Federal Ministry
for Economic Cooperation
and Development

Electromobility

Overview, Examples, Approaches

Sustainable Urban Transport Technical Document #15

Published by giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

SUTP. 15 years serving the sustainable urban mobility community

Sustainable Urban Transport Project

SUTP supports decision-makers worldwide to plan and to implement innovative and sustainable mobility solutions. SUTP offers a comprehensive knowledge platform, capacity development, hands-on advice and networking opportunities. Within the past 15 years, more than 5,000 decision-makers, planners and students have benefited from our training offers. We‘ve produced a rich library of Sourcebook Modules, Technical Documents, Case Studies, Factsheets, Policy Briefs and Reading Lists. All documents are accessible through our webpage, along with a comprehensive photo collection and a video channel.

Be invited to use and distribute them!

http://www.sutp.org

About the authors

Dipl.-Soz. tech. ***Christian Scherf*** studied sociology at the Technical University of Berlin with particular focus on transportation science. Since 2010 he works as a researcher in the Innovation Centre for Mobility and Societal Change (InnoZ), where he coordinated the “BeMobility” project. His work and research focuses on the integration of electric vehicles into public transport systems. Since 2014 he also supports public relations at InnoZ and has started his doctoral thesis.
christian.scherf@innoz.de

Dr rer. pol. ***Frank Wolter*** studied economics at the University of Münster and later worked as assistant professor in the field of environmental management at the Institute of Marketing (Prof. Dr Dr h.c. mult. Meffert). In 2001 he received his doctoral degree. Until summer 2002 he taught environmental management and business at the University of Münster.
In autumn 2002 Dr Wolter started to work for Deutsche Bahn AG in different corporate strategy departments. In 2010 Dr Wolter began work at the Innovation Centre for Mobility and Societal Change (InnoZ), where he was responsible for the coordination of the multi-partner research projects “BeMobility” and “BeMobility 2.0”. In 2013 Dr Wolter organised the Berlin UN High-level Dialogue on Implementing Rio +20 Decisions on Sustainable Cities and Transport (19 to 21 June 2013) in Berlin. Since October 2015 Dr Wolter has been working as startup manager within Deutsche Bahn and works as keynote speaker, presenter and moderator.
frank.wolter@innoz.de

Acknowledgements

We would like to thank all those who have reviewed earlier versions of this document, including ***Alexander Jung***, GIZ; ***Frederik Strompen***, GIZ; ***Oliver Lah*** and ***Manfred Breithaupt***.

Electromobility

Overview, Examples, Approaches

Sustainable Urban Transport Technical Document #15

In the cities of Asia and Latin America, increasing population density and motorisation are leading to a rapid rise in transport and environmental problems. The aim of this paper is to show how electromobility can help mitigate the challenges, and to derive recommendations for the use of electromobility in meeting various targets and prerequisites. The paper shows the diverse range of electromobility applications and provides a snapshot of the various support schemes and pilot projects that have been carried out in recent years.

Disclaimer

Findings, interpretations and conclusions expressed in this document are based on information gathered by GIZ and its consultants, partners and contributors.

GIZ does not, however, guarantee the accuracy of completeness of information in this document, and cannot be held responsible for any errors, omissions or losses which emerge from its use.

TABLE OF CONTENTS

Abbreviations

BEV	Battery Electric Vehicle
GDP	Gross Domestic Product
CCS	Combined Charging System, (charging standard for electric vehicles with which both direct current and alternating current charging methods can be used; Kuther 2012)
CHAdeMO	Acronym for "Charge de Move", or "charge for moving"
FCEV	Fuel Cell Electric Vehicle
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GW	Gigawatt
H	Half year
ICT	Information and Communication Technology
km	Kilometres
km/h	Kilometres per hour
kW-hr	Kilowatt-hour
MW/h	Megawatt/hour
NMT	non-motorised transport
NO_x	Nitrogen oxides (harmful substances produced during the combustion of fossil fuels that can lead to respiratory diseases)
OECD	Organisation for Economic Co-operation and Development
PT	Public Transport
PHEV	Plug-in-Hybrid (partially electric vehicle with hybrid drive, whose accumulator can also be charged externally via the electricity grid; VDI/VDE 2016b)
Pkw	Passenger car
REEV	Range Extended Electric Vehicle, electric vehicle with "range extender" (additional power units in an electric vehicle that increase the vehicle's range; VDI/VDE 2016c)
TCO	Total Cost of Ownership (the sum of total operating costs that includes not only the acquisition cost but also takes into account costs of subsequent use such as energy, repair and maintenance)
PRC	The People's Republic of China
WHO	World Health Organization

Preface

For many years we have been conducting work in the mobility market, dealing with trends, market developments and innovative solutions and approaches. The challenges faced by the transport sector in making necessary contributions to climate protection and improved air quality have never been greater. The technology of the internal combustion engine is reaching its limits in terms of reducing fuel consumption and pollutant levels. It is also becoming increasingly clear that it will soon be necessary to revise the leitmotif of the fossil fuel-powered private car in car-friendly cities. This realisation is currently gaining headway in the densely populated megacities and major metropolises of Asia. It is in these places that new solutions are being developed and applied.

During the past eight years or so, the controversial debate on electromobility has been gathering momentum (again). There is general agreement that the electric motor is an inevitable and central factor in the future of transportation. The established automotive industry in North America and Central Europe is facing stiff competition from Asia in the area of electric battery technology, but also in hybrid propulsion and hydrogen technologies. Increasingly, new players such as Tesla, and also BYD, Geely Kandi, Mahindra and Zytel are making inroads into the automotive market. Electromobility is acquiring central importance for the automotive industry, and this is a key factor in the spread of national funding programmes.

Since the beginning of the German support programme "Electric Mobility in Pilot Regions", the authors have been exploring a range of research questions involving electromobility, and have also been testing practical applications themselves. The implementation of electromobility requires an integrated and holistic approach to exploit the advantages of the electric motor for both the environment and transport systems. These are the aspects that this paper focuses on. In its introductory phase, the ideal application area for the electric motor is not in private cars, but rather in other means of transport and transportation concepts, which we will introduce in this paper. In Asia, electromobility is being widely adopted in the area of scooters or e-bikes. In the public transport sector, there are funding programmes for the electrification of buses, taxi fleets, and also so-called three-wheelers. But the electric vehicle is also increasingly being incorporated into innovative transport concepts such as carsharing (car clubs) and, looking to the future, automated transport or autonomous driving.

Fig. 1: *The Paris E Mobility Carsharing System, Paris 2012.*
© Tobias Gorges

Using selected examples from countries around the world, we will show the wide range of uses and pilot applications incorporating electromobility. As electromobility is making particularly strong advances in Asia, we would like to use this opportunity to encourage an international exchange of experience in the field. We will also derive broad recommendations for developing electromobility concepts, differentiated according to motivation, share of CO_2-free electricity in the energy mix as well as technical and economic prerequisites and population density of the respective urban environment. Underlying this endeavour is the fundamental realisation that we need systematic solutions based on a simultaneous transformation of mobility and energy systems. Only then will it be possible to bring about sustainable transport solutions for more liveable cities.

The authors, Berlin, January 2016

1. Introduction

For several years now, electromobility has been the subject of intensive discussion revolving around ecological and economic arguments. When it comes to the international development of electromobility, it is particularly instructive to examine the Asian example. Countries such as the People's Republic of China, Japan and South Korea, and also India and other countries present interesting approaches to promoting and implementing electromobility. Although technological capability and economic purchasing power are key factors in helping to bring about a breakthrough in the area of automobile electromobility, there are notable examples of success in non-industrialised countries in the area of two- and three-wheeled electric vehicles as well as electromobility in public transportation systems.

Against the background of increasing air pollution in cities, a steady rise in the numbers of motor vehicle registrations and the growing transport-related and financial challenges in the mobility systems of many expanding cities across the world, it is essential to examine the contribution that electromobility can make to solving these problems. To this end, we have conducted an in-depth examination of the practical feasibility of electromobility and presented selected examples from Asian countries in particular.

In concentrating on Asia, we have deliberately put the focus of the study on a part of the world which, from a technological or economic standpoint, is playing an important role in the further development of mobility as a whole. In the longer-term perspective, particular global relevance can be identified in mobility solutions that are transferable to those countries and can meet the challenges that exist there. Moreover, particularly in the PRC a dynamic of its own is developing, which in turn is increasingly leading to unique concepts. The following findings and descriptions are by no means intended to give the impression that electromobility is a "magic bullet" that will solve all the world's transport problems – this is neither the case in Asia, Latin America nor in Europe.

Following an outline of the challenges and fundamental problems relating to mobility (Chapter 2), we will examine the possible solutions that electromobility can offer in terms of both transport and ecology (Chapter 3). This will be followed by an examination of common motivations in the promotion of electromobility (Chapter 4). There are considerable differences between the underlying conditions and user requirements in the various countries and cities around the world (Chapter 5). Transferability and general recommendations are thus not universally applicable, but are instead differentiated according to different clusters. Finally, there is a summary of examples of various electromobility applications for the different clusters (Chapter 6).

Fig. 2: *Electric vehicles, used by the Eco Mobility World Festival 2013 in 2013, Suwon, Korea.*
© Nikola Medimorec

2. Transport-related Challenges and the Solutions Presented by Electromobility

2.1 Increasing urbanisation with increasing demand for transport

The current global population is around 7 billion people, the majority of whom – around 4.25 billion – live in Asia. The most populous countries are the People's Republic of China (with around 1.35 billion people) and India (with around 1.26 billion people). In 2014, the global degree of urbanisation – the proportion of city dwellers in the total population – averaged around 53 %. Asia, at approximately 46 %, shows a below-average degree of urbanisation in a comparison of continents. At the same time, by global comparison, Asia has a high number of very large cities with a high population density. The degree of urbanisation is expected to surpass 60 % by the year 2018 (World Bank, 2011). Latin America will likely soon surpass Anglo America as the region with the world's highest degree of urbanisation (Berlin Institut, 2007). In Canada and the United States, 80 % of the population currently resides in cities (Destatis, 2014).

The growth of cities also leads to increasing mobility. Cities rely on transportation for the movement of goods and labour. City residents themselves must also be mobile, and their mobility generates traffic. In many rapidly-growing cities, historically established quarters in which local supply structures existed in close proximity to residential areas have increasingly been replaced by functionally separate urban structures, or monofunctional areas have been built on the perimeters. One notable example is the "danwei system" that existed in communist China before its markets became more open, which combined workplace and residential areas. In cities there were various village-like communities that also assumed diverse welfare functions, such as guaranteeing a lifelong job. The close proximity of places of residence and work did not require a comprehensive traffic infrastructure for commuters; however such an infrastructure had to be built after the system was largely abandoned (Neubert, 2012).

Mobility provides access to various functional spaces and is thus indispensable for meeting our supply and social needs. In addition, the increasing expansion of cities in conjunction with inadequate or failed spatial and transport planning leads to increasing commuter distances and subsequently increased traffic (London School of Economics). On an average day in Mexico City for example, all of the city's residents together spend around 17 million hours in traffic. This corresponds to the daily working hours of around 2.2 million people (Planzelt, 2014). In Beijing, it often takes hours to get from one part of the city to the other using the underground train system. Many people then have to walk for kilometres in order to reach their final destination. Thus, it is no surprise that many people wish to have a car of their own. Today, 64 % of all travel made is within urban environments and the total amount of urban kilometers travelled is expected to triple by 2050. In People's Republic of China, the modal split for passenger cars in the urban transport sector is set to increase steadily (in terms of distance travelled) until the year 2047. This applies in the case that the government continues to pursue a car-friendly and road-oriented policy. For major Chinese and Indian cities, significant modal split shares of 78 and 67 % respectively are expected for the year 2050 for the passenger car sector (International Transport Forum/OECD, 2014). But shares of 35 and 40 % are expected to be reached by the year 2027. The clear losers are bicycle and pedestrian traffic, whose share is expected to shrink from 40 % to under 10 % (Drewitz/Rommerskirchen, 2011). Here, a particular critical focus is placed on motorised individual transport (MIT) based on passenger cars.

- Today, there are one billion passenger cars in use around the world. A comparison of motor vehicle density (motor vehicles not including two-wheeled vehicles) per 1,000 inhabitants shows that the major countries of Asia still lag far behind the levels in North America, Europe and Latin America. In the year 2011, the United States (786/1,000), Germany (588/1,000), Argentina (315/1,000) and Mexico (275/1,000) had significantly more vehicles per 1,000 residents than, for example, the People's Republic of China (69/1,000) and India (41/1,000) (World Bank, 2011). Nevertheless, in particular in developing countries with a growing middle class, the number of vehicles has increased exponentially in recent years (Statista, 2016).

- Because of the significantly higher population densities in major Asian cities, the number of passenger cars in a given area is often just as high as in Western industrialised countries. Calcutta, with only 61 passenger cars per 1,000 inhabitants, has a very low rate of car ownership. In Berlin, more than five times as many inhabitants own a passenger vehicle (356 per 1,000 inhabitants). However, since the population density of Calcutta (24,000 inhabitants/km²) is over six times higher than Berlin (3,900 inhabitants/km²), the number of passenger cars per square kilometre is similarly high: Berlin (1,367 automobiles per km²) and Calcutta (1,421 vehicles per km²).
- According to the International Organization of Motor Vehicle Manufacturers (OICA), the number of passenger vehicles is increasing globally by more than 60 million units a year. Due to the high economic and automotive dynamic of emerging economies, the number of cars in those countries will continue to increase sharply over the next years. In the growing upper and middle classes of many emerging economies, automotive mobility is an indicator of individuality and economic capacity. Moreover, automotive mobility is still perceived as an outward sign that one's concept of life is in line with the Western lifestyle. India's middle class, for example, which consists of some 300 million people, is entering a widespread phase of automobilisation. Currently, two-wheeled vehicles have a share of 75 %, and thus constitute the most important mode of transportation. The International Energy Agency expects the number of vehicles to grow to 1.7bn passenger cars by the year 2035 (Mobility Model MoMo in the New Policy Scenario; IEA, 2013). Correspondingly, vehicle density would more than triple in India, more than quadruple in Indonesia, and in the People's Republic of China it would increase tenfold. Scenarios show that by the year 2050 there could be an even greater increase in the Asian vehicle market, up to 2 or 3 billion passenger cars (Chamon/Mauro/Okawa, 2008). In Latin American metropolises with over 500,000 inhabitants, the number of vehicles (four-wheeled only) will increase around fourfold by the year 2050 if current trends continue (International Transport Forum).

Fig. 3: *Charging at a public charger, London.* © Carlosfelipe Pardo

2.2 Limited transport infrastructure and extensive spatial usage

The desire for access and participation in mobility options leads to traffic with diverse modes of transport, using various transportation infrastructures. The rapid growth in demand for mobility leads to an increasing strain on existing transportation infrastructure. This results in a decline in average driving speeds, longer travel times, greater congestion and increasingly unpredictable travel times. Already, urban commuters spend many hours in traffic per year. Many cities in Asia, in particular Ho Chi Minh City, Bangkok, Jakarta, Manila, Bangalore and Beijing, suffer from high levels of traffic congestion. But consistent data is not available for all cities. TomTom data from 2014 shows that some eastern European and Latin American cities are more affected by traffic congestion than Chinese cities. Nevertheless, many Chinese cities are extremely prone to congestion (TomTom, 2014).

