

STUDY

E-mobility Index

Q1 2017

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1 Key takeaways of the E-mobility Index for Q1 2017

- > While in terms of **technology** Germany has moved into the lead position, in **industry** China has taken over the lead thanks to its higher levels of production and value creation. In terms of the **market**, all seven leading automotive nations are increasingly on the same level
- > The supply situation for materials used in the production of lithium-ion batteries remains critical in the medium term, characterized by great dependency on China, Congo, South Korea and Japan
- > The role of cities is growing with regard to emissions legislation. The issuing of license plates is already linked to the type of drive in many major Chinese cities. In addition, London plans to introduce an ultra-low emission zone in 2020, Paris is to ban diesel engines (also from 2020), and Norway is considering banning all internal combustion engines from 2025
- > The broad focus is on convenience of charging, with fast charging becoming increasingly important for customer acceptance. The E-mobility Index takes this into account by re-weighting the technology index

2 Summary comparison of the competitive positions of the world's seven leading automotive nations

In terms of **technology**,¹ Germany has moved into joint first place with France, overtaking Japan (in second place) and Korea (in third). This is partly because German OEMs are significantly expanding their offering of partially as well as fully electric vehicles, and partly because they now in some cases offer customers longer ranges at constant prices. French OEMs do not offer the same variety of products, continuing to focus on small, low-cost BEVs. However, they remain ahead in terms of value for money. By contrast, Korean OEMs have a relatively thin product pipeline and their mainly dedicated PHEVs and BEVs sometimes reach the market with significant delays. Relatively little movement is seen for Chinese OEMs. They also plan to launch a large number of new models over the next few years but will mainly position them in technically less valuable segments. US OEMs are increasingly moving away from their "signal strategy" in the high-margin segment and more towards positioning vehicles in medium-sized segments. Japanese OEMs are largely content to modernize their existing series, expanding product portfolio is planned by only some OEMs in medium-term. Overall the much faster decline in the price of lithium-ion cells and the rapid integration of a new generation of cells from 2018 will lead

¹ The way the technology index is calculated has been changed to include the criterion "On-board charging technology", an important factor in customer acceptance. This results in absolute and relative shifts in the technological performance levels for the seven leading automotive nations.

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OEMs to add BEVs with long ranges to their offering, resulting in a more pronounced shift in this direction for the model mix in the medium term (Figure 4).

Regarding the scale of national R&D funding programs for e-mobility, minor changes are occurring in some countries due to particular programs coming to an end, particularly in China. However, the relative positioning of the seven leading automotive nations remains fundamentally unchanged. All seven nations continue to invest in programs aimed at optimizing the technological system. Besides funding R&D, countries are subsidizing the market boom and the expansion of infrastructure, as shown by the recently introduced purchase incentives and the planned charging-station infrastructure program in Germany (Figure 5).

In **industry**, China has confirmed its pole position. The reason for this is the continuing rapid growth of the market, more than 90% of which is supplied with lithium-ion cells produced locally. This high local share is partly due to the fact that subsidies only apply where there is local value creation. However, foreign cell manufacturers also generally lack the necessary permits to set up local manufacturing facilities. These two trends work against Japan both in terms of vehicle production and national share of global cell production, forcing it into third place. The US, by contrast, benefits from this development, moving into second place. At the same time, the US and Europe are seeing a trend towards stronger regional differentiation of markets. German OEMs mainly dominate the European markets and their US counterparts dominate the North American markets – but neither has made any significant inroads into Asia (Figure 6).

