 310	0,3071	min 63 max 68	min 89 max 95
BEV 2013 Renewable Energy Range 150km	0,93	0,9	0,9	0,9	min 0,8 max 0,86	min 0,81 max 0,87	120	170	min 206 max 221	min 288 max 310	0	min 0 max 0	min 0 max 0
BEV 2016 Coal based electricity production Range 250km	0,95	0,95	0,92	0,91	min 0,85 max 0,9	min 0,86 max 0,91	110	160	min 162 max 171	min 233 max 246	0,6706	min 108 max 115	min 156 max 165
BEV 2016 **EU 2014** Range 250km	0,95	0,95	0,92	0,91	min 0,85 max 0,9	min 0,86 max 0,91	110	160	min 162 max 171	min 306 max 324	0,2759	min 45 max 47	min 84 max 89
BEV 2016 Renewable Energy Range 250km	0,95	0,95	0,92	0,91	min 0,85 max 0,9	min 0,86 max 0,91	110	160	min 162 max 171	min 233 max 246	0	min 0 max 0	min 0 max 0
FCEV 2016 Coal based electricity production Range 600 km	NA	NA	Hydrolisis and Fuel cell efficiency 0,33	0,91	min 0,85 max 0,9	min 0,86 max 0,91	110	160	min 407 max 431	min 585 max 620	0,6706	min 273 max 289	min 393 max 415
FCEV 2016 **EU 2014** Range 600 km	NA	NA	Hydrolisis and Fuel cell efficiency 0,33	0,91	min 0,85 max 0,9	min 0,86 max 0,91	110	160	min 407 max 431	min 585 max 620	0,2759	min 112 max 119	min 162 max 171
BEV 2030+ **EU 2030+** Range 600	0,96	0,96	0,93	0,92	min 0,86 max 0,91	min 0,87 max 0,92	90	150	min 125 max 133	min 207 max 219	0,18	min 23 max 24	min 37 max 39
	NEDC engine efficiency ***	WLTP engine efficiency ***	ICE to wheel efficiency NEDC ***	ICE to wheel efficiency WLTP ***	TTW efficiency at NEDC	TTW efficiency at WLTP	Wheel Energy Consumption (Ideal) mid-size car at NEDC Wh/km	Wheel Energy Consumption (Ideal) mid-size car at WLTP Wh/km	NEDC based Total Consumption of Primary Energy Wh/km	WLTP based Total Consumption of Primary Energy Wh/km	CO2 from fuel g/Wh **	WtW CO2 NEDC based g/km	WtW CO2 WLTP based g/km
ICE **2016** Range 600km	min 0,24 max 0,26	min 0,31 max 0,34	min 0,83 max 0,87	min 0,84 max 0,88	min 0,20 max 0,23	min 0,26 max 0,30	110	160	min 486 max 552	min 535 max 614	0,2608	min 127 max 144	min 139 max 160
ICE **2030+** Range unknown	min‡ 0,27 max‡ 0,3	min‡ 0,38 max‡ 0,43	min 0,85 max 0,9	min 0,86 max 0,91	min 0,23 max 0,27	min 0,33 max 0,39	90	150	min 333 max 392	min 383 max 459	0,2608	min 87 max 102	min 100 max 120
												NEDC	**WLTP**
								2016 minimum type approval CO2 for an average medium car [g/km]				89	103
								2030+ minimum type approval CO2 for an average medium car [g/km]				58	73

Table 1: Evolution of primary energy consumption of battery electric vehicles (BEV), Fuel Cell Electric Vehicles (FCEV) and comparison to the conventional powertrain. Minimum type approval CO_2 emission WLTP for ICE in 2016 and 2030 are 103 g/km and 73 g/km, respectively due to migration factors from WTW analysis.

#Energy needed to move an ideal mid-sized vehicle in the NEDC (New European Driving Cycle). °Reduced battery weight.
*Cars smaller than the reference vehicle may have less energy consumption.

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