Traffic jams result in lost work time and consequent economic losses. They also take an emotional toll on those affected and as a result can have an adverse effect on the health and safety of the population. Traffic congestion currently costs Asian economies 2 to 5 % of their gross domestic product as a result of idle time and higher transport costs. The estimated cost for South Korea, for example, is 3 % of GDP (Korea Transport Institute, 2014), while for Manila it is 4 %, for Beijing 5 %, and for Lima/ Peru, it is as high as 10 % of GDP.

The increasing strain on existing infrastructure also leads to a growing need for maintenance and upkeep. The maintenance backlog that exists in many parts of the world not only creates further impediments to traffic and causes accidents, it can also lead to increasing financial burdens, as problems that are not repaired at an early stage often result in further damage, which can cause maintenance costs to increase exponentially. Growing cities are then confronted with inadequate capacity in their public transport systems, overburdened rail and road infrastructures, an exploding volume of motorised private transport on road infrastructures in need of repair, and a shortage of parking; all of which takes a serious economic toll. Road infrastructure presents additional conflicts of use between the various modes of transportation and the way that traffic is organised. Areas for safe pedestrian and bicycle paths, and also separate lanes for buses and taxis, compete with areas used for motorised individual transport, in particular by private passenger cars.

Asian cities, confronted with increasing numbers of motorised vehicles, have placed the priority of public sector investment on the expansion and reinforcement of the relevant infrastructures. Bangkok has increased the number of roads suitable for motorised traffic, Shanghai has built a network of urban motorways, and Manila and Jakarta also created more room for individual vehicle traffic. The transport and urban development in many of Asia's metropolises is occurring in an unplanned manner and is characterised by a considerable gap between rich and poor. In cities where centralised structures are lacking, the public transport system is organised by numerous private companies and small service providers. The result is often unregulated, cutthroat competition without attention to safety or environmental standards. Motorised individual transport is increasingly replacing not only public transport, but also bicycle transportation.

In recent years there has been recognition in many cities in East Asia that simply building new roads cannot solve the challenges facing the transport infrastructure. Additional roads lead to greater motorisation, which in turn will lead to more traffic congestion in the future (induced mobility). Particularly in densely built-up cities, the space required for substantial new road construction often does not exist, and even if it does, such construction measures are very cost-intensive. Increasingly, therefore, political measures are being incorporated into urban and transport planning in an attempt to reduce the demand for motorised individual transport.

2.3 High energy consumption and global warming due to transport

The transport sector is currently responsible for around 25 % of global primary energy consumption (IEA, 2012). Road transport accounts for nearly 75 % of this amount, while 50 % is attributed to passenger car traffic — and thus the largest share of energy consumption in the transport sector (Felming *et al.,* 2009). Road transport is responsible for around 43 % of the world's oil consumption (Roland Berger, 2013). The consumption of fossil fuels by the transport sector is rising sharply, and, relative to other sectors, disproportionately.

Most Asian economies must import vast amounts of oil to meet their increasing transport needs. The People's Republic of China is the second-largest oil consumer in the world. India's demand for oil has increased by over 35 % in recent years. And in future, demand for oil is expected to increase by approximately 20 %. Japan's oil demands, by contrast, have fallen by around 15 % in recent years. This trend is expected to continue in the future on account of its population decline and the growing share of regenerative energy sources in the country's energy mix (Roland Berger, 2013). A reduced dependency of national economies on crude oil imports from a small number of supplier countries, which are often located in politically volatile regions, is not only an economic goal, but also a priority in terms of security policy. Besides strategic security considerations, the burning of fossil fuels results in strain on the atmosphere as a catch basin for so-called greenhouse gases, and facilitates the spread of airborne pollutants in urban environments. CO_2 is the most harmful of the transport-related greenhouse gases.

With regard to projecting developments in the future, various scenarios are employed. The “business as usual” scenario assumes that energy consumption and greenhouse gas emissions will increase by 50 % by the year 2030 and by 80 % by the year 2050, relative to 2009 levels. The increase in this scenario is based primarily on the increasing global vehicle stock (Slocat, 2014). This trend is contrary to international climate protection targets that call for a reduction of anthropogenic greenhouse gases by 50 % by the year 2050, relative to 1990 levels. Industrialised countries need to achieve reductions as high as 80 to 95 % in order to meet international climate targets. These targets can only be reached by implementing extremely ambitious measures, in particular in the transport sector, both in industrialised and emerging economies.

2.4 Increase in traffic-induced air pollutants

Particulate matter, NO_X and other contaminants stemming from motorised road traffic often pollute city air to such a degree that it poses a serious health risk to city dwellers. According to WHO calculations, in 2012 around 3.7 million people around the world died of strokes (40 %), heart attacks (40 %), chronic bronchitis (11 %), lung cancer (6 %) and other diseases (3 %) attributable to air pollution. 88 % of air pollution-related deaths occur in countries with low to medium income levels, the majority in the Western Pacific region and Southeast Asia. Low to medium level income groups suffer far more than population groups with higher incomes.

In global comparison, as the daily measurements of global urban air pollution published on Internet platforms clearly show (see Figures 4a, b), cities in Asia are most heavily impacted by air pollution (Asian Development Bank, 2014). According to Chinese environmental authorities, only three of the People’s Republic of China 74 major cities met the state standard for good air quality in the year 2013. In 2014 as well, the limit for particulate matter recommended by the World Health Organization (WHO) was exceeded on numerous occasions as much as 20- to 30-fold (WHO, 2011). During periods of heavy smog, authorities recommend remaining indoors.

2.5 Contributions of electromobility

The development of possible solutions to the urban challenges that exist in the transport sector is an issue that currently has significant relevance on the international stage. Particularly in Asia, the current and anticipated challenges in the transport sector are dramatic. There

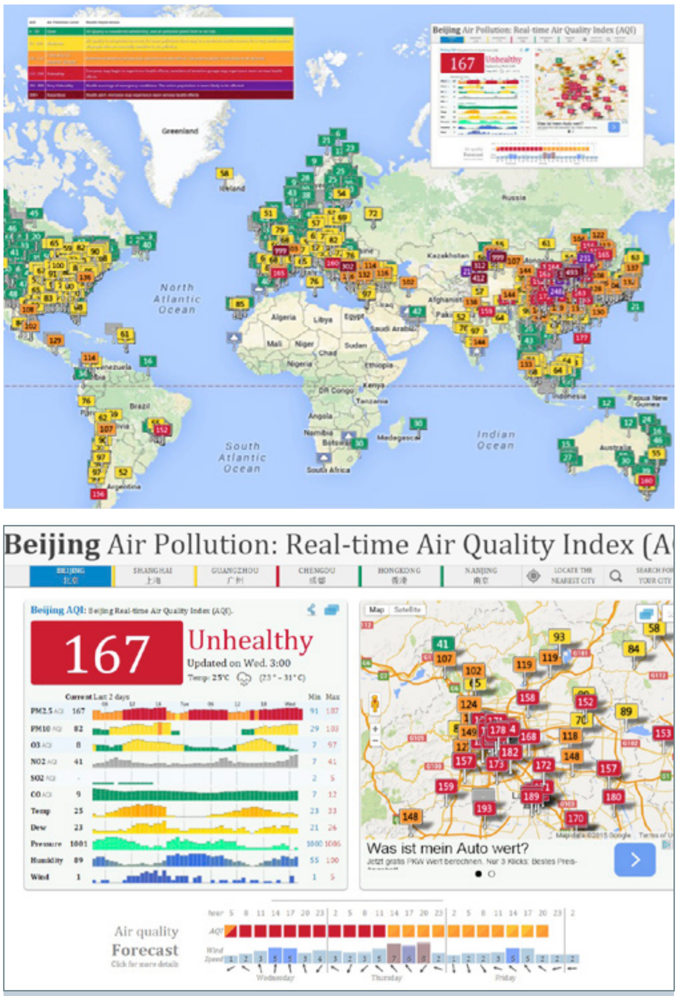

Fig. 4a, b: *Air pollution according to an index of cities around the world.*
Source: http://aqicn.org (28 July 2015)

are clear limits to simply transferring the existing, car-based mobility model to the rest of the world and heterogeneous metropolitan areas around the world. There are legitimate fears that the pressing problems resulting from an increase in motorised road traffic will continue to grow, thereby leading to serious impediments to economic growth, significant environmental impact and a deterioration of quality of life.

New approaches are therefore being sought which will enable a high degree of mobility for the population and a continuing increase in prosperity, but without continuing or repeating the above-mentioned negative developments in the transport sector. Against this background, the Asia Development Bank recently expanded its criteria for awarding funding to transport projects to better serve the three priorities of economic, social and environmental interests. Until a few years ago, the development bank was focused for the most part on funding road construction projects; now the aim is to develop transport systems that are accessible, affordable, safe and environmentally friendly (Leonzon, 2010).

With regard to ecological measures, the paradigm in transport policy is now "avoid/reduce – shift – improve". This simple approach assigns different measures to these three categories (see Figure 5).

Among other things, electromobility is currently seen as a contribution to solving both transport and environmental challenges. Electromobility is generally understood as transport modes with electric motors that utilise various forms of energy supply. Overall, there is a wide spectrum of electric vehicle types available (*e.g.* electric scooters, electric cars, electric buses), although the deployment strategy differs according to country and region. Heavy utility vehicles and electric trains are not the subject of this study.

Electromobility for the most part falls under the category of improvement measures, as, depending on electricity generation and efficiency; it increases vehicle efficiency by reducing pollutant emissions per energy unit. But the internal combustion engine still has potential for optimisation as well: In the future, innovations such as direct injection, downsizing, gearing optimisation and other developments will make combustion engines more efficient and cleaner. To date, however, all benefits achieved by improved engine technology have been at least in part negated by higher vehicle weight and increased annual mileage. In addition, further technological optimisation of the internal combustion engine has physical and technological limits. Nevertheless, compared to industrialised nations in particular, many emerging and developing economies still have the potential for bringing about improvements when it comes to conventional engines. Additionally, these countries can gradually enforce more stringent emissions limits for motorised transport, thereby boosting the overall sustainability of the transport sector.

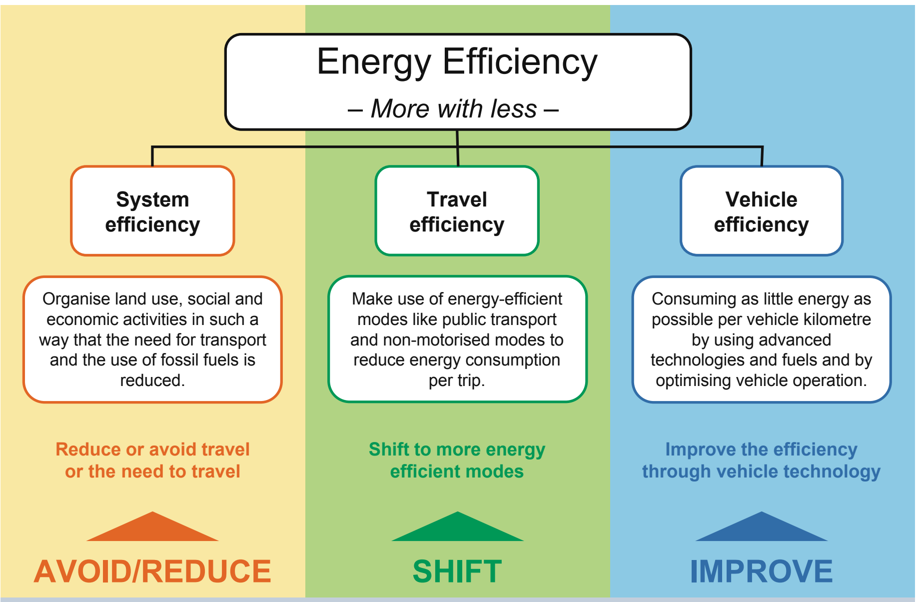

Fig. 5: *Classic approach to avoid, shift and improve in the transport sector.*
Source: GIZ, Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities, Module 5e: Transport and Climate Change

Alternative propulsion systems can also bring about further improvements. Electromobility carries the promise of these additional improvements and increases in efficiency. Compared to internal combustion engines, the use of electric engines in vehicles can have a significant advantage in terms of efficiency, since the energy utilised does not first have to be converted into heat as is the case in the combustion engine; this means that much greater levels of efficiency can be attained (see Figure 6). The optimum efficiency level of the combustion engine today is at 37 % (petrol) or 43 % (diesel), although under real-world operating conditions it is usually much lower. Electric propulsion systems, by contrast, have significantly higher optimum efficiency levels of up to 90 % (ifeu, 2011). Moreover, the energy sources used in electricity generation can be replaced by energy sources with lower CO_2 output levels and less harmful emissions. Higher energy efficiency and the use of electricity produced from regenerative sources are thus two important leverage points that electromobility has in the transport sector.

However, the full potentials of electromobility in meeting the transport-related and environmental challenges can only be achieved if supplemental measures are taken as well, such as using renewable electricity and expanding the charging infrastructure. An appropriate use of electric vehicles (in collective transport rather than in private individual transport) can prove to be a key impetus in the shift toward energy-efficient modes of transport. Depending on the level of occupancy, there can be a significant decrease in pollutant emissions per person. Additional motorised private transport can also be avoided if this is combined with increased passenger numbers in electrically driven public transport or the increased shared use of private electric vehicles (carsharing). These options will be explored in the following sections.

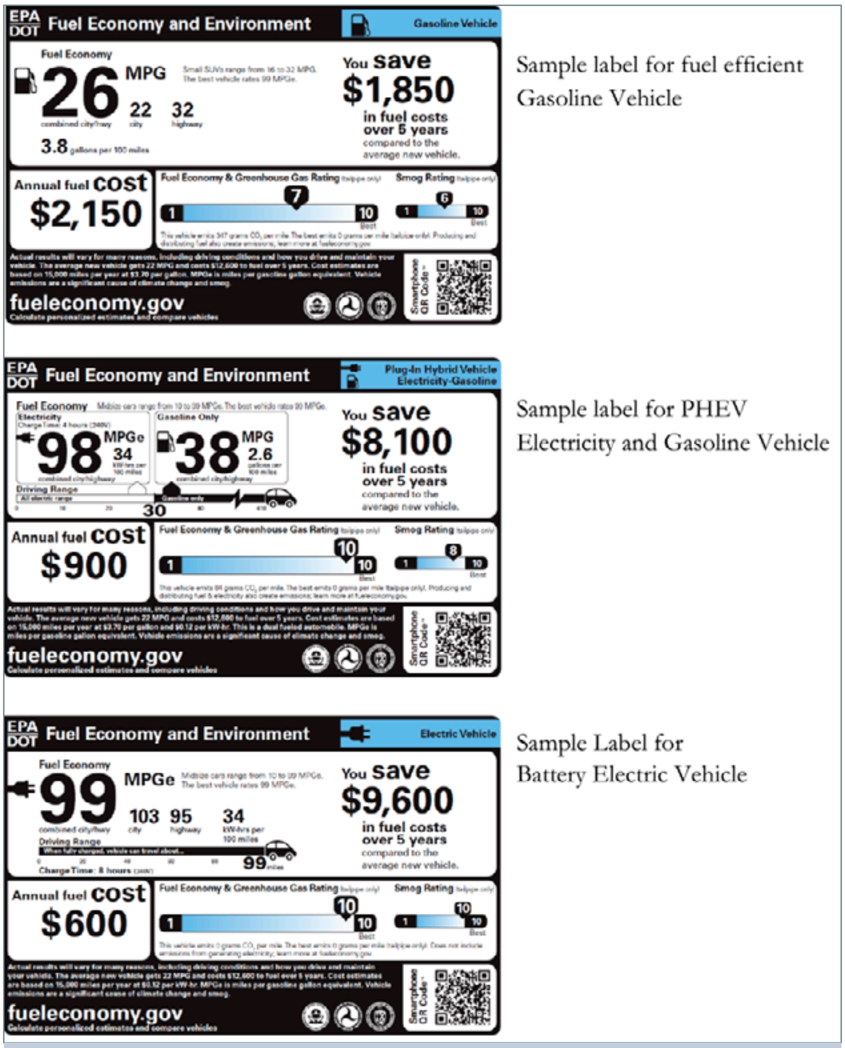

Fig. 6: *Energy labels for cars from the United States.*
Source: United States Environmental Protection Agency, 2011

3. Forms of Electromobility

Electromobility is currently being discussed as a central issue all over the world. Electric motors are being used in various areas of passenger transport; as a result, electromobility must tackle specific challenges and conditions at different stages of the transport market. For several years now, vehicles that cater to the mass market are — once again — being sold on the market. This applies in particular to two-wheeled electric vehicles, and also to shunting vehicles such as forklifts, etc. A number of automobile manufacturers are selling electric series production vehicles, and specialised electric vehicles such as taxis and buses are also available on the market. The following section will differentiate and briefly explain the use of electric motors in two-wheelers and three-wheelers, as well as in passenger cars and buses.