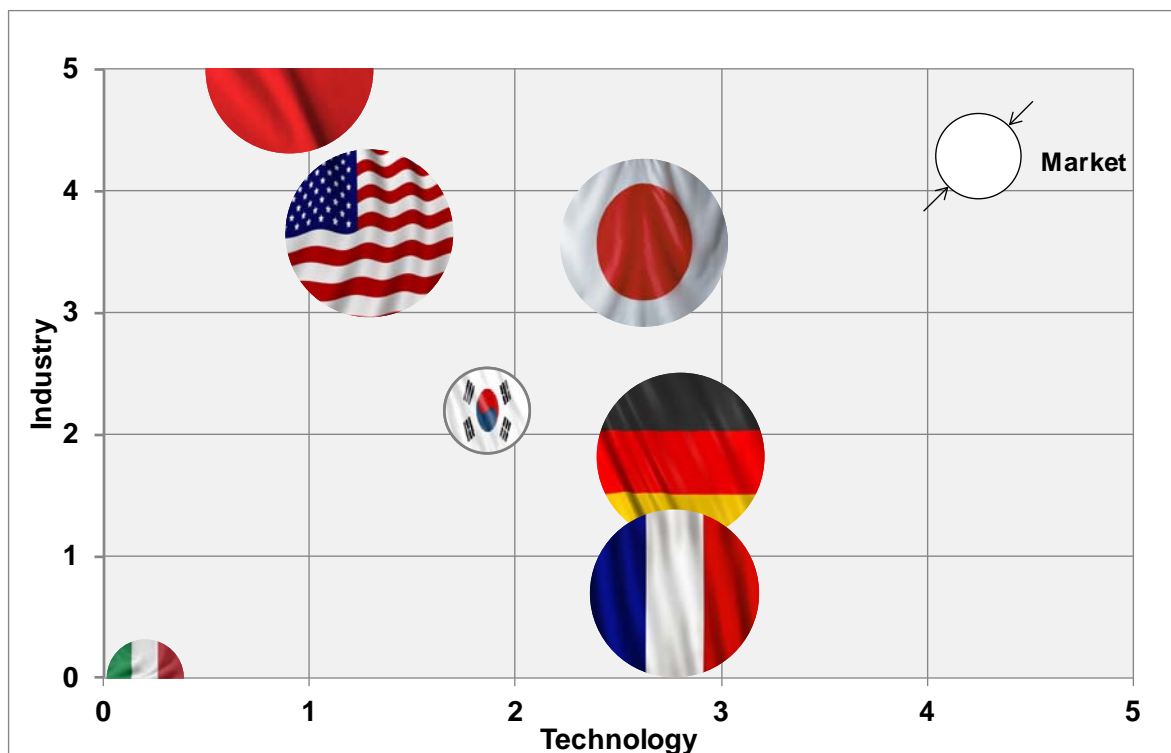
In cell manufacturing, weight continues to shift strongly towards China. As a result, Chinese cell manufacturers have moved into the leading positions with regard to their share of global cell production. At the same time, however, Korean cell manufacturers are gradually winning market share in China by producing their own cells locally. Korean and Japanese cell producers have announced localization projects in the US and similar projects should be expected in Europe in the medium term. However, we expect to see inroads being made toward the creation of a local cell producer, potentially with the support of OEMs, at the end of the decade at the earliest. The increase in demand for cells due to the greater market penetration of pure electric vehicles with long ranges will be accompanied by a pronounced decline in prices, resulting in no more than moderate net market growth. The need for greater capacity combined with a constant market size will lead to a significant increase in investment volume on the part of cell manufacturers (Figure 7).

In terms of the **market**, China has seen a sharp increase in demand and now moves into second place – behind France, which has a bigger market share despite its considerably lower absolute

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volumes. In third place comes the US. Compared to the previous period, sales have more than doubled in China and grown by around 50% in both Germany and France. Japan has also seen growth well into double digits. By contrast, growth in the US and Italy has slowed down considerably, remaining in single digits in both countries. In the US, substitution effects between PHEVs and full hybrids prevent an even greater slowdown in growth. Korea, on the other hand, actually saw a slight decline. As mentioned above, in the medium term there will be a shift in the model mix towards BEVs with a nominal range of more than 300 km. Overall, the share of partially and fully electrified vehicles will only make it over the 1% mark in China and France in 2016. The market share of partial or fully electric drives needed in Europe is thus still a long way off meeting the fleet emission targets expected post-2021 (Figure 8).

Figure 1: Japan remains in pole position – China has overtaken the US and moved into second place due to industry and market growth



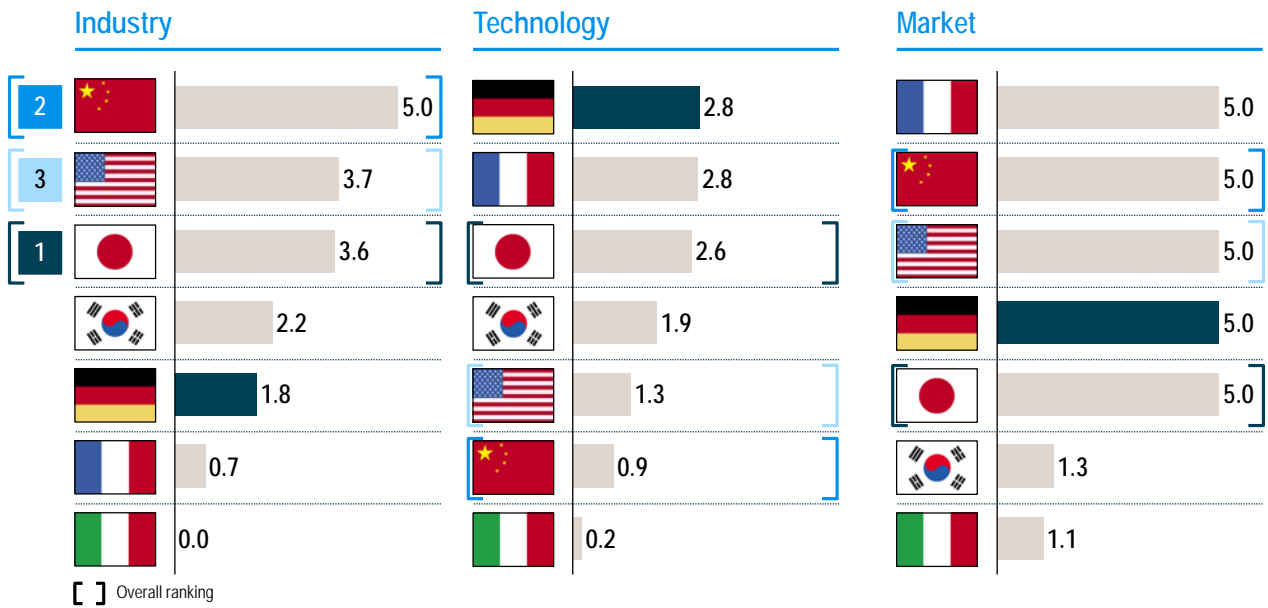
Note: Circle size shows EV/PHEV share of total vehicle market