3.1 Specific characteristics of *two-wheelers* and *three-wheelers*

A lack of alternatives in the public transport system as well as increasing mobility needs accompanied by rising household incomes are among the reasons why motorised individual transport (MIT) is gaining in importance in many Asian countries. Especially in emerging economies, MIT generally manifests in the form of motorised two-wheeled vehicles, electric bicycles and so-called scooters and mopeds. These modes of transport dominate the traffic of entire Asian cities, often creating considerable challenges in the process. The transport sector, according to the Asian Development Bank, accounts for 30 % of all atmospheric emissions in non-OECD Asian countries. Out-dated and inefficient combustion engines contribute in no small measure to this problem (see Figure 7). Besides diesel buses, other major sources of pollutants include scooters and motorised three-wheelers with two-stroke engines.

The People's Republic of China has already responded to the problem and has banned conventionally powered scooters. This move was motivated by both environmental and traffic safety concerns. Electric bicycles, both those with and without pedal-assistance, are allowed, however. This has led to the rapid spread of electric bicycles, so-called e-bikes, which are relatively inexpensive. The possibility of charging at home and at work means it is hardly necessary to build a broad-based charging infrastructure for these vehicles (see Figure 8). It is estimated that as of late 2014 there were around 230 million e-bikes on the road in the People's Republic of China (OECD/IEA, 2015).

In addition to the motorised two-wheelers popular in Asia and the United States, which are controlled by a throttle twist grip, there are also so-called pedalecs, which are electric bicycles whose motor is activated simply by engaging the pedals. The pedelec (pedal electric cycle) has a maximum of 250 watts of auxiliary electric power and can reach speeds of 25 km/h. Pedelecs are especially widespread in Europe and have until now not played a significant role in Asia. Pedelecs are considered to be a "partially active" means of transportation, which also has a health benefit for users. Riders of pedelec e-bikes can attain higher speeds over longer periods without physical exertion than can riders of non-motorised bicycles. This makes the technology accessible to people with health restrictions and expands the deployment radius of the bike. The pedelec has, for the most part, the same legal status as the conventional bicycle; the bikes require neither special insurance

Fig. 7: *Smog in Ningbo, PRC.* © 显龙, CC-BY-SA 2.0

Fig. 8: *E-bikes being charged in Wuchang's Garment District, PRC.* © Vmenkov, CC-BY-SA 2.0

nor registration or a driver's licence; in some countries, including Germany, riders of pedelecs are not required to wear a helmet. Electric bicycles require between 0.5 and 2 kW-hr per 100 kilometres (on average around 1 kW-hr); this corresponds to approximately 1 litre of petrol. Pedelecs have a range of between 30 and 80 km (with an average range of 60 km). A battery can be re-charged 300 to 500 times on average before the capacity decreases noticeably (pedelec-portal, 2011).

A distinction must be made to the so-called speed pedelecs, also called "Swiss class". These vehicles function like pedelecs, but have a capacity of up to 500 watts, enabling riders to achieve speeds of up to 45 km/h. In Germany these bikes require an operating permit and may only be used by persons aged 16 years and older. The rider must also have a driving licence, must insure the bicycle (licence tag) and must wear a helmet while riding the bike (ADFC, 2015).

The global market for two-wheeled electric vehicles is expanding with the emergence of more inexpensive products, improved technology and increased availability. According to an estimate from the year 2013, around 40 million e-bikes and pedelecs are sold annually, and the trend has been increasing from year to year. At the beginning of the 1990s, the People's Republic of China prioritised the development of e-bikes as a technology objective. Today, the People's Republic of China accounts for over 85 % of worldwide sales of electric two-wheelers, followed by Europe (approximately 1.8 million), Japan (approximately 440,000) and the United States (around 185,000). Trends such as electric utility bicycles, retrofitting kits that are easy to install, and the use of e-bikes for police and security services have also contributed to the boom. In addition to the private use of electric bicycles, there is increasing focus on new models of usage. Parallel to bike sharing schemes, electric bicycles and electric scooters are being used (in various German cities, among other places) in rental schemes being tested as a supplement to conventional public transport (see Figure 9).

Fig. 9: *Pedelec rental scheme of Deutsche Bahn subsidiary DB Rent in Stuttgart.* © EnBW@Facebook

Infobox 1: Promotion of e-tricycles in the Philippines

Three-wheeled vehicles are a central means of transport on the streets of many Asian cities, while in European cities they have so far been an exception. In the Philippines alone, according to figures by the Asian Development Bank (ADB) there are around 3.5 million three-wheeled mini-transporters, also referred to as tricycles, on the roads. They are used as taxis and as a supplement to public transport services, or are used as an alternative where no conventional public transport services are available. In the Philippines, tricycles make up 75 % of all public transport services. These simple two-stroke engines, however, emit a disproportionate amount of pollutants and contribute to emissions-related air pollution (smog).

This is why the ADB is providing around USD 300m to help fund a project in the Philippines to promote the use of electric tricycles. Another project by the Philippine Government, which provides USD 99m in funding, will run for five years until the end of 2017; during this period, 100,000 conventionally operated tricycles are to be replaced by electric tricycles. This approach aims to achieve various objectives: In addition to the intended reduction of environmental impact (decline in annual CO_2 emissions by around 260,000 tonnes), it is also intended to reduce the Philippines' dependency on fuel imports (savings of USD 100,000 per year) and to provide drivers of tricycle taxis better income prospects. Electric vehicles are more energy efficient and enable savings of up to USD 5 per day in fuel costs. Furthermore, more passengers can be transported with electric tricycles than with conventional ones. In one pilot program, drivers were able to more than double their daily income. The e-trikes are offered under leasing contracts. Finally, local manufacturing of electric three-wheelers provides jobs for the local economy. By the end of the project, 10,000 new jobs are expected to have been created (Asian Development Bank, 2012).

Tricycles are already available on the market. "Terra Motors", for example, a Japanese manufacturer of electric scooters, sells a tricycle called the Y6, which is fully electric and is thus emission-free in operation. The vehicle can carry up to six passengers and can reach speeds of up to 55 km/h. The manufacturer specifies an electric range of 100 kilometres. The possible saving in energy costs is one of the main sales arguments (Terra Motors, 2015).

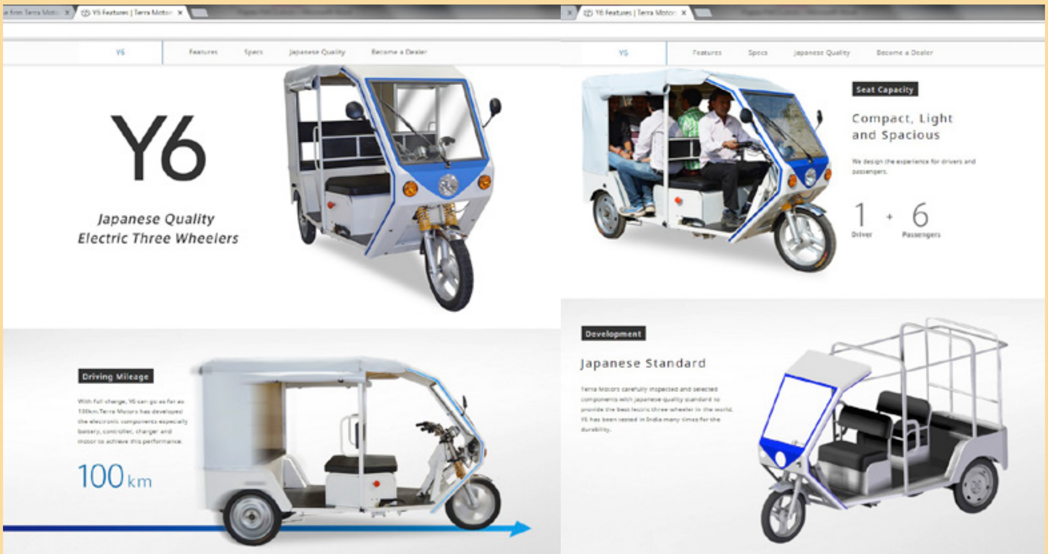

Fig. 10a, b: *Terra Motors website–specifications of the electric Y6.* © Terra Motors, 2015

3.2 Specific characteristics of bus transport

Buses, particularly those with older combustion engines, are a significant cause of pollution in cities. This is particularly true in the growing cities of emerging economies with a high population and building density, where in many cases buses with 30-year-old diesel engines are still in operation. However, the idea of using electric buses in the public transport system is by no means new. Siemens introduced the world's first trolleybus ("Elektromote") in Berlin as far back as 1881. Further developments between 1920 and 1960 led to the global dissemination of the trolleybus. Today there are more than 40,000 trolleybuses in operation around the world; they are used in over 310 cities and 56 countries, including in Eastern Europe, the post-Soviet states, the People's Republic of China and North Korea, and also in South America (UITP, 2015). The following section will summarise the extensive experience that has been gained in this area.

Fig. 12: *Trolleybus in Sofia, Bulgaria , 2016.* © Manfred Breithaupt

Trolleybuses are powered by one or more electric motors and draw their power via pantographs (power collectors) from overhead wires that run above the road (see Figures 11 and 12). This means that these buses are lane-bound not track-guided vehicles. To enable short-term use away from overhead lines, modern trolleybuses are usually equipped with auxiliary power units. This system is sometimes battery-operated as well, as is the case in Beijing Guangzhou and Jinan, where the buses use battery power for sections of bus routes that do not have overhead lines. For the most part, however, combustion engines are used for auxiliary power generators for the electric motors. These generators are operated primarily with diesel fuel and have a smaller fuel tank than conventional diesel buses.

Fig. 11: *Trolleybuses in Pyongyang, North Korea (PRC), August 2012.* © Suez (sophia), CC BY-SA 3.0

The trolleybus can be compared to a diesel bus system or an electric (*streetcar*) tram: Depending on the measurement, noise levels are 50 to 90 % lower than conventional diesel buses and around 25 % lower than trams. The energy consumption of trolleybuses is around 40 % lower than diesel buses, but around 30 % higher than that of trams. Modern trolleybuses have better acceleration than diesel buses and thus offer more stable operation on shorter journey times. High pull-away speeds also allow for fast and safe merging into the traffic flow as well as smooth operation even in steep terrain. Compared to trams, trolleybuses can also make turns with a tighter radius. And trolleybus lines can be built faster than tramway lines: The new construction of a trolleybus route normally takes between two and four years, while the rail-bound tram requires five times as long from planning to completion (S2R Consulting, 2009).

The acquisition costs of trolleybuses are higher than for conventional vehicles; currently, trolleybuses are around two to three times as expensive, since the production runs are often smaller or they are customised models. However, the higher acquisition cost of the vehicles is

Fig. 13a, b: *Trolleybus in Valparaiso, Chile manufactured in 1945, and its vehicle registration document, 2014.*
© Manfred Breithaupt

made up for by the trolleybuses' improved operational performance and lifespan, as electric propulsion systems have lower levels of wear. The amortisation period of a trolleybus is usually 15 to 20 years, and the buses can be used for 30 years and longer. In Valparaiso (Chile) some trolleybuses have been in operation for 70 years now (see Figures 13a, b). It is not uncommon for buses to attain operational performance levels of around a million kilometres and more. In North Korea, older trolleybuses with operational performance levels of to 2.5 million kilometres are still in operation.

In addition to the acquisition cost of the vehicles themselves, the cost of the overhead lines must be taken into account. Here too, costs vary depending on local conditions (including topography and urban development). New overhead lines are — at least in Europe — depreciated over a period of 25 years and can be used for 40 to 50 years before they need to be replaced (Winterthur Transport Company, Swiss Federal Office of Energy, 2002). While the investment costs for trolleybus systems are well above the cost of a diesel bus system, they are far below the cost of a new construction of a tramway (by up to 80%), at almost the same passenger capacity (TROLLY – Promoting electric public transport, 2011).

The operating costs of trolleybuses can be 10 to 20% higher than for diesel buses; on the one hand this is because of the higher costs for maintenance, repairs and regular inspections of the overhead lines, on the other hand because of higher maintenance costs, in particular for the trolleybuses' pantographs (power collectors). The electric motor itself is low-maintenance and energy costs are significantly lower than for (purely) diesel buses, although they are higher than for trams (due to the lower rolling resistance of wheel-rail systems). However, modern trolleybuses are equipped with systems for energy recuperation through regenerative braking, for example, which can lower operating costs to a point that is comparable to diesel buses. The degree of recuperation is highly dependent on local topographical conditions.

In addition to trolleybuses, there are also purely battery-operated buses, in which power is supplied by traction battery systems in the buses themselves. Charging is normally carried out via a cable at the terminal stop or at the bus depot.

Infobox 2: Electric buses from the PRC

The Shenzhen-based company BYD has had particular success in this segment. The cornerstone of their success is the K9 model, which has been in production since September 2010. The 12-metre long bus weighs 18 tonnes and is equipped with low-floor access. Its centrepiece is BYD's own iron-phosphate battery with a range of around 250 km per charge. Charging takes approximately five hours and should be carried out overnight at the bus depot. The sale price, depending on configuration options, is between USD 395,000 and USD 592,000. In the meantime, other models have become available on the market. BYD emphasises that it is quite possible to operate electric buses profitably, and that under optimal circumstances have economic advantages over diesel buses.

E-buses have been tested in many cities of the People's Republic of China since around 2011. In 2011, the first 200 BYD electric buses were deployed in Shenzhen, followed by tests in Changsha, Shaoguan, Xi'an and Haikou City in 2011 and 2012. In the year 2014 alone, 600 electric buses were sold to Nanjing and 1,200 to Dalian. BYD is thought to sell around 4,000 electric buses per year in the PRC alone. The International Energy Agency estimates (IEA, EV Outlook, 2015) that there are around 36,500 electric buses on the road in the PRC as of late 2014.