Source: fka; Roland Berger

Figure 2: Japan is losing ground but remains in pole position. The basis for the technology index has been adjusted – Germany and France are in the lead

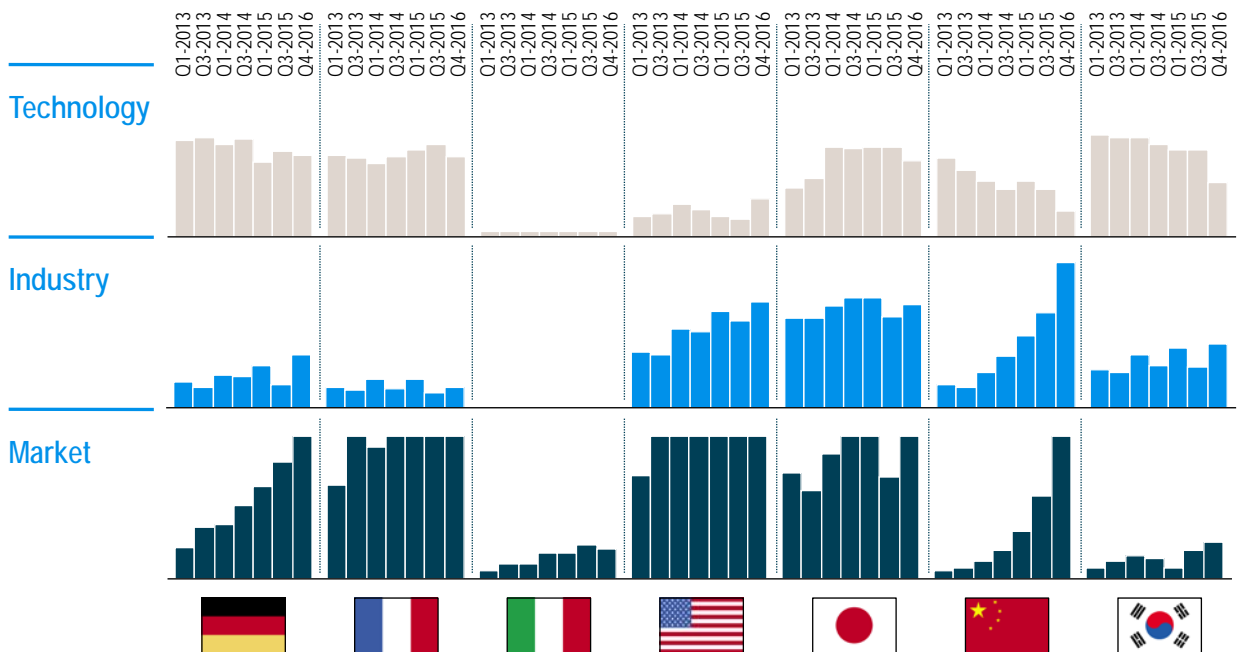
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E-Mobility Index – Ranking by indicator



Source: fka; Roland Berger

Figure 3: While the market index is developing positively most everywhere, changes in the technology and industry indices are much more uneven



Source: fka; Roland Berger

3 Detailed analysis

3.1 China presents a radical amendment to emissions legislation to boost sales of xEVs

Chinese sales of pure EVs and plug-in hybrids more than quadrupled between 2014 and 2015 to 330,000 units. As a result, China has become not only the world's largest passenger vehicle market by sales volume but also the single largest market for partially or fully electrified vehicles. However, as elsewhere, xEVs still account for less than 1% of all vehicles sold and more efforts are needed to put China on track to achieve the goal of five million xEVs on Chinese roads by 2020 stipulated in China's 13th Five-Year Plan.

E-mobility is viewed by China's policymakers as an opportunity to both charge ahead of the global competition and reduce the country's dependence on imported oil. To this end, the administration has now put forward the most comprehensive framework yet to force OEMs to meet aggressive sales targets for EVs and PHEVs of 7 percent in 2020 and 15 percent in 2025. Currently the market average is at less than 2 percent.

The proposed mechanism will combine a Corporate Average Fuel Consumption rating (CAFC) with a credit mechanism for New Energy Vehicles (xEVs), where xEV credits can be used to offset negative CAFC ratings or be traded. The intended transaction price, industry experts believe, will be between RMB 7,500 and 10,000 (roughly USD 1,000-1,400) per 1 NEV credit. The rule is still under discussion but will likely become effective as early as 2018.

3.2 Availability of raw materials

In the medium term, lithium nickel cobalt aluminum oxide (NCA) and lithium nickel manganese cobalt oxide (NMC) battery cells will dominate both partially and fully electrified drives in automotive applications, with NMC expected to have the larger market share (70%) in the medium term. By contrast, lithium iron phosphate (LFP) – originally favored especially by Chinese OEMs due to its relatively high thermal resistance – will lose ground due to its lower power density, as Chinese OEMs also migrate towards NMC. Lithium titanate is widely used in stationary applications and commercial vehicles due to its high cycle stability, but it is unsuitable for automobile applications for that same reason. Lithium-ion technology will therefore only develop within very narrow technical parameters to the end of the decade. Technical changes will be mainly limited to alterations in the ratios of the reactive cathode elements nickel, manganese and cobalt, where a shift from NMC 111 (a ratio of 1 Ni:1 Mn:1 Co) to NMC 622 and then NMC 811 is expected.