BYD also began early on to look for suitable locations around the world to deploy its electric buses; in 2011 it began to test its buses on the international market, deploying them in the United States, Canada, as well as various countries in Latin America and Europe. In Asia, its buses are used among other places in Bangalore (India), Bonifacio (the Philippines) and Kyoto (Japan). In Brazil, the company even has plans to build its own production plant for BYD buses, where it will in future be able to produce 500 units per year for Brazil, Colombia, Chile and Uruguay (Fan, 2014). In Bogotá (Colombia), BYD buses are being tested in the BRT system TransMilenio. São Paulo is also using BYD buses in its public transport system. Particularly notable is the use of BYD electric buses in the first Asian Bus Rapid Transit Programme in Kuala Lumpur (Malaysia). Rapid KL, a subsidiary of the state-owned company Prasarana, is using 15 buses here on a 5.4 km route (see Figure 14). Prasarana is responsible for the planning and management of the public transport system in Malaysia (MYrapid, 2015).

BYD has expanded its production sites in the PRC and is planning to build its first international production sites. In the United States, one plant has already been opened in California, which will be used to supply the American market. For the year 2015, the company aims to sell up to 6,000 buses in countries around the world.

Fig. 14: *Electric Bus BRT, Kuala Lumpur, 2015.*
© Manfred Breithaupt

Fig. 15: *Trolleybus in Beijing, China, 2016.*
© Manfred Breithaupt

As an alternative to the longer charging cycles at the bus depot, so-called super-capacitors are also used, which enable rapid absorption and storage of large amounts of power. In Shanghai, a so-called "Capabus" has been deployed for test purposes starting in 2005 (see Figure 16). These buses are equipped with power collectors and are charged at bus stops by way of an overhead line that is installed only at the stops themselves. Since 2009, this technology has been employed in regular operations on the bus route no. 11. In 2013, 17 buses were operating on three other such bus routes in the city. Based on the higher cycle stability and longer lifespan of the capacitors, operators expect that electric buses equipped with super-capacitors will be less expensive to operate than buses with Li-ion batteries. Compared to diesel buses, savings of at least USD 200,000 per bus are expected over the entire lifespan (Hamiltion, 2009).

Fig. 17: *Fuso hybrid bus in Japan, 2009.*
© Cassiopeia_sweet, public domain

Fig. 16: *"Capabus" in use in Shanghai.*
© Ywchow, public domain

This technology is being advanced and tested around the world, including by Bombardier under the name "PRIMOVE" for use in electric cars, buses and trams. It is possible to reach very high charging capacities of 200 kilowatts, so that a stop of only a few minutes is sufficient to supply enough electric power for around 15 km (Schwarzer, 2015). Currently, Berlin's public transport system BVG is also testing such a bus.

Daimler has been testing the use of hybrid buses since 1969. Although they are expensive compared to conventionally powered buses, they have also been used in regular operations for several years now. Other bus manufacturers also offer hybrid buses. Diesel-electric hybrid buses have an electric propulsion system as well as a diesel engine that recharges the Li-ion batteries. The buses also have braking energy recuperation systems. According to manufacturers, this enables fuel savings of 25 to 30 % compared to diesel buses. At the same time, this technology produces 90 % less soot particulates, 40 % less nitric oxides and 30 % less greenhouse gases. While hybrid buses have been used in North America since 2008, where they have been in operation in New York City under the name Orion VII HybriDrive, the "Mitsubishi Fuso Truck and Bus Corporation" (MFTBC), a subsidiary of Daimler, has built the hybrid bus "Aero Star Eco Hybrid" in Japan for the Asian market (see Figure 17). Initial tests took place in 2002 during the football World Cup. In Japan, the bus has been used in scheduled service for several years now (Omnibusarchiv, 2009). In summer 2013, Volvo received a major order from Bogotá. 200 Hybridbusse buses based on Volvo's bus chassis B215RH were purchased and will be used as shuttle buses in the TransMilenio BRT system (Bulut, 2013). Latin America is also starting to test electromobility concepts, with initial applications in areas such as courier services, bus, taxi and other passenger transport services, as well as in car-sharing operations. In India, the company Fuso has been manufacturing lorries and buses for export since 2014, selling them in particular to the growing markets of Asia and Africa (Doll/Tauber, 2014) (see Figures 18 and 19).

Fig. 18: *Trolleybus in Mexico City, 2011.*
© Manfred Breithaupt

Daimler sees the diesel hybrid bus as a precursor to electric fuel cell buses that will run on hydrogen. As far back as 1997, Daimler-Benz demonstrated with its *NEBUS* how fuel cell propulsion technology can be used in urban transport. Starting in 2002, the successor model *Mercedes-Benz Citaro BZ* was deployed in ten European cities, as well as in Perth and Beijing (Scherf, 2008).

Fig. 19: *E- Taxi in Mexico City, 2011.*
© Manfred Breithaupt

Toyota is currently testing a passenger bus in Japan that is equipped with two fuel cells and two 150-HP electric motors from the hydrogen car ***Mirai*** as well as eight hydrogen tanks. The bus is being tested in scheduled service in Toyota City. At the moment, however, the acquisition costs for fuel cell vehicles are still considerably higher than all other electric alternatives, and supplying the vehicles with hydrogen is still considered to be difficult, as there is not yet a corresponding filling station infrastructures.

3.3 Specific characteristics of electric cars

In OECD countries, most discussion revolves around the market for passenger cars as the main area of application for electromobility. Beginning around 2008, numerous governments introduced clear development targets for electric vehicles at policy level (plug-in hybrids, battery electric vehicles and fuel cell vehicles). The period between the 2008/2009 global economic crisis and around 2014/2015 can be seen as the market preparation phase for electric cars. During this phase, manufacturers and scientific institutions were involved in research programmes with a particular focus on proportional assumption of investment costs in the form of material and personnel expenditures and on the creation of both national and international platforms for exchange on technological and regulatory questions. With a view to the strained national budgets, however, it is to be expected that these funding support programmes will expire in the near future, or at least that they will not be continued at previous levels.

In 2020/2021, the European Union's next stage of CO_2 legislation for passenger cars will come into force, which will put more pressure on automobile manufacturers. Specifically, this will require new cars to comply with an average emissions limit of 95 grams of CO_2 per kilometre by the year 2021. This corresponds to a consumption level of 4.1 litres of petrol or 3.6 litres of diesel per 100 km. The electrification of at least of some segments of the vehicle fleet can make it possible to meet these more stringent fleet emission limits. It is assumed that conventional internal combustion engines can reach an average of 110 to 115 grams per kilometre (Raabe/Borgmann, 2014).

The challenge therefore will be to produce PHEVs and BEVs at sufficiently low costs to ensure high levels of vehicle sales. Manufacturers also receive so-called "supercredits" for electric vehicles: For a transitional period, electric cars can be calculated into the fleet multiple times, thus "artificially" lowering the average consumption of the respective manufacturer. Specifically, an automobile that emits less than 50 g CO_2/km can be included in fleet calculations twice in 2020, 1.67 times in 2021 and 1.33 times in 2022; a vehicle is counted once in the fleet calculation only starting in 2023. These "supercredits" are intended to make the transition to electric propulsion technologies easier, in particular for premium automobile manufacturers. Furthermore, due to the higher purchasing power of their buyers, premium segment vehicle manufacturers can absorb the higher market costs of electrification better than volume manufacturers. After several manufacturers were initially sceptical, nearly all market players are now pinning their hopes on the technical developments associated with electromobility, albeit with varying degrees of scope and pace of development.

The battery cost is a decisive factor in the acquisition cost of a BEV. In 2012, one kilowatt hour (kW-hr) of a lithium-ion battery cost around EUR 400. At the time, the battery of a Nissan LEAF, for example, with its 24 kW-hr capacity, accounted for around 1/3 of the vehicle price. Today, one kilowatt hour costs around EUR 200. Elon Musk, the founder of the company Tesla Motors, was right in 2012 when he said, "I do think that cost per kilowatt hour (kW-hr) at the cell level will decline below that, below USD 200, in the not-too-distant future" (Mein Elektroauto, 2012). Predictions regarding future battery prices are regularly undercut by real developments.

In addition to the acquisition costs, the lifetime costs must also be taken into consideration when calculating the cost of an electric vehicle. The so-called Total Cost of Ownership (TCO) is on average 30 % lower for electric vehicles than for internal combustion vehicles (Global EV Outlook, 2013). This is based on the assumption that the acquisition cost of electric vehicles is higher and the operating costs are lower than is the case with comparable conventional vehicles. The electric motor requires considerably less maintenance and the kilometre price of an electric vehicle is lower than that of a conventional vehicle. Depending on factors such as type of vehicle, vehicle occupancy and driving behaviour, energy consumption is between 15 and 25 kW-hr per 100 kilometres, which corresponds to around 1.5 to 2.5 litres of petrol. By comparison, a vehicle with an efficient petrol-operated engine consumes on average around 6 litres per 100 kilometres.

Fig. 20: *Charging station, Mexico City, 2011.*
© Manfred Breithaupt

The energy cost per kilometre depends on local petrol/diesel prices and local electricity prices, as well as on the fuel consumption level of an internal combustion vehicle and the electricity consumption of a battery electric vehicle. There are significant differences in petrol and diesel prices at filling stations around the world. If the fuel price is subsidised at local level, efficiency differences are hardly economically relevant for the user. Savings can accumulate quite quickly, however, if fuel prices are subject to high taxes (Wagner, 2014). Whether and how quickly the purchase of a so-called battery electric vehicle

(BEV) becomes economically viable continues to depend on the vehicle's specific operating profile (milage, battery lifespan and resale value of vehicle). Today, depending on the battery type, batteries can reach up to 2,000 charge cycles. Toward the end of the life cycle, the battery performance falls to 70–80 % of the initial available battery capacity (VDMA, 2014). The original battery of an electric car will last around eight years, after which point the car can still be driven, although the range is reduced.

A distinction is made between battery electric vehicles (BEV) and so-called fuel cell electric vehicles (FCEV). A fuel cell supplies the electric motor with energy either generated directly from hydrogen or methane, or stored temporarily in a traction battery. The additional battery — in most cases a lithium-ion battery — enables energy recuperation (*e.g.* from braking) and provides relief for the fuel cell from load-change cycles. Initial small production series of vehicles are already on the road; the first passenger vehicle models were sold in 2015. With ranges of around 500 km and the possibility of fast refuelling, FCEVs are considered an extension of BEVs, and ideal for covering longer distances. For the time being, however, the infrastructure for refuelling is not adequate and the entry-level price for a vehicle with such a propulsion system is far higher than the cost of a comparable internal combustion vehicle. Since they have only recently become available as a series production vehicle, FCEVs will not be the focus of this paper.

To summarise, it can be concluded that the high mileage per year and the long lifespan of electric passenger cars and light utility vehicles already make them a worthwhile investment today. This applies in particular to commercial vehicle fleets. At the same time, electric vehicles still require much more explaining to the customer than do conventionally powered vehicles. The possible economic advantages are not easy to communicate and can differ considerably from country to country, while the possible restrictions in terms of range are apparent:

- Battery electric vehicles have a limited range. Depending on the battery system, manufacturers specify average ranges fewer than 200 km for all-electric vehicles – with a few exceptions, such as the *Tesla Model S*. However, everyday experience has so far shown that lower ranges are sometimes attained in real-world conditions, depending on factors such as weather conditions, driving behaviour and usage of other electricity consuming applications in the vehicle (*e.g.* air conditioning). With an average usable range of approximately 100 km, electric vehicles often only reach around one fifth of the range of a conventional vehicle. ***Tesla's Model S*** by contrast, which is equipped with an 85 kW-hr battery, has a range of around 480 km, but its purchase price is significantly higher than that of other electric vehicles. The car is the first all-electric vehicle with five seats (plus two additional seats) that, based on its extensive range and a top speed of 250 km/h, is considered to be completely autobahn-compatible. With over 18,000 units sold, the car is the top-selling luxury all-electric car in the United States.
- The range restriction is keeping a large number of potential buyers from purchasing an electric vehicle, even though the average daily mileage for passenger vehicles in the U.S., for example, is only around 46 km and the average trip distance is 15 km. Because the U.S. has the highest average distance travelled per day in the world, it can be assumed that electric vehicles

Fig. 21: *Small city vehicle, Paris, 2012.*
© Tobias Gorges

Infobox 3: Vehicle charging and charging infrastructure

Conventional, slow charging: In contrast to refuelling with petrol, recharging an electric vehicle takes considerably longer, depending on the charging technology used and battery charge level. For example, a standard AC recharging cycle via a Schuko plug socket (Type F socket, widespread in Europe) with 230 volts and restricted to 2.3 kW takes a significant period of time to complete. On average, manufacturers specify charging times of around seven hours (a Tesla ***Model S***, by contrast, would need up to 24 hours to charge). Charging with three-phase current allows the transmission of larger output. In Europe, the 400-volt power grid is used with three-phase alternating current. For different currents (16 A, 32 A, 63 A, 125 A) and outputs (11 kW, 22 kW, 43 kW, 85 kW), the five-pole CEE plug has become the standard. Auxiliary charging devices can also be used for accelerated charging. The "Type 2" connector made by Mennekes, which became the norm in Europe in 2013, enables outputs of 3.6 kW (1-phase) to 43 kW (3-phase). In addition, the corresponding connector enables continuous communication between vehicle and charging point, for example in order to support a simultaneous adjustment of charging power at heavily utilised charging stations or regulated charging with self-generated solar power. In this case, the charge time decreases to an average of 1 to 3 hours (the ***Model S*** would take 4.5 hours to charge). In 2012, according to the Electric Vehicle Initiative, there were approximately 8,000 conventional charging stations In the PRC, 3,000 in Japan and 1,000 in India (Global EV Outlook, 2013).

Fast charging: Finally, the much faster DC charging must be mentioned. A distinction is made between CHAdeMO and Combined Charging System (CCS). Both standards can be implemented in the vehicle with a relatively low amount of effort and cost. The expensive charging technology is integrated into the charging station, and the traction battery is charged directly with adjusted higher direct current. This requires data exchange between the vehicle and the charging station in order to ensure smooth and safe charging. Because of the power output, a heavy, thicker connector cable is necessary, which is permanently attached to the charging station. Fast charging, however, creates a higher strain on the power grid and requires appropriate safeguards. On average, an 80 % charge takes 20 to 30 minutes. The so-called superchargers made by Tesla Motors enable a charge of 50 % of the battery capacity in 20 minutes, 80 % in 40 minutes and 100 % in 75 minutes. Superchargers will be installed on motorways in sufficient numbers so that long-distance trips can be easily made with only a small number of stops. In the People's Republic of China alone, there are currently around 70 of Tesla's fast charging stations (Teslamotors, 2015). They are located for the most part close to service facilities such as motorway restaurants, cafés, hotels and shopping centres. Japan has the highest density of fast charging stations. In 2012, according to the Electric Vehicle Initiative, Japan had a total of 1,400 fast charging stations operating on the CHAdeMO standard (IEA, 2013).

can already cover the daily mobility needs of the majority of car drivers. For the year 2020, the company Robert Bosch has announced a doubling of the energy density, and with it a corresponding increase in the average range (Schwarzer, 2015).

- Other key questions revolve around the charging infrastructure: How dense is it (see Figure 20)? Who provides it and in what form (see Infobox 3)? And, based on that: How expensive will it be to charge a vehicle? In many cities, particularly in emerging economies, but also in countries that are frequently hit by natural catastrophes, the capacity and stability of the public electricity network is not sufficient to allow for the establishment of a reliable charging infrastructure. In these cases, the development of decentralised solutions could help overcome barriers (see Infobox 4).
- In larger cities, many vehicle owners do not have a garage of their own or access to a private area where they could charge an electrically powered vehicle. Here, users must rely on a publicly accessible charging infrastructure, both on private property (*e.g.* in a car park, in supermarket car parks or at their place of work) and on public property. In addition, longer trips can require top-up charging, which makes it necessary to develop a public charging infrastructure that is accessible "on the road". It is in particular the creation of a charging infrastructure that is considered

Infobox 4: Decentralised charging infrastructure of the company Mahindra (India)

The Indian vehicle manufacturer Mahindra has developed and built its own charging infrastructure; the rapid charging stations in Bangalore are an example of its products (dna india, 2014). As early as 2012, there were around 1,000 public charging stations in operation in India. Due to the relatively high costs associated with the charging infrastructure, however, Mahindra is no longer willing to cover all the costs on its own. The company is striving for a public-private partnership and has stated that they are working on open standards (Mishra, 2014).