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The limited range of technical alternatives within lithium-ion technology makes the automotive industry indirectly dependent on a small number of key raw materials and processing steps. Besides lithium, nickel, manganese and cobalt, this also applies to the anode material, graphite. The critical issue here is meeting demand for graphite and cobalt. Some 95% of today's reserves of natural graphite are found in China and almost half of global demand for cobalt is served by Congo, where not only geographical concentration but also political instability jeopardize security of supply. More than 50% of silicon also comes from China but the amount used in cell production accounts for only a fraction of total world production. The same goes for manganese, which is mainly used in steel refining; about a quarter of manganese comes from South Africa and smaller amounts from China and Australia. One third of lithium comes from Chile and one third from Australia. Processing is similarly concentrated in specific countries, for example spherical graphite is predominantly processed in South Korea and Japan.

One alternative is artificial graphite, which already accounts for around one-fifth of global demand for spherical graphite. However, artificial graphite is significantly more expensive to produce than natural graphite. Exploiting new deposits will ensure growing demand can be met but it will make little difference in terms of geographical distribution and dependence on a few key countries. To secure their own supply, many market participants have signed long-term contracts with other players at different stages of the value chain. The oligopolistic market structures mean that there is little cost transparency, however, and such contracts often place the cost risks entirely on the customer's side. Considerable investment in developing new deposits would be needed to change these structures in the long term, combined with massive spending on upstream processes, which would moreover entail considerable risks for the environment. Overall, therefore, a fundamental improvement in the supply situation is not expected in the medium term (Comp. Nationale Plattform Elektromobilität with Roland Berger and Rohstoffallianz. "Roadmap integrierte Zell- und Batterieproduktion Deutschland").

3.3 Megacities take the lead in emissions legislation. Example: London

Rhona Munck is Senior Strategy & Planning Manager – Environment and Walking, at Transport for London (TfL). TfL manages London's public transport, strategic road network (including the city's 6,000 traffic lights) as well London's Congestion Charge and Low Emission Zones.

Wolfgang Bernhart: In 2003, London became the first city in the world to introduce a congestion charge to curb inner-city traffic. Since then we've seen a number of cities around

the globe implementing similar policies. In fact, in some regions we now see states as well as large municipalities driving the environmental agenda to a much greater extent than national legislative bodies – for example by introducing low or ultra-low emission zones. Against this backdrop, how would you characterize Transport for London's strategic priorities?

Rhona Munck: The Mayor, Sadiq Khan, recently set out his new vision for London in the publication *A City for All Londoners*. This includes his ambitions for London's transport and environment, in particular to bring air quality down to safe levels, to make the city zero carbon by 2050, and to encourage walking and cycling. This is set in the broader context of supporting London's growth, meeting the housing challenge, ensuring London remains the world's top global business city, and making a city for all Londoners through social integration. In all of these areas, transportation has a role to play.

WB: So what role does e-mobility occupy in this strategy and what measures are you taking to encourage its adoption in London?

RM: TfL supports the switch from diesel and petrol vehicles to ULEVs as they are critical to reducing emissions from London's vehicle fleet and improving air quality, and they can assist in developing London into a zero-carbon city by 2050. We actively encourage the switch to ULEVs in taxi and private hire vehicle fleets, commercial vehicle fleets and car-sharing fleets. In July 2015 we published the Ultra Low Emission Vehicle Delivery Plan which sets out fifteen key actions to encourage the uptake of electric vehicles, including through infrastructure, vehicle uptake, and marketing and incentives. We are introducing an Ultra Low Emission Zone in the center of London in 2020 (and the Mayor is currently consulting on bringing this forward to 2019), which will mean that all buses driving in the zone will be hybrid or electric, all new black taxis will have to be zero emission capable from 2018, and all new private hire vehicles will have to be zero emission capable from 2020.

WB: How do you ensure that a sufficiently dense network of charging points is installed throughout the city?

RM: TfL has conducted a wide range of research on charging infrastructure provision in London, including to support our ULEV Delivery Plan. This research has highlighted that a lack of adequate charging infrastructure provision is a key barrier to the uptake of electric vehicle (EV) use in London.

We are currently undertaking a number of projects focused on increasing the provision of charging infrastructure and refueling infrastructure for ULEVs, including our Rapid Charging Infrastructure Project and London's Go Ultra Low City Scheme (GULCS).

TfL is committed to deploying a rapid charging network across London which will support the introduction of zero emission capable (ZEC) taxis, private hire vehicles and other commercial vehicles. Informed by our research, we will deliver 150 rapid charge points in London by the end of 2018. By the end of 2020, we will have delivered 300 rapid charge points in total. These will be delivered via a market-led approach with help from the public and private sector.

London was awarded GBP 13 million funding from the Office for Low Emission Vehicles

(OLEV) for supporting the uptake of ULEVs through the GULCS scheme. This project is focused on accelerating the provision of charging infrastructure in London, and is divided into four work streams: delivering 1,150 on-street EV charge points for a residential charging network; delivering up to 1,000 charge points for car club fleets to support car club vehicles switching to ULEVs; contributing to the delivery of 300 rapid charge points for commercial fleets by 2020; and creating "Neighbourhoods of the Future", which are area-based schemes promoting innovative charging infrastructure, policies and initiatives.

These projects will complement the existing public charge point networks which allow EV users to top up when away from their homes/depots. We refer to this type of infrastructure as "destination/top-up charging". Two of the main destination/top-up charge point networks in London are Source London (operated by BluePointLondon, a subsidiary of the Bolloré Group) and POLAR (operated by Chargemaster). Between them, BluePointLondon and Chargemaster have made public commitments to deliver a total of over 7,000 publicly accessible charge points across London by 2018.

WB: Another way of addressing individual transportation needs at the same time as minimizing congestion is car sharing. What is TfL's policy regarding car sharing?

RM: TfL, the car club operators, the Greater London Authority, London Councils and key stakeholders jointly published a comprehensive Car Club Strategy for London in May 2015. The Strategy sets out a collaborative approach to accelerate the growth of the sector in London and take car clubs from a niche service to a mainstream transport option, helping to achieve mode shift away from private car use. To do this, it sets out ten actions to provide a common framework for further research, to put in place requisite policy enablers and related infrastructure developments (including EV infrastructure) as well as create incentives and awareness among private individuals and the business community.

WB: Looking ahead, could you see London taking similarly radical steps to other municipalities that are now considering banning conventionally-powered vehicles from their streets?

RM: Soon after his election in May this year, the Mayor of London, Sadiq Khan, called for new proposals to urgently tackle London's current poor air quality. The Mayor invited Londoners to share their experiences and ideas about improving air quality, and asked for their views on the measures he was proposing. We have now developed detailed proposals for the implementation of the Emissions Surcharge (ES), and ideas for improving the Ultra Low Emission Zone (ULEZ), and these are now subject to further public consultation. The proposals are:

- > Introducing the Emissions Surcharge (more commonly known as the "T-Charge") in 2017 for the older, more polluting vehicles driving into and within central London. This would be in addition to the Congestion Charge
- > Bringing forward the introduction of the ULEZ to 2019, instead of 2020
- > Extending the ULEZ from Central London to London-wide for heavy vehicles (heavy goods

vehicles, buses and coaches) as early as 2019 but possibly later

- > Extending the ULEZ from Central London up to the North and South Circular roads for all vehicles, as early as 2019 but possibly later

3.4 Advanced charging technology for greater customer acceptance of EVs

For many people a major barrier to buying an EV is the question of how to charge the battery conveniently. Convenience of charging depends partly on how long it takes to charge the battery sufficiently for the rest of your journey. But it also depends on how easy (or difficult) it is for the driver to carry out the charging process. In terms of technology, fast-charging technology and inductive charging make it possible to provide convenience of charging and in so doing significantly improve acceptance of EVs by customers.

The high charging powers available at DC charging stations makes it possible to cut charging times. Infrastructure is currently in place for charging powers of 50-120 kW, enabling drivers to charge batteries to 80% of capacity in 20-30 minutes. However, the higher the charging power, the faster the battery deteriorates. For this reason the strength of the current is continuously reduced once the 80% point is reached. This reduction greatly increases the length of time needed to charge the battery to its full capacity. In the short term, there are plans to raise the maximum charging power to 150 kW, which will cut the charging time still further. In the medium term, the goal is to install fast-charging infrastructure offering charging powers of up to 350 kW. These high levels will require adjustments to the design of the battery system, including powerful cooling systems and a substantial increase in voltage. In some cases these adjustments can create a conflict between the goal of greater efficiency and the goal of larger capacity. On the infrastructure side, DC charging stations with high charging powers place increased demands on grid and cable capacitance and may have to be connected to the medium-voltage grid. A national charging infrastructure consisting of a fast-charging network (> 22 kW) and a normal charging network (<= 22 kW) can be seen as the key to electric mobility achieving a breakthrough. Accordingly, the seven leading automotive nations have launched funding initiatives aimed at overcoming the technological challenges described above and expanding the infrastructure (e.g., the LIS program in Germany).

An alternative to manual, cable-based charging – and the inconvenience associated with it – is cordless, inductive charging. In the medium term, EVs will be launched that are equipped with the necessary technology. The first series designs will have a charging capacity of up to approximately 8 kW, although it should be noted that the efficiency of the stationary charging process is slightly lower than in the case of conductive charging. In the medium term, an increase in the potential charging capacity for inductive charging is expected: Systems with up to 40 kW

have already been developed and tested in public research projects. Nevertheless there are restrictions relating to safety aspects, the size of the charging pads and the minimum air gap, which limit the maximum inductive charging capacity for passenger vehicles. It is possible to reduce the air gap by having a moveable charging slab on the ground (such as the Z-Mover) or by lowering the vehicle (e.g., via an active chassis). However, due to the positioning tolerances of just 5-10 cm either way (forwards or backwards, right or left), positioning assistance is necessary. This can take the form of instructions to the driver via HMI or automatic driving or parking functions, which offer increased user convenience and improved efficiency in positioning the vehicle. The growing penetration of driver assistance systems and increasing level of vehicle automation make this type of automatic vehicle positioning possible. In the medium term, all inductive charging systems will be able to connect to the vehicle autonomously.