For electric two-wheelers, one solution is offered in the form of easily removable, exchangeable batteries that can be charged from the existing home electricity network. Since no charging infrastructure is required for electric two-wheelers and hybrid cars, the National Electric Mobility Mission Plan (NEMMP) does not provide for infrastructure development measures until the year 2017. One of the major challenges in India revolves around the capacity and stability of the power grid. On average, 80 % of capacity is utilised, and capacity overloads regularly cause power failures. This is why in India, strategies to develop an autonomous energy supply, for example in the form of solarports as a supplement to the electric vehicle, are of particular importance.

In this context, the potential to supply electric power not only to the vehicle itself but also to the power grid should not be underestimated. From an environmental standpoint, such approaches to developing a decentralised power supply also have the advantage that they make use of renewable energy sources. Electric vehicles that are charged with regular mains power do not have an environmental benefit, since in India electricity is largely produced in coal power plants (Klötzle *et al.*, 2013).

Fig. 22: *Parking lot with solar charger at Mahindra in Bangalore, 2013.*

to be a key prerequisite for the global success of electromobility.

Mass demand for electric road vehicles will only come about once an adequate infrastructure exists at public or publicly accessible sites. Conversely, the building of an infrastructure will only be profitable for potential operators once there is sufficient demand resulting from a corresponding increase in the number of electric vehicles. It is not common to see charging infrastructure developed by private stakeholders. There are, however, some cases in which automotive manufacturers have become active in the development of a charging infrastructure. Tesla Motors, for example, is building fast charging stations on motorways (also in Asia), which will enable free charging for Tesla customers. Japanese manufacturers are jointly supporting a state-funded programme to build charging stations. However, the development of a blanket charging infrastructure requires, first and foremost, efforts from the public sector, in particular from city municipalities.

- Further hurdles on the path to electromobility include uniform standards, easy access (opening and operating the charging point), and a simple billing procedure for the charging process. Technical standards for charging and billing are currently being developed. The current development is characterised by government standardisation and jointly coordinated activities of various manufacturers/manufacturer groups. Toyota, together with its competitors Nissan, Honda and Mitsubishi, have launched the joint venture “Nippon Charge Service”. In the future, the joint venture will operate the charging stations for electric vehicles and plug-in hybrid vehicles in Japan and will ensure that drivers are able to charge their vehicles at any station. In Europe, BMW, Daimler and other companies have joined together to form the company Hubject. All partners receive access, via e-roaming contracts, to all public charging stations that are connected to the platform (Hubject, 2015). Against the background of the low global sales volume per vehicle model, internationally standardised norms for plugs and charging standards will help to bring about cost reductions (see Table 1).

Depending on the intended use of the vehicle, it may be that drivers who currently want to cover many kilometres may not buy an electric vehicle due to the limited range, the lack of infrastructure and the relatively long charging cycles. Typically, drivers such as commuters who have to cover long distances (> 100 km), employees in customer services or travelling sales representatives are not attracted to all-electric vehicles, as it is only possible to travel long distances in one go with a battery operated vehicle if many longer interruptions are taken into account. However, various mobility studies have shown that the range of a battery electric vehicle is in fact sufficient to cover the global daily average for distances travelled by car (under 50 km per day) (*cf.* WWF, 2008, p. 99). This means that electric vehicles are ideally suited to meet the requirements of daily urban vehicle use and commuting, provided that there are charging possibilities at home and/or at the place of work.

And finally, potential buyers are often attracted by the prospect of the direct acquisition cost over the longer-term running costs of conventional vehicles. Buyers also consider potential situations that do not occur on a daily basis, as well as uncertainties about future developments — including the possible resale value — when deciding whether to buy a car. A typical example of the non-daily situation that the potential buyer considers when deciding to make a purchase is the prospect of a one-time, long-distance holiday trip with the entire family. Everyday vehicle use, by contrast, often entails just one person driving to work or to the shopping centre.

In additional to legal requirements and national funding policies, other framework conditions also play a decisive role in the success of electromobility. Essential factors in this respect are, in particular, urban density and functional access to the charging infrastructure, and also supplemental mobility services. Such supporting framework conditions are essential if the scope of electrification is to be expanded. Innovative services such as vehicle sharing schemes could play an important role in this context.

Regardless of whether the electric vehicle is used privately or as part of a corporate fleet, the vehicle's

Table 1: Overview of public charging infrastructure

	Private charging in private areas	Public charging in private areas	Public charging in public areas	Fast charging
Charging duration *)	5–8 hours	1–3 hours	1–3 hours	20–30 minutes
Electricity network	no or limited network expansion is required	strengthening of grid could be required	connection to grid required, typically below ground, near buildings	expansion of grid access required
Usage behaviour	home charging typically between 19:00–7:00, workplace charging typically between 8:00–18:00	charging during the day, several charging cycles throughout a day	charging 24/7, several charging cycles throughout a day	charging similar to vehicle refueling, several charging cycles throughout a day
Challenge	–	dependency on private party	no business case, public investment needed, cities as indispensable partners	high initial investment, integration of utilities, business case

* based on a 25 kW-hr and begin of changing 20 % SOC

Source: Own data

information services are of particular importance. Due to the limited range and limitations that still exist in the charging infrastructure, the so-called connectivity of the vehicle plays a significant role. Special ICT services can at least help mitigate the associated barriers. Some examples include forecasting the vehicle's remaining range, displaying the surrounding charging infrastructure on the navigation device, and remote smart phone access to the vehicle to check its charge level. A further optimisation feature is the capability to engage the vehicle's air conditioning while it is still connected to the charging station, before the driver begins to operate the vehicle. The connection of the vehicle to the grid can also make other services available, such as an update of the car's software, as is the case with Tesla Motors (Berhart *et al.,* 2014).

Due to their specific operating profiles (*e.g.* a large number of short trips in a carsharing context), electric vehicles are often particularly well suited for use in a fleet. Electric taxi fleets, which were tested for the first time with the ***BYD e6*** in Shanghai (electric vehicle news, 2010), are now being tested in various cities around the world http://www.thinkworth.com/think-xperience). They are in operation in Shenzhen (the biggest fleet in the world, with 850 taxis), São Paulo, Curitiba, Mexico City, Montevideo, Santiago, Bogotá, London, Brussels, Rotterdam, San Diego, New York, San Francisco and Chicago (BYD, 2015a, b). The manufacturer Nissan has electric vehicle models – ***Leaf, NV200*** – that are increasingly being used as taxis in various cities around the world, including in Hong Kong, New York City, Barcelona and London. Both the BYD and the ***Nissan NV200*** are available with a range of approximately 300 km, which is enough for the typical daily use as a taxi (Steffen Edelstein, 2015).

The use of electric vehicles in carsharing fleets is also being tested internationally. However, efforts often do not get past the announcement and test phase, as was the case with the unsuccessful crowdsourcing campaign carried out by Roda Rio 2014 (THE CROWDFUNDING CENTRE, 2015). Some announcements have not yet been put into practice, as in the case of the cooperation, announced in early 2015, between BYD and DirijaJa to establish a corresponding carsharing service (Luan, 2015).

Infobox 5: Colombia

A good example of national and local promotion of electric vehicles is Colombia. Each year, 750 EVs and 750 hybrid vehicles are exempted from the country's import tax of 35 %. The country can also import 100 rapid charging stations and 1,500 home charging stations for hybrid and electric vehicle users with no tariff. In Bogotá, electric vehicles are also exempted from the "Pico y Placa" regulation, under which vehicles are prohibited from driving in the centre of the city at certain times, according to their licence plate numbers.

Measures to promote electromobility in the country began with the public transport system. The city of Bogotá plans to electrify 50 % of its taxi fleet by the year 2024. The city began in 2012 to introduce an all-electric taxi fleet, with 43 ***BYD e6*** taxis. There are currently 50 electric taxis operating in Bogotá. By 2016, approximately 1,000 electric taxis are to be in operation (Marchaìn/Viscidi, 2015).

The energy distribution company CODENSA/EMGESA has the first and largest electric fleet in the country, consisting of 16 ***Mitsubishi i-MiEV*** electric vehicles and 48 electric bicycles. The fleet is available internally to employees on a rental basis.

In May 2014, the local government also passed a draft agreement to incentivise the use of electric vehicles through the creation of more charging stations. At that time, Codensa introduced a charging station for electric vehicles at a cost of 500 million pesos. The station contains 13 chargers, charges electric taxis, and operates all day long. As of May 2015, there are four charging stations in the city.

In accordance with its Technological Advancement Plan, the District plans to improve the SITP fleet in line with national and local legislation. In April 2015, 30 hybrid buses (operating both on selected bus lines and separate TransMilenio lanes) entered service to support the Portal de la 80 terminal. TransMilenio currently possesses a fleet of 260 hybrid buses.

Infobox 6: The “Kandi Machine” — electric carsharing in the PRC

A particularly illustrative example of the commitment to electromobility in the People’s Republic of China is the so-called Kandi Machine. About 200 kilometres south-west of Shanghai lies Hangzhou, the capital of the People’s Republic of China Zhejiang Province, with a population of about 8.8 million across the entire metropolitan area. Hangzhou has a growing urban (transport) infrastructure. In 2012, the first line of a new underground train system was opened, which by the year 2050 is to reach a total length of around 375 kilometres. The “Hangzhou Public Bicycle” is also the largest bicycle sharing system in the world (80,000 bikes at over 2,400 stations) and the first of its kind in the PRC (ICLEI, 2011).

Under the initiative of the Chinese vehicle manufacturer Kandi, the project “Self-driving Electric Vehicle Rental for Public Transportation in Hangzhou” (Kandi Technologies, 2012) was launched in 2012 as an initiative to introduce electric city vehicles. The project is based on the combination of sustainability through electric motors (elimination of local emissions), usage efficiency through carsharing (a large number of people sharing a small number of cars) and space saving through mechanical parking facilities (stacking of many vehicles in a small space during the charging process; see Figure 23).

The electric vehicle ***KD-5011*** has a range of up to 160 km at 60 km/h and a maximum speed of 80 km/h (Kandi Technologies, 2014a). Initially it was not available for purchase, but could only be used in the context of carsharing or leasing models. The carsharing rental system is intended to compete with the local taxi service in terms of price (LeSage, 2013). In addition to two-seaters, 200 all-electric four-seaters (***JL7001BEV***) were deployed in Hangzhou in late 2013. By the end of 2014 a total of 9,850 electric vehicles were in use. Initially, this carsharing service was station-based, *i.e.* the vehicles had to be picked up and dropped off at the same station. In the meantime, however, vehicles may also be dropped off at other stations. The fee is CNY 20 per hour for a two-seater and CNY 25 per hour for a four-seater. In addition to the hourly tariffs, the vehicles are also rented out to local communities for a year at a time (Jing, 2015).

The project’s unique feature is the rental stations. These are multi-storey mechanical car parks, also referred to as “smart vertical parking and charging facilities” or — because of their similarity with a self-service vending machine — as “Kandi Machines” (Rogowski, 2013). In these facilities, the electric cars are stacked vertically on hydraulic lifting platforms, where they are also charged at the same time. Each parking space has its own power supply and a clearly visible charge status indicator. Users pick up and drop off the vehicles at a small parking area in front of the building. This concept is meant to save valuable parking space, which especially in Chinese cities is becoming increasingly scarce. In September 2013, four of these stations were completed. By late 2014, five were in operation, eight were about to be opened and five more were under construction. In a joint venture between the companies Kandi Technologies and Geely Automotive 750 such facilities will be constructed in the coming years. Similar systems are also being built in other Chinese metropolises, for example in the city of

Fig. 23: *The “Kandi Machine” in Hangzhou (PRC), 2013.*
© Alexander Jung

Nanjing (7.5 million inhabitants), which is currently engaged in negotiations with the joint venture (Brown, 2014).

In 2014, the Hangzhou programme was transferred to Shanghai, where 3,000 to 5,000 electric vehicles are soon to be deployed. The company Zhejiang Zuo Zhong You Electric Vehicle Service (*ZZY*) operates the carsharing venture and is the first provider of a publicly accessible carsharing programme that operates exclusively with electric vehicles (Kandi Technologies, 2014b). In early 2015, a contract was signed with the city of Chengdu, a city in central PRC with a population of 7 million: By the end of 2015, a total of 5,000 electric vehicles are to be delivered for a new carsharing system (Electric Car News, 2015).

With this concept, Wie Gong Jiao has implemented an innovative and hitherto unique approach to solving the issue of parking, a critical problem for carsharing as a whole. In addition, by using electric vehicles, the provider can circumvent the local restrictions on vehicle registration and driving bans and take advantage of government vehicle subsidies for the entire carsharing fleet

On the one hand, there are location-based concepts that reserve a fixed parking place for a vehicle, where it must be parked and connected again after use. The Chinese company Kandi, for example, offers such a concept in Chinese cities. On the other hand, electric vehicles are increasingly being used in so-called flexible carsharing concepts. In this scenario, a vehicle fleet operates freely in a service area, *i.e.* without fixed parking places and without an obligation to return the vehicle to the pick-up point (one-way). If the charge level falls below the minimum, charging takes place either by the customer at a public charging station or by a service team, either within the public charging infrastructure or at the customer's own charging point. The carsharing providers ***car2go***, ***DriveNow*** and ***Multicity*** offer electric vehicles at dedicated stations as well as for flexible use ("free-floating carsharing"), both in Germany and in some other European and North American cities. Combined concepts are also conceivable, *i.e.* the possibility of using carsharing vehicles between fixed stations, so that the vehicle does not have to be brought back to its original pick-up location. One example of this is the ***Autolib*** system in Paris (see Figures 24a, b; 25 and 26). This ensures high initial charging levels, since as long as the stations are equipped with charging capability, the vehicles can always be connected (if needed the provider grants a "grace period" until the next available station).

Flexible electric carsharing systems in particular make it necessary to develop and expand the local charging infrastructure, which can also be utilised by private vehicle owners. Such systems can provide a wide cross-section of the population with the possibility to become familiar with electric vehicles. Finally, the limited range of electric vehicles has the effect that drivers must fall back on other means of transport when it comes to taking longer trips. In such situations, public transport such as train or long-distance coach can be used or, alternatively, a rental car with an internal

Fig. 24a, b: *Smart fortwo electric drive by car2go in Stuttgart, 2016.* © Mathias Merforth

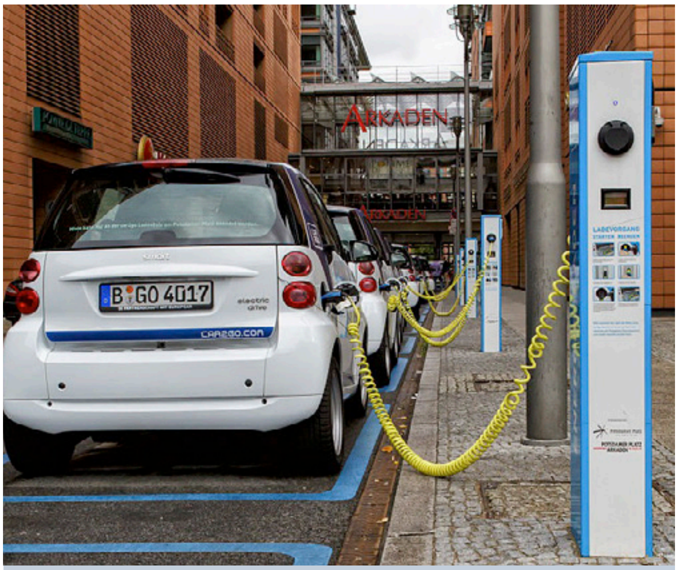

Fig. 25: *Smart fortwo electric drive by car2go in Berlin.*

combustion engine or hybrid drive. Such information is also increasingly being incorporated into the vehicle's electronic information system.