In the coming years, an increase in charging capacity and the introduction of inductive charging functions in EVs is expected. Advanced charging technology will help improve customer acceptance – but the systems in the vehicle will have to be modified or even restructured in response to the technical challenges.

4 Methodology

The relative competitive position of individual automotive nations is compared to that of the others on the basis of three key indices:

- > **Technology:** The current status of technological development in vehicles made by indigenous OEMs and the support for vehicle development provided by national subsidy programs
- > **Industry:** The regional value added in the automotive industry by national vehicle, system and component production
- > **Market:** The size of the national market for electric vehicles based on current customer demand

Roland Berger and fka weight the individual indices (value range 0-5) and combine them to form the E-mobility Index (Figure 10). The E-mobility Index makes it possible to compare the competitive positions of the world's seven leading automotive nations (Germany, France, Italy, the US, Japan, China, and South Korea), juxtaposing their individual automotive markets on the basis of uniform global standards. The E-mobility Index thus reveals the extent to which individual nations are able to participate in the market that e-mobility is creating. The criteria applied are assessed as discussed below.

Technology

- > Technological performance and value for money of electric vehicles currently on the market or soon to be launched

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- > National e-mobility R&D programs – only research grants and subsidies are taken into account (not credit programs for manufacturing, budgets for purchase incentives, etc.)

Industry

- > Cumulative national vehicle production (passenger cars, light commercial vehicles) for the period 2014-2018, taking account of BEVs and PHEVs
- > Cumulative national battery cell production (kWh) for the period 2014-2018

Market

- > Electric vehicles' current share of the overall vehicle market (over a 12-month period)

The Q1 2015 E-mobility Index was the first to include projections for 2017, while the Q1 2017 Index was the first to include projections for 2018. The additional volume is reflected in higher scores for industry in all markets. However, this does not affect the shifts between markets, and the E-mobility Index's comparability with previous indexes is thus not compromised.

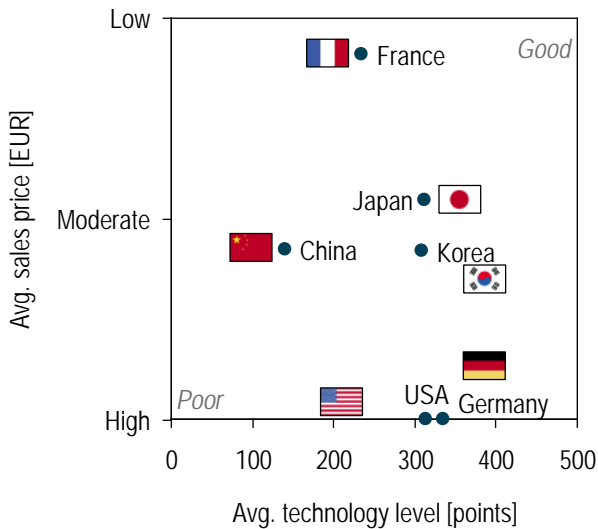
In the Q1 2017 E-mobility Index the way in which the technology index is calculated has changed. The previous methodology for measuring technological performance has been tightened up on specific points (safety features) and the criterion "On-board charging technology" has been added. Overall, this changes the level of the technology index compared to previous editions of the E-mobility Index. It also results in a shift between individual countries due to the inclusion of the new criterion.

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Figure 4: Technology levels have shifted due to the new methodology and changes in average value for money as a result of expanded model ranges

Value for money of market-ready BEVs and PHEVs

EV value for money



Note: Italian OEMs have no mass-produced EV/PHEV models

Country

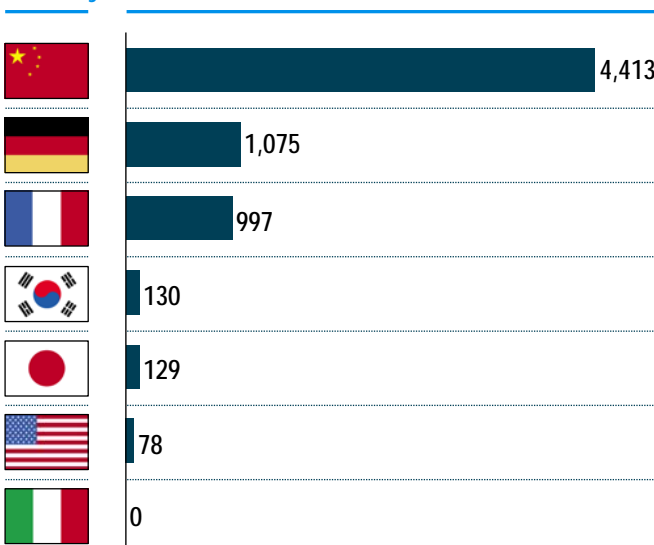
- > Redesign of existing models and expanding model range are leading to higher average price level
- > High-priced vehicles are very relevant
> Increasing offer also in mid-ranges segment
- > Continuing trend toward electrification (PHEVs) in upper and mid-range segments
> Increasing number of models offered
- > Slight improvement in technological level in conjunction with increase in vehicle price level
- > Renault Zoe Z.E. is dominant model with low price level
> Expanding model range
- > Increasing number of electrified vehicles from Kia and Hyundai

Source: fka; Roland Berger

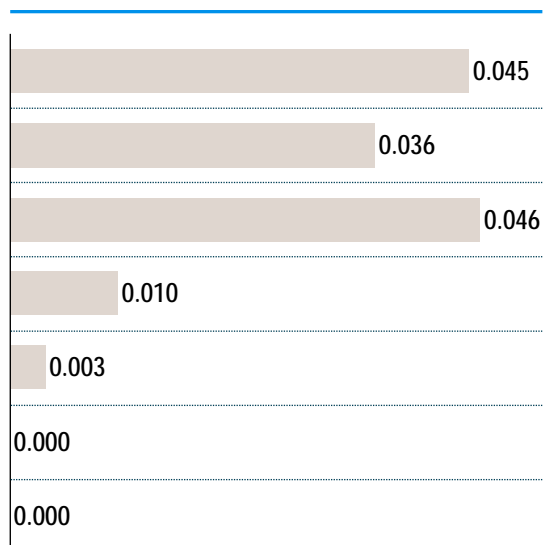
Figure 5: Some R&D funding programs coming to an end in China and Japan, funding as a share of GDP constant in other nations

State R&D funding for e-mobility

Country [EUR m]



[% of GDP]¹⁾









1) Subsidies expressed as a proportion of current GDP (2015)

Source: fka; Roland Berger

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Figure 6: Increased vehicle production in all markets – China is the clear leader

Projected production of EVs and PHEVs through 2017

Country	Domestic production of EVs/PHEVs ['000 units]	Top 3 models in each country
	1,230	BYD Tang, BYD Qin, BAIC E150EV
	708	Tesla Model S, Nissan Leaf EV, Chevrolet Volt PHEV
	439	VW Golf GTE PHEV, BMW i3, Audi A3 e-tron
	392	Nissan Leaf EV, Mitsubishi Outlander PHEV, Toyota Prius PHEV
	174	Renault ZOE Z.E., Renault Kangoo Z.E., smart fortwo ED
	50	Chevrolet Spark EV, Kia Soul EV, Hyundai Sonata PHEV

Note: No significant EV/PHEV production is expected in Italy

Source: fka; Roland Berger

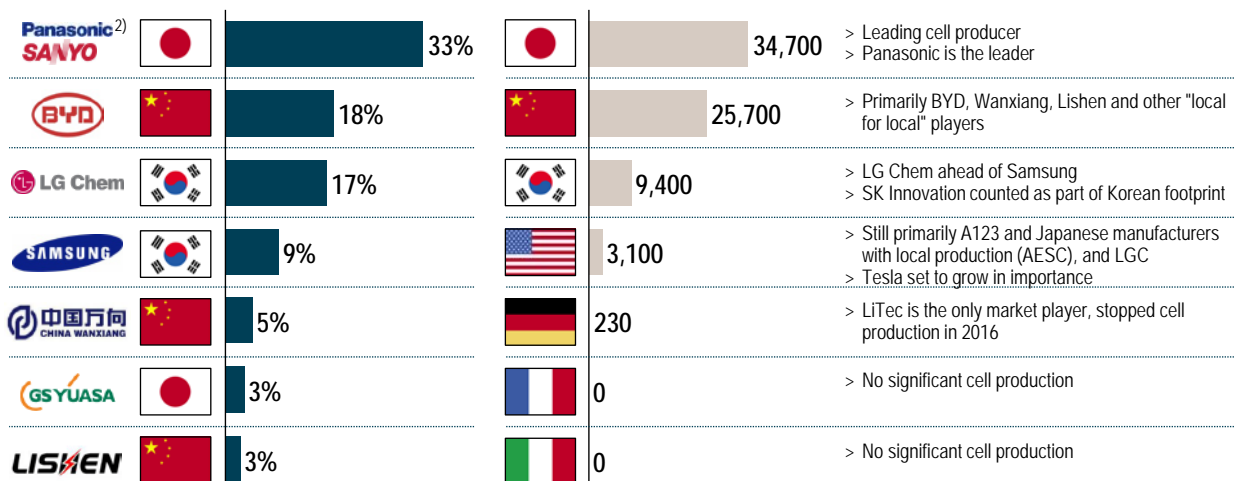
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Figure 7: China has moved into second place and is catching up with Japan – No cell production in Europe

Cell manufacturers and production, by country, through 2018

Projected global market share, 2018¹⁾

Domestic cell production, 2014-2018 [MWh]