Once other means of transport or mobility services become accepted as an alternative to a privately owned (electric) vehicle, there could be a decline in the use of private cars in the city, even when it comes to driving shorter distances. It is possible that we will see new solutions to the fundamental question of the necessity of owning a car. Carsharing services will mean that an automobile is always available when required. In the everyday transport profile of a carsharing customer, there is often an increasing use of public transport or bicycles (bcs, 2007). Customers who become active in carsharing often use different modes of transport for different trips (multimodal), or even use different modes during the same trip (intermodal). The existence of both innovative sharing concepts and an attractive public transport system is a prerequisite for sustainable mobility and a "stepping stone" of electromobility.

The more vendors and service providers are active on the mobility market and the more offers that are available, the greater the flexibility of the user. At the same time, the growing complexity also makes it more difficult for the user to become informed and to utilise the various offers. The user must collect relevant information from different sources and gain access to the different modes of transport, charging infrastructure and parking areas. If the customer is expected to take on this extensive task of integrating the wide range of information and services, it could prove to have a detrimental effect on user acceptance of carsharing services. It would therefore be beneficial to combine as many interfaces as possible on the supply side, and to develop corresponding partnerships between various service providers as necessary. This would offer the customer a range of service components from one source, including a joint billing component. The existence of a unified system of information, access and payment thus constitutes another success factor on the road to sustainable mobility.

In many places, there are a variety of different systems of information and access, pricing and sales in place, as well as a lack of overall transparency when it comes to travel time, price and comfort. This situation makes it difficult for the user to engage in multi- and intermodal transport behaviour and often brings about excessive transaction costs for the user. The digital linking of information, booking and invoicing systems is beneficial for all user groups. For example, drivers of private electric vehicles can also profit from information on the charging infrastructure, access, parking and transfer possibilities offered by other modes of transport.

In the past two decades, there has been considerable progress in the area of integrated information, access and payment systems of public transport with regard to "shared mobility". This is due, on the one hand, to new technical possibilities. Features such as electronic and contactless smart cards (see Table 2), and increasingly digital solutions in conjunction with smart phones, are now enabling some of the following applications:

- Real-time information processing and networking (*e.g.* via app);
- Paperless verification (using check-in/check-out procedures);
- Situation-specific pricing (such as prepaid and postpaid processes according to best price methods, peak pricing, etc.);
- Cashless billing of user authorisations (by way of e-ticketing/mobile phone ticketing, for example).

These services offer something of a "countermodel" to the non-networked private vehicle. Notably in Asian metropolitan areas, electronic access systems have been

Table 2: Electronic access systems for public transport services, etc. (selection from Asia)

System	City (country)	Main user	Service module	Technology	Starting date	Cards (year)
CEPAS/ EZ-Link	Singapore	Land Transport Authority	Bus, taxi, parking, commuter train, e-payment	CEPAS	2002	
COMMET	Jakarta (Indonesia)	KA Commuter Jabodetabek	Bus, train	FeliCa	2013	
easycard	Taipei (Taiwan) *et al.,*	Taipei Metro	Bus, metro, e-payment, parking	MIFARE	2002	23 million (2010)
MoreCard	Delhi, Mum-bai, Jaipur (India)	Jaipur City Trans-port *et al.,*	Bus, train (in planning: ferry, toll, parking, taxi)		2012	
Nagasaki Smart Card	Nagasaki (Japan)	Nagasaki Electric Tramway	Bus, tram	FeliCa	2002	320,000 (2005)
Octopus	Hong Kong (PRC)	MTR Corporation	Bus, underground, train, e-payment, parking	FeliCa, NFC	1997	24 million (2006)
PASPY	Hiroshima (Japan)	Hiroshima Electric Railway u. A.	Bus, train, ferry	FeliCa	2008	
Shenzhen Tong	Shenzhen (VR China)		Bus, metro, taxi, e-payment	Time COSFLY/ RFID-SIM	2004	3 million (2008)
SPASS card	Dhaka (Bangladesh)	Bangladesh Road Trans-port Corp.	Bus	FeliCa		
Suica	Tokyo region *et al.,* (Japan)		Commuter train, e-payment	FeliCa (also mobile)	2001	30 million (2009)
STPC	Shanghai (PRC)	Shanghai Pub. Transport	Bus, metro, ferry, taxi, e-payment	FeliCa	1999	
Touch 'n Go	Malaysia		Public transport, road tolls	MIFARE	1997	
Yang Cheng Tong	Guangzhou (PRC)	Guangzhou Metro Corp. *et al.,*	Bus, metro, ferry, taxi, parking, e-payment		2001	5 million
Yikatong	Beijing (PRC)	Beijing Municipal Adm.	Bus, subway, taxi, bike sharing, e-payment	MIFARE	2003	42 million (2011)

Source: Own data, AECOM 2011 *et al.,*

used for years and are becoming increasingly widespread. Although the focus here is for the most part on public transport offers (smart ticketing), electronic interfaces also offer ideal starting points for additional services, both within and beyond the mobility sector. Not least, electronic access systems also offer state authorities and local government the possibility to influence the development of electromobility in their respective area of responsibility. For example, it is possible to link mobility service user cards/user applications with a local toll or parking management system, granting privileged terms to users of electric vehicles. Information on the type of propulsion system, provided via card or app, can serve as legitimation to use certain traffic areas, stopping bays or parking spaces.

Standards must be defined as the diverse stakeholders are brought together and the information interfaces are developed. This can entail considerable administrative effort and costs. An example is the Indian ***MoreCard*** that is currently being developed; at the same time, existing applications from Delhi, Mumbai and Jaipur are being expanded, so that a standard for all of India will be established, and will ultimately cover ferries, taxis, parking, toll and paratransit services (India Today, 2011). Based on the data collected, Internet and smart phone based services will have the potential to establish new customer interfaces and make changes to the value creation chains. This presents both opportunities and risks for all stakeholders, since such a process also raises questions about distribution power, *i.e.* about who controls the customer interface. There is a real risk that established suppliers could lose this control as a result of newly developed distribution paths, thus becoming direct service suppliers instead. On the whole, however, it is important to keep in mind the chance that this development presents, namely that in the context of increasing digitalisation, there will emerge a large number of new applications and business opportunities.

In conclusion, the following can be said: The internal combustion engine and the electric propulsion system represent different mobility concepts that are, however, not mutually exclusive. Most experts are in agreement that, at least in the near future, the electrification of propulsion components will increase while the internal combustion engine will continue to be used. The objective of this hybridisation is to increase efficiency levels (fuel consumption/CO_2 emissions). Hybrid vehicles are characterised by the combination of two drive concepts: Combustion engine and electric motor with energy storage unit (battery). There are various possible combinations: From micro-hybrids with start-stop function and electrified auxiliary units, to mild hybrids with so-called torque assist during acceleration as well as energy recuperation from braking (***Toyota Prius***), to full hybrids that can switch to all-electric operation for shorter or longer distances. As a rule, highly "hybridised" passenger cars consume up to 25 % less fuel. A similar concept is pursued with vehicles equipped with range extenders (REEV), which operate electrically for the most part, and engage the combustion engine only to achieve an increase in range (***BMW i3 plus, Opel Ampera/ GM Volt***). The present study focuses only on those vehicles that can be externally supplied with electric energy and that can travel short or long distances on a purely electric basis. Such vehicles are referred to as plug-in hybrid vehicles (PHV or PHEV).

Fig. 26: *Smart fortwo electric drive by car2go, Stuttgart, 2016.*
© Mathias Merforth

4. Motivations of Promoting Electromobility

Electrically powered modes of transport can, with appropriate support, be used even in otherwise unfavourable cost situations. This is the case, for example, if comparable internal combustion vehicles are not permitted due to regulatory intervention – such as is the case with the ban on conventionally-powered scooters in many Chinese cities. Relevant tax provisions or disadvantages in the use of road lanes and parking spaces, for example, can also make electric modes of transport more attractive than conventional vehicles (see Figure 27).

In all likelihood, it will still require many years of government support in order to firmly establish electromobility for everyday purposes.

At national level, different motivations in the support of electromobility can be identified, and these usually exist in combination with each other. The next section will examine the following five motivations:

- Reduction of economic and political dependency (raw material imports);
- Contribution to international and national environmental protection (climate targets);
- Reduction of local environmental impact (air pollution and noise);
- Development and expansion of competitive advantages (automobile manufacturing, battery technology);
- Electromobility as a starting point for a systemic transformation (networking).

The effects of the measures unfold at various administrative levels (international, national and regional). These supraregional targets are easier to achieve if integrated into the plans and programmes of city governments. Taking into account the necessary purchasing power, infrastructure needs, and last but not least the urgency of the problem at hand, electromobility will initially prevail in the most populous and densely developed of urban areas. Even there, however, the promotion of electromobility is most promising if it supports the local needs of the cities where it is implemented. The local government authorities, by providing spatial and infrastructure planning, financial incentives and regulatory and informal parameters, set the framework in which electromobility is even able to develop in the urban environment. Ultimately it is the overall package,

Fig. 27: *Reference to public charger, Paris, 2007.*
© Andrea Broaddus

i.e. a well-balanced mix of measures, which determines the success or failure of sustainable mobility in general, and of electromobility in particular. The following section will introduce various motivations, also taking into account the situations in emerging and developing economies in Asia. In practice, specific motives tend to overlap and country-specific and city-specific characteristics often develop, which we will illustrate by way of example.

4.1 Reduction of economic and political dependency (raw material imports)

One possible motivation for the promotion of electromobility is the high dependency of the transport sector on oil. In the long term, a reduction of dependency on fossil fuel imports is achieved by the increased use of electric propulsion systems in traffic and the charging of these systems with self-generated, regenerative electricity. Both in industrialised countries and in many emerging and developing economies, in particular cities, electricity networks are for the most part already in existence. Therefore, at least for battery electric vehicles, no fundamentally new infrastructure must be built. Japan, which has few natural resources, is interested in decreasing its dependency on oil, and the country has for years been exploring possibilities of energy savings and of using fossil-free energy sources. This is one of the reasons why the development and market launch of hybrid and electric vehicles has been consistently pursued in Japan. The electricity used to power electromobility can be generated from different sources and, given corresponding national production possibilities, helps to reduce the dependency on fossil fuel imports. In the process, the expansion of additional renewable energy capacities plays an important role.

From a climate policy standpoint, it therefore seems promising to give countries that already have a relatively high share of renewable energy in their electricity mix a priority when it comes to electromobility projects. In Asia, some of the more promising countries include Armenia, Bhutan, Georgia, Kyrgyzstan, Tajikistan (> 500 kW of power generation per 1,000 residents and over 30 % hydropower) as well as Laos and Sri Lanka (> 100 kW of power generation per 1,000 residents and over 50 % hydropower) (Schiffer, 2015). If fossil fuels remain the predominant source of energy for electric vehicles, such as is the case in the People's Republic of China, electric cars will have a negative CO_2 balance compared to petrol and diesel operated vehicles.

Replacing large numbers of conventional vehicles with electric vehicles leads only to a moderate increase in electricity consumption; in Germany, for example, if all passenger cars were to be operated with electricity, the required volume of electricity would increase by around 16 % (Wüst, 2008). For the countries of Latin America, renewable energy is becoming increasingly important as the energy supply system on the whole is being expanded and diversified. Already, hydropower makes up a significant share of the energy used for electricity generation. In several South American countries, it accounts for the highest share of electricity generation capacity (Brazil 69.6 %, Colombia 67.5 %). But other forms of regenerative electricity production also have a great potential for expansion in Latin America. In Chile, for example, substantial investments have recently been made in solar power — a development that is also occurring in Mexico. Over the next five years in Latin America (including the Caribbean), new solar power installations are expected to total nine gigawatts in capacity.

The driving markets are in particular Brazil, Chile and Mexico. The overall PV capacity of all projects in the pipeline across the region is over 22 gigawatts (GW). In Brazil, a greater diversification of the energy supply system is planned, based on the increased exploitation of wind power (Deutsche Welle). In Argentina as well, where electricity generation from renewable energy sources (not including hydropower) only makes up approximately one %, there is an enormous potential for electricity from the sun and wind. By the year 2016, under the Argentinean Renewable Energy Law, the share is to increase to eight %. For countries that already have large shares of CO_2-free electricity generation through hydropower (such as Brazil and Colombia), electromobility is already a sustainable alternative for propulsion technology. In other countries with a relatively high share of fossil fuels in electricity generation (including Argentina and Chile), efforts should initially be focused on creating a solid renewable energy foundation (including increasing the yield from solar and wind power).

The development of electromobility thus does not seriously threaten the regenerative orientation of electricity production. On the contrary, electromobility could be another way to prove the sustainability of such an energy policy. This could provide a subsequent motivation for countries with high dependency on energy imports to promote renewable energy policies. This would eventually also make them candidates for the broad introduction of electromobility on a sustainable basis.

Hybrid vehicles, plug-in hybrids and all-electric passenger cars, however, require special parts and components and a variety of exotic raw materials such as neodymium and praseodymium, dysprosium and terbium, gallium and germanium. Many of these elements f can be subsumed under the term “rare earths”. Only a few countries in the world extract these raw materials; just a few years ago there was a widespread fear that the supply of these resources for the mass production of large vehicle batteries could in the medium term lead to a dependency on these countries. The People's Republic of China holds 40 % of the known reserves of rare earths, the U.S. 13 % and the countries of the former Soviet Union 20 %. Since many countries did not mine rare earths until recently, nearly 97 % of these deposits come from Chinese mines. After the country established a market dominant position in this area, it restricted exports again in 2010. Demand continued to increase, however, and with it the price. Since summer 2010, prices for certain rare earths have increased 10- to 15-fold within a period of one year (Leuphana Universität, 2013; Öko-Institut, 2011, p. 39).

Since then, however, the United States and Australia have begun mining rare earths, and large-scale efforts to recycle rare earths from batteries have also begun. As a result, prices for rare earths fell. At the same time new materials were found to replace rare earths so that demand declined. In early 2015, the Government of the People's Republic of China decided to lift the export restrictions on rare earths. Currently there are no unilateral dependencies, and at least in the medium term, no unilateral dependencies on one or on a small number of exporting countries in the area of battery manufacturing are to be expected (Sorge, 2014).

4.2 Contribution to (inter-)national environmental protection (climate targets)

The high level of energy efficiency associated with electromobility when combined with decentralised, regenerative electricity production offers considerable potential for reducing transport-related greenhouse gases, as long as the electricity supply is based on renewable energy. Unlike other economic sectors, the contribution of motorised traffic to climate protection has in the past been minimal or even negative due to the significant growth rates of motor vehicle transport and the dependence of the transport sector on oil. For this reason particular efforts should be made in this sector, so that by switching energy sources the internationally adopted "2-degree target" (*i.e.* the restricting of global warming to below two degrees Celsius) can be achieved. In Paris, the "COP 21 Declaration" recently lowered the target to 1.5 degrees.

The emerging economies of Asia and Latin America, where population and economic growth is significant and motorisation is in its early phases and catching up to that in other countries, play a key role in this process. However, whether or not an electric passenger car or a conventionally powered car is the superior form of individual motorisation from a climate protection standpoint requires more in-depth and long-term analysis across the entire life cycle.

4.2.1 Driving-related CO_2 emissions

If in a first stage, only energy-related CO_2 emissions in vehicle operations (tank-to-wheel) are considered, an electric vehicle is superior to a vehicle with an internal combustion engine. If one includes the CO_2 emissions that come about in the production of petrol/diesel fuel or electricity (well-to-tank), one arrives at the total amount of CO_2 emissions generated from fuel production and vehicle operations (well-to-wheel). A significant amount of CO_2 emissions is produced in the extraction of fossil fuels. Much of the electricity used to power electric engines is produced in power plants that also transform electric power by way of thermal energy – which also leads to corresponding transmission and efficiency losses in the supply chain. If that thermal energy is generated by fossil fuels, it produces considerable CO_2 emissions. In the well-to-well assessment, the difference between the internal combustion engine and the electric motor is thus much less pronounced. The environmental benefits of electric vehicles are therefore crucially determined by the method of electricity production (finite or renewable energy sources). However, an electric vehicle has the potential – depending on the electricity mix that it is powered by – to emit significantly less CO_2 than a vehicle with a conventional combustion engine.

4.2.2 Vehicle production and disposal

If the comparison between conventional and electric vehicles takes not only the CO_2 emissions for the propulsion system into account, but also the environmental effects of the production and disposal of the vehicle, the result is yet again different: The production of a conventional vehicle with an average weight of around 1.5 tonnes consumes around 70 tonnes of resources.

Alone the production process of passenger cars, depending on vehicle performance over the entire utilisation period, accounts for between 15 and 20 % of all CO_2 emissions. The mass production of vehicle batteries can lead

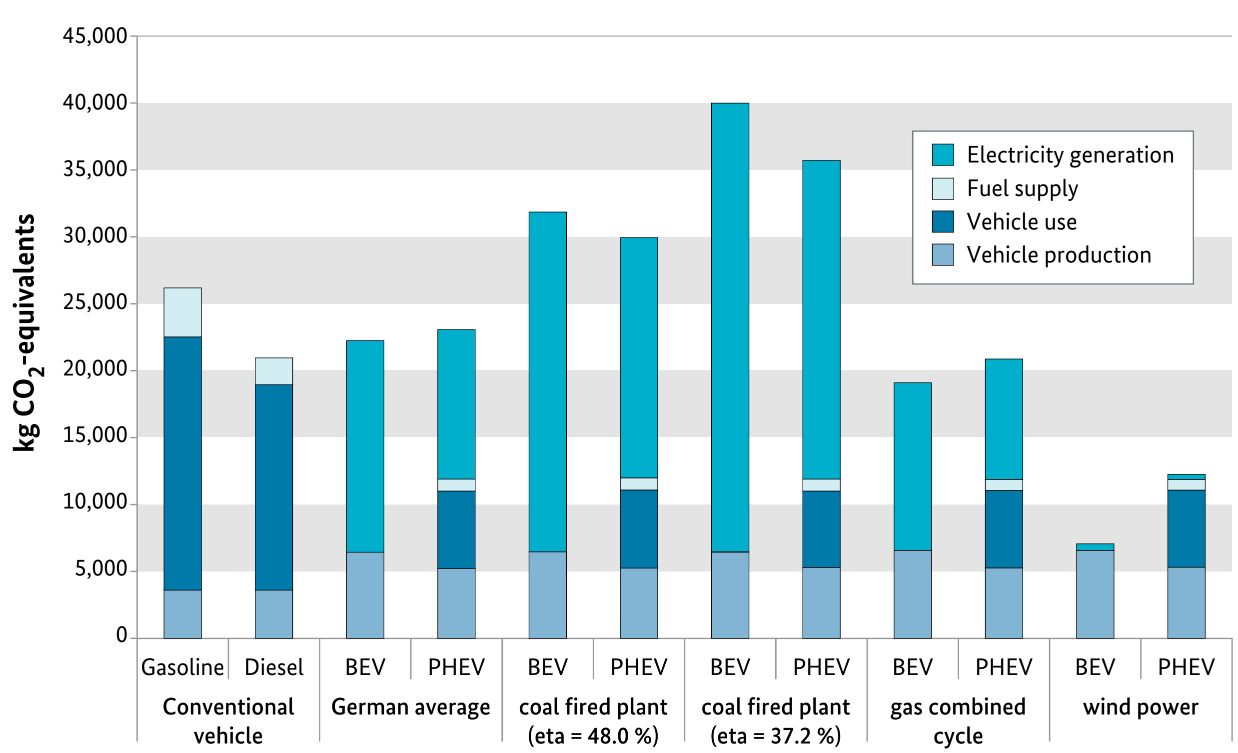

Fig. 28: *Comparison of the CO_2 footprint of passenger cars with different propulsion systems.* Source: ifeu, 2010

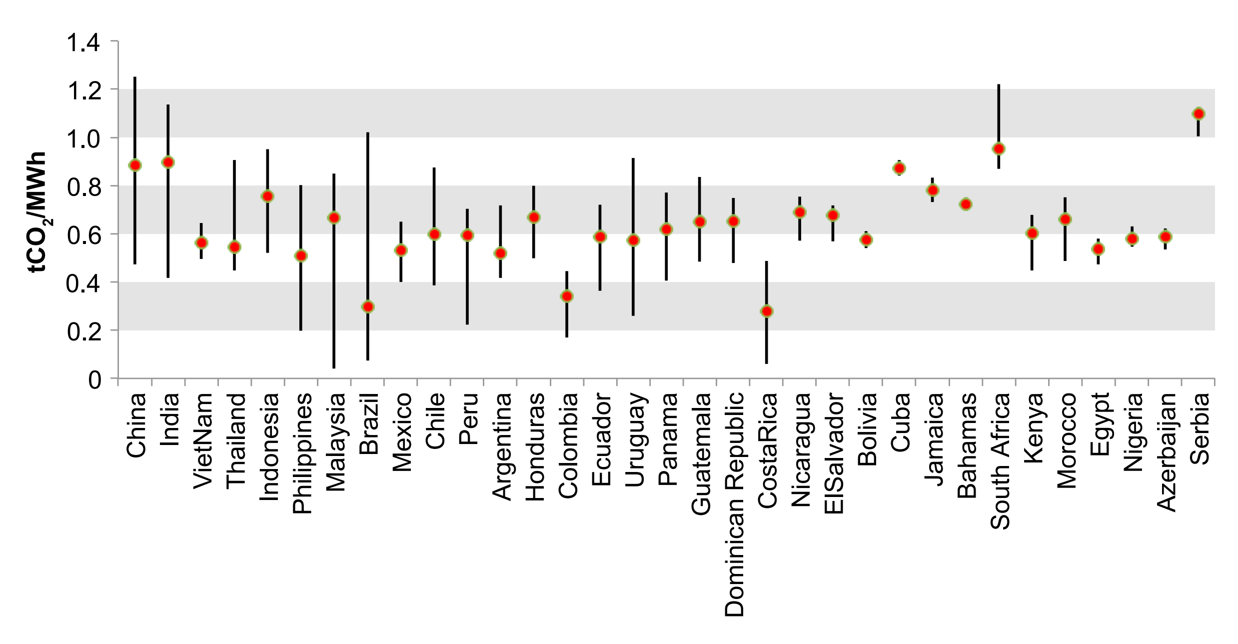

Fig. 29: *Grid Emission factors.* Source: IGES database of Grid Emission factors

to considerable environmental problems because their high-performance accumulators mainly use lithium, a metal whose extraction can cause significant harm to the environment. As a result, regardless of the dimensioning of the vehicle battery systems, the manufacturing of electric vehicles can in the worst case have an eco-balance that is twice as harmful as the manufacturing of conventional vehicles. Taking into account the entire life cycle of an electric vehicle, the manufacturing process today accounts for over 30 % of its environmental impact. This is based on the assumption that the lifespan of an average passenger car requires 1.5 batteries and produces nearly 11 tonnes of greenhouse emissions. In this case, the environmental impact of an electric vehicle is twice as high as that of a conventionally powered vehicle, which produces around six tonnes of greenhouse emissions. Vehicle disposal and maintenance, by contrast, play only a minor role (emobil-umwelt.de, 2015) (see Figure 28).

4.2.3 Electricity mix

Increasing electrification of transport is one of the main entry points for increasing the share of renewable energy in the sector; however, for electric vehicles, it is important to consider how the electricity is generated (and in addition, to consider the proximity of these emissions to populated areas). For example, considering that the GHG intensity of a typical coal-based power plant is about 1gCO_2/MWh at the outlet for a battery-electric vehicle with an efficiency of 200 Wh/km, this would equal vehicle emissions of about 200 gCO_2e/km, which is higher than for a hybrid light duty vehicle (Slocat, Renewable energy and transport – Decarbonising Fuel in the Transport Sector, 2015)

Figure 29 shows the variation in grid emission factors for different countries (23). Countries that have large hydropower capacity (*e.g.* Costa Rica, Colombia or Brazil) will have relatively clean electricity, while countries with coal-based electricity generation will produce electricity with higher embedded CO_2 emissions (*e.g.* South Africa, Serbia).

The negative environmental effects of battery production, however, can be overcompensated if the charging electricity mix stems from renewable energy sources and if the vehicle gets good mileage. An undifferentiated and widespread substitution of conventional vehicles with electric vehicles is not necessarily advantageous, at least from the point of view of the eco-balance across the entire life cycle. Firstly, electromobility requires the development and implementation of additional regenerative electricity capacity. The more regenerative the electricity mix, the better the eco-balance. If an electric vehicle were to use 100 % green electricity, the added environmental impact from the battery manufacturing, compared to a conventional passenger car operating on fossil fuel, would be compensated after around 30,000 km (ifeu, 2010). The less "favourable" the electricity mix, the higher the mileage of an electric vehicle must be in order to achieve a positive overall effect.

4.2.4 Vehicle use

To what extent electric vehicles can achieve high performance, or a performance comparable to that of conventional vehicles, requires a more detailed examination of possible forms of vehicle usage against the background of the restrictions associated with electromobility. The lowest fuel consumption and thus the optimal energy level of an automobile with an internal combustion engine per 100 km is achieved at an average speed of between 70 km/h and 110 km/h in the highest gear. Higher speeds bring about a steep increase in energy consumption as a result of the greater air resistance. Below this optimum level, the engine is used in the so-called partial load operational range, which results in lower performance and higher consumption. Electric vehicles are therefore particularly well suited for use in urban traffic environments with high mileage as well as for regular commuter trips between 30 and 50 km per route. In such usage scenarios, electric vehicles could make an important contribution to reducing urban emissions and noise levels, since the electric motor has considerable advantages over the internal combustion engine in particular when it comes to urban use. The additional greenhouse gas emissions from battery production can be compensated starting at an operational mileage of around 50,000 km and an electricity mix of about 40 % of CO_2-free energy sources. Based on an average, mixed vehicle usage (city, overland and motorway driving), this would be the case only after 90,000 to 100,000 km. A city BEV has an advantage over a diesel passenger car starting at around 100,000 km (ecomobil-umwelt, 2015). Average daily mileage levels show that electromobility pays off in particular for commuters living in the environs of medium- to large-sized cities, as well as for commercial users such as couriers or nursing service staff. Despite these potential benefits for certain user groups, drivers normally want their vehicles to have a high range, even if this often has only a psychological effect. The question therefore is whether, when it comes to deciding what kind of vehicle to purchase, the buyer will consider an electrically powered vehicle if no additional advantages exist or are generated.

4.3 Reduction of local environmental impacts (air pollution and noise)

Another key objective in the implementation of electromobility is to maximise its local environmental benefits, *i.e.* the absence of local air pollution and noise emissions. An electric motor emits no exhaust whatsoever, which means that in particular in urban areas, electromobility can reduce the typical emissions of nitrogen oxides, particulate matter, etc. and improve air quality and the health of local residents. Provided that the electricity is not generated from emissions-intensive fossil sources close to where the electric vehicles are in use, it can be assumed that the substitution of conventionally operated vehicles with electric vehicles results in an improvement of local air quality. The typical vehicle engine noise is also absent. Electric scooters, passenger cars and buses have lower noise emissions, particularly when they are operated at lower speeds. The noise reduction effect achieved with electric vehicles is particularly pronounced in slow stop-and-go traffic, as the noise caused by the acceleration of conventional engines is eliminated. This is another argument in support of using electric vehicles in densely populated urban and suburban areas. For this reason, the promotion of electromobility may even be advantageous for countries without a "clean" electricity mix.

Furthermore, electrically operated modes of transport can open up additional mobility options. The fact that the electric motor is very robust, requires little maintenance and has a relatively long service life makes it superior to the internal combustion engine particularly in regions with little infrastructure. And even in places where conventional vehicles are not (or no longer) welcome, electric vehicles can provide additional advantages. With little cost and effort, electric bicycles can be used to cover longer distances, even in hilly terrain. Electric cargo bikes as well as vans and light lorries enable pollution-free transport and a non-invasive delivery service (*e.g.* in restricted zones or time periods). Especially in cities with emissions-related traffic restrictions, exceptions for electric vehicles could create a significant incentive for their purchase, not only due to private, but also due to commercial considerations (electric transporters). Electric scooters are ideal for flexible, long-distance travel, also in areas without public transport availability or in cities where the public transport system is often overcrowded.

4.4 Development and expansion of competitive advantages (automobile manufacturing, battery technology)

Particularly for those countries with their own vehicle manufacturing industry (scooters, bicycles, and also automobiles), there is yet another reason to support electromobility. Industrial policy motives can justify the early development of industrial structures and the institution of market stimulating measures in the area of electromobility. It may therefore be advisable to gain experience with electromobility at an early stage in order to achieve economies of scale in the near future that can lead to or help build a strong international market position. Such a strategy makes particular sense for the People's Republic of China and India. Because the manufacturing of electric vehicles is built around different industries and new value creation and production chains (compared to conventional vehicle manufacturing), these countries have the opportunity to overcome the advantage of established vehicle manufacturers in the early industrialised countries and become new technological leaders at an early stage. However, this requires the systematic development of expertise in the areas of research and development, training and further qualification measures as well as maintenance and service. This also allows emerging economies to develop long-term sales and export opportunities in foreign markets. Less beneficial, on the other hand, are strategies that aim only at short-term and symbolic success, for example through the purchasing of components or the recruiting of experts from abroad to facilitate the creation of "home-grown" prototypes. In addition, the traditional industry locations with strong automotive industries have also recognised this development and have set corresponding market targets.

4.5 Electromobility as a starting point for a systemic transformation (networking)

Electromobility can mean more than just the vehicle propulsion system. It is first and foremost a vision of a new world of transportation that is networked and sustainable. Electromobility can help to overcome old ways of thinking and open up new planning horizons for cities (see Figure 30).