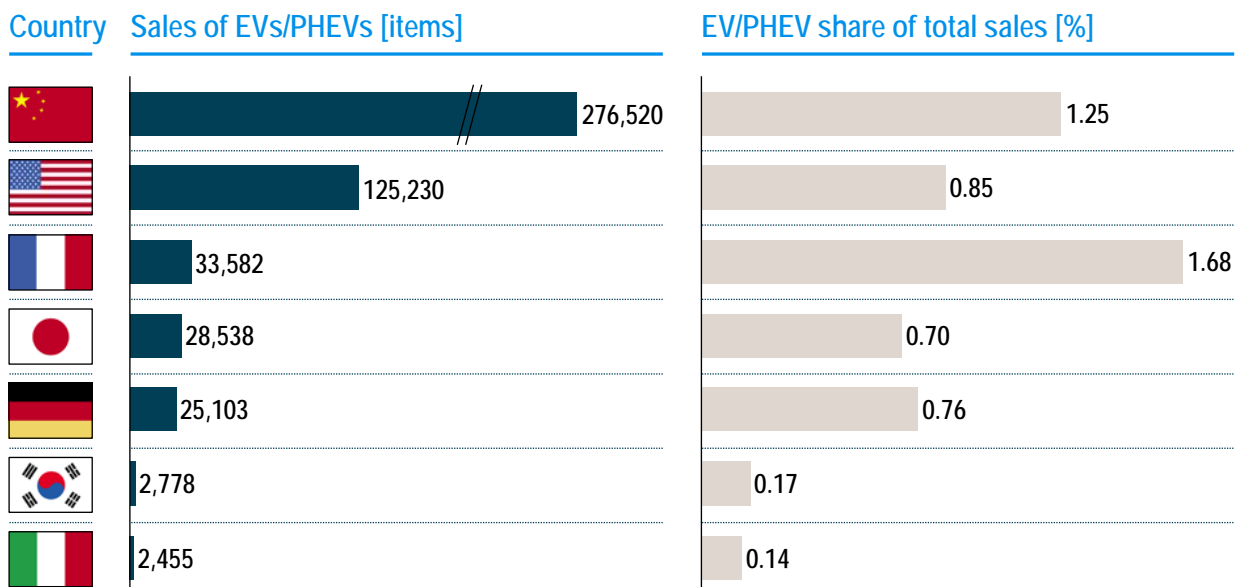


1) 2018 market value in USD calculated as follows: 280 USD/kWh for PHEVs and 200 USD/kWh for EVs; shift from single to dual sourcing strategies expected mid-term
2) Including Primearth's market share

Source: fka; Roland Berger

Figure 8: China has doubled its sales of EVs on last year and is now the leading market for electrified vehicles

Sales figures and market share of EVs/PHEVs, Q3 2015 to Q2 2016

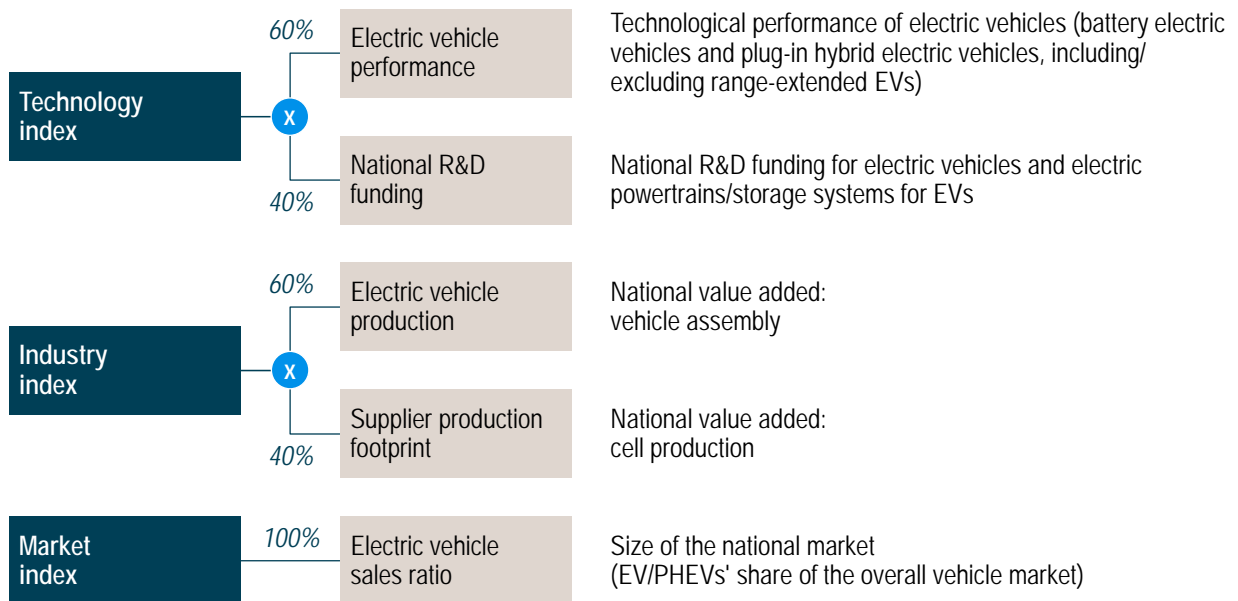


Source: fka; Roland Berger

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Figure 9: The E-Mobility Index compares automotive nations on the basis of three parameters

E-Mobility Index – Three parameters: Technology, industry, market



Source: fka; Roland Berger

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We welcome your questions, comments and suggestions.



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