Steady progress in the electrification of the central modes of transport (cars, bicycles, buses, lorries) leads to expansion of the urban charging infrastructure, which becomes an essential component of the urban infrastructure. Users of electromobility will develop a different mobility behaviour compared to drivers of internal combustion vehicles. They will choose to drive in a more efficient and environmentally friendly way so that they can drive as long as possible with a limited battery capacity, using electricity produced from regenerative sources whenever possible. The range limitation of the electric vehicle will continue to make it necessary for the user to incorporate alternative forms of transport (in addition to the car) into his/her transportation mix. This will encourage intermodality and multimodality, *i.e.* the inclusive use of different modes of transport in the form of mixed travel routes or alternating transport decisions.

The higher acquisition cost of electric vehicles also increases the appeal of carsharing models, which save space and increase capacity utilisation. We can expect to see the development of integrated systems of public transport, including new mobility services, which are likely to include electric vehicle based carsharing and later possibly autonomous electric vehicle fleets that will supplement the public transport system. Low or zero-emission zones and environmentally friendly areas will become more prevalent, and these will gradually change the urban transport system and shape the urban experience (Kim/Park, 2012).

As this process unfolds, the expansion of regenerative energy production should be coupled with the dissemination of the electric propulsion system. In the medium term, a convergence between the transport and energy infrastructures could come about. Public electric vehicle fleets can also be used to stabilise an expanding system of regenerative energy supply. In this case, controlled vehicle charging can be used to supply electricity to the grid in periods of energy scarcity.

In conclusion it can be said that there are generally a wide range of motivations behind the promotion of electromobility. It is questionable, however, to promote electromobility based on environmental objectives, without the ability to utilise sufficient supplies of regenerative electricity in the respective country.

Fig. 30: *Electric Bus in Seoul, 2014.* © Nikola Medimorec

5. Different Approaches in the Promotion of Electromobility

The market for electric vehicles is growing. In 2011, around 45,000 (partly) electric vehicles were sold worldwide: In 2012 around 113,000 units were sold, in 2013 around 200,000 and in 2014 around 300,000 (ZSW, 2015). The total number of electric passenger cars in operation around the world is estimated at over 665,000. For the year 2015, global sales of electric vehicles are expected to surpass 1 million units. Currently, most of the vehicles sold are hybrids and plug-in hybrids, while only very few pure BEVs are sold. The robust increase in volume that can be observed is attributable to factors such as new models, a large number of manufacturers, and significant cost reductions for batteries and other components. Nevertheless, the existing stock of electric vehicles accounts for only a fraction of the global vehicle stock.

A number of governments have set expansion targets for electromobility (see Table 3). In particular in countries with their own automobile industries, there are volume targets for electric passenger cars which are supported in a range of different ways. Due to the major influence that government funding has on value creation in the electromobility sector, corresponding programmes and initiatives significantly affect local value creation. Around the world, different measures such as purchase premiums, procurement rules for public vehicle fleets, tax reductions, shorter depreciation periods for electric vehicles, and also stricter pollution and CO_2 emissions limits for internal combustion engines are used in various combinations in the promotion of electromobility.

The different funding support and regulatory frameworks also mean that manufacturers sometimes vary their model planning according to the different sales regions of Europe, Asia and America, which can make it difficult to develop electric vehicle models in significant quantities for a global market (Roland Berger, 2015a). Furthermore, the heterogeneous framework conditions in the promotion of electromobility lead to differing technological advancements, production volumes and sales volumes of electric vehicles in individual countries.

On the one hand, countries such as Norway, where electric vehicles make up over one % of the total vehicle stock, and also the Netherlands, the United States (in particular California) and Sweden, are considered relatively successful in the promotion of electromobility (see Figure 31). On the other hand, in the 3rd quarter of 2014, electrically powered passenger cars made up less than one % of fleet shares in key automobile markets (France: 0.79 %, Japan: 0.73 %, United States: 0.7 %, Germany: 0.35 %, PRC: 0.13 %, South Korea: 0.09 %) (Roland Berger, 2014b).

The consultancy firm Roland Berger regularly monitors various countries that are taking a leading role in

Table 3: Promotion of automotive electromobility by international comparison

Country	Cumulative sales target for electric vehicles by 2020	% of global sales	Sales premiums	Priority provisions for procurement of public fleets	Motor vehicle tax relief
P. R. China	5.0m	19 %	X	X	
Germany	1.0m	4 %			X
India	6.0–7.0m	n. d.	X	n. d.	n. d.
Japan	0.8m	11 %	X	X	X
South Korea	0.2m	n. d.	X	n. d.	n. d.
U. S. A.	1.0m	38 %	X	X	X

Source: Christian Hochfeld (GIZ), 2015

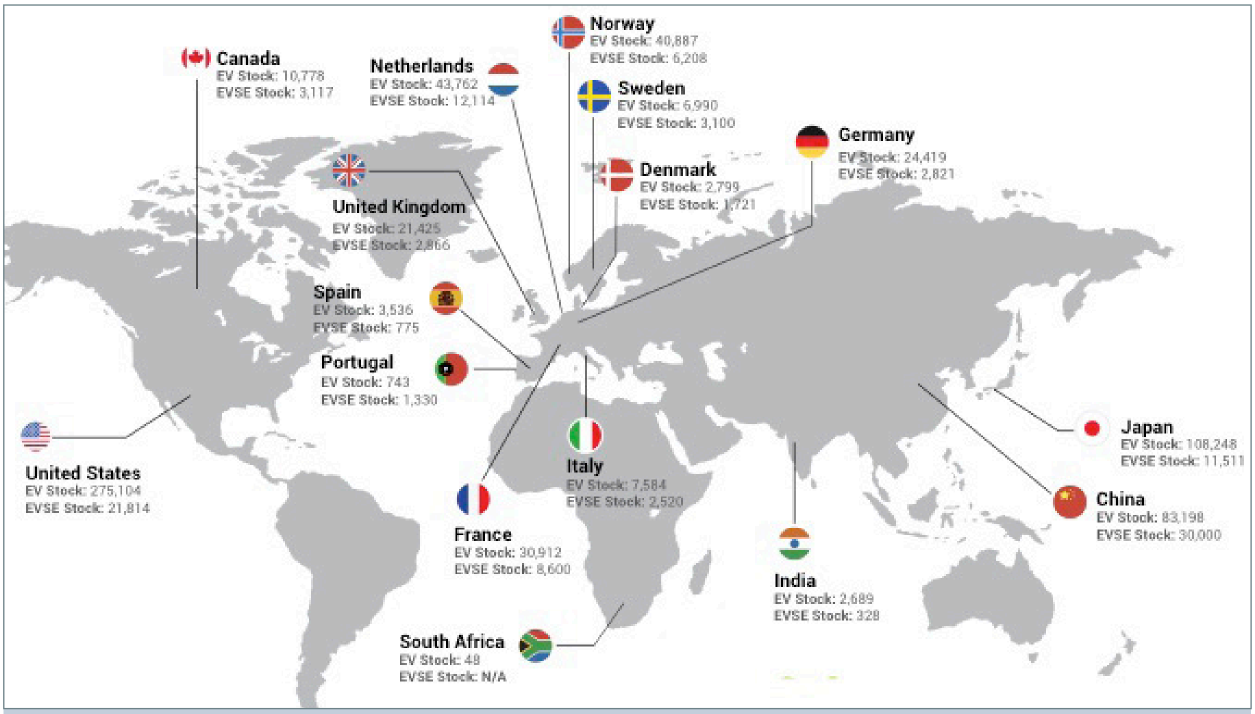

Fig. 31: *Stock of electric vehicles and charging points 2014.* Source: EV Outlook, 2015; International Energy Agency, 2015

electromobility (automobile manufacturing as well as cell production). In the process, it identifies factors such as national industry position (national value creation of production of electric vehicles and cells), technology (technological performance of vehicles and government support for research and development) as well as the size of the national market, and ranks the most important countries in the electromobility sector according to several ranking standards (see Figure 32). Three of the seven leading nations are currently in Asia: Japan, the People's Republic of China and South Korea. Japan is presently in the top position (Roland Berger, 2015).

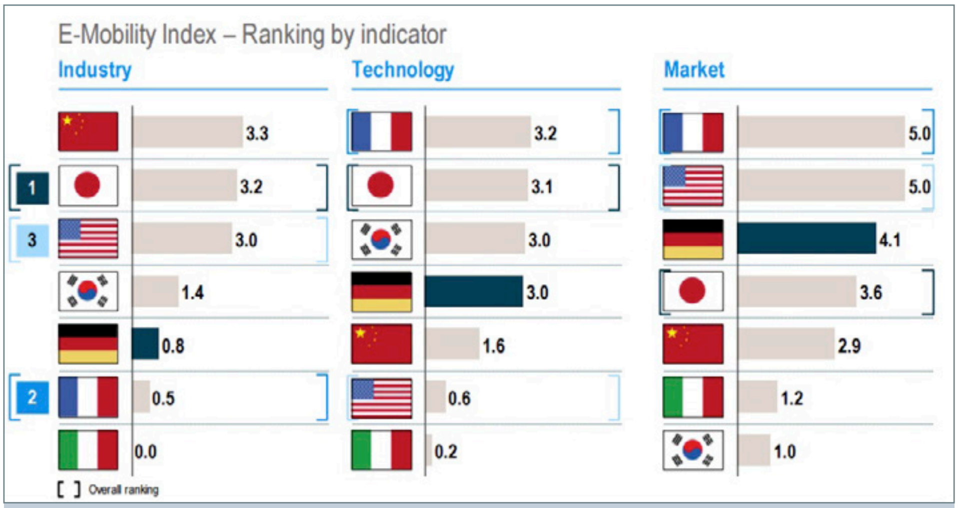

Fig. 32: *Ranking of leading electromobility nations.* Source: Roland Berger, 2015

One of the central challenges is the high acquisition cost of an electric vehicle, which particularly in emerging and developing economies means that private electric cars only come under consideration for the upper classes. The Mexican government supports the purchase of electric vehicles with an exemption from new vehicle tax. In addition, a special electricity meter was developed for owners of electric vehicles, enabling them to pay a lower tariff for charge current. Furthermore, electric vehicles are exempted from the usual driving restrictions in Mexico City, which limit how many days cars can drive per week (the so-called “Hoy No Circula” programme). In 2015 there were an estimated 200 electric vehicles on the road in Mexico. There are around 150 public charging stations, most of them located in the country’s metropolitan areas.

In Brazil, electromobility is in fierce competition with the ethanol propulsion system. Plant-based ethanol has long been used in Brazil as an energy source for the transport sector. While buyers of hybrid vehicles must only pay a reduced import tax, all-electric vehicles are not eligible for the reduction. Electric vehicles are, however, exempted from the motor vehicle tax in several Brazilian states. While there are currently only around 50 public charging stations in the country, there are around 3,000 small EVs and commercial EVs in use (Marchán/Viscidi, 2015).

The following section will analyse different Asian countries with regard to their promotion of electromobility and look at selected examples of electromobility applications.

5.1 Japan

Japan is a high-technology, densely populated country with no notable natural resources of its own. This is why the government wants to continue to reduce its dependency on oil imports in particular. Japan is the country with the highest vehicle density in Asia, with nearly 600 motor vehicles (not including two-wheelers) per 1,000 inhabitants and 453 passenger cars per 1,000 inhabitants. Considerable efforts are therefore being made for optimisation and efficiency improvements, particularly in the transport sector. Technical solutions are being explored to employ alternative energy, increase energy efficiency and further reduce environmental impacts. Electromobility has a high potential in Japan and has been receiving steady political support for many years.

Japan is considered to be the leader in the area of cell technology. In the early 1990s, it was the company Sony that launched Li-ion battery technology for electronic

Infobox 7: The Japanese vehicle model Nissan Leaf

The ***Nissan Leaf*** first went public in August 2009 and was the first mass-produced electric car designed from the start with an electric propulsion system in mind, rather than being retrofitted with an electric drive after production. The ***Leaf*** was the world’s best selling electric vehicle in 2014.

The success of this vehicle is the result of a long history that began in the year 1947 with the electric compact car Tama, produced by the Prince Motor Company, which later merged with Nissan. Starting in 1970, Nissan introduced several electric vehicles. In the 1990s, the company began cooperation with Sony in order to build a series production electric vehicle incorporating the lithium-ion battery developed by Sony. Approximately 30 ***Prairie*** series models were converted to ***Prairie EVs***. Other models followed, which in subsequent years were produced in small series. In the early 2000s, Nissan continued to develop the battery technology together with the company NEC, in order to manufacture Li-ion batteries in a new form that would be able to store twice as much energy in the same size battery. With the advancement of battery technology, which was further accelerated in particular with the rise of mobile telephones, new concept vehicles were developed, such as the ***Pivo*** (2005), ***Mixim*** (2007) and ***Nuvu*** (2008), before the ***Leaf***, which was based on these predecessor models, was released as a series model in 2009 (Saving-volt, 2015)

Fig. 33: *Taxi in Thimphu, Bhutan, 2016.*
© Manfred Breithaupt

devices. At the time, the Japanese Ministry of Economy, Trade and Industry (METI) began to support the development of traction batteries based on this technology (Shimizu, 2013). This gave Japanese companies a technological advantage in the area of cell production which they still enjoy today; Japanese manufacturers such as Panasonic, Sanyo, GS Yuasa, Toshiba and NEC are market leaders in the area of automobile batteries. Roland Berger estimates that by the year 2016, Japan will account for around 60 % of global battery cell production, followed by South Korea with approximately 16 %.

Against this background it is hardly surprising that the Japanese company Panasonic, together with Tesla Motors, is building the so-called "gigafactory" in the United States. By the year 2020, this factory is to produce lithium-ion cells and battery packs for use in electric vehicles at a price approximately 30 % lower than current levels. According to Tesla Motors, the plant will produce battery packs for around 500,000 electric vehicles per year.

Japan is also a leader in vehicle technology and an important production location for electric vehicles (see Infobox 7). In the manufacture of electric road vehicles, the Japanese automobile industry sets new standards for the global development of electromobility. The country is also a leader in the area of hybrid vehicles (especially since 1997 on account of the ***Toyota Prius***), and also of plug-in hybrid vehicles (***Toyota Prius PHEV, Honda Accord PHEV***). Japanese automobile manufacturers also offer a strong range of BEVs (including the ***Nissan Leaf, Mitsubishi i-MIEV***).

Purchase incentives, a good publicly accessible charging infrastructure and a well developed high-speed rail system have led to a high degree of acceptance for electromobility in Japan. Today, electric vehicles are very popular in Japan, and many (partly) electric vehicles can be seen driving on Japanese streets. However, due to the lack of space for parking – in the year 2013 there were only 580 public car parks for every 10,000 passenger cars – private electric vehicles are hardly found in major cities; instead, they are more common in rural regions, where they are used as a transportation link to railway connections. On the other hand, companies often use electric vehicles in cities, since these are better suited than cars with internal combustion engines for use in densely populated areas. In cities, carsharing enjoys increasing popularity. In 2013, there were around 290,000 registered carsharing users in Japan and over 8,800 registered carsharing vehicles. Electric vehicles are increasingly being deployed here (Bierau *et al.*, 2014).

Infobox 8: The Ha:mo mobility concept

The ***Ha:mo*** mobility concept developed by the Japanese company Toyota is an example of how electric vehicles can be used in carsharing, and is an expression of a holistic, integrated approach to electromobility. ***Ha:mo*** stands for "harmonious mobility", and the concept is designed to provide optimal mobility options based on real-time transport information, while also incorporating public transport services. Users have access to Toyota's ***i-Road***, a three-wheeled two-seat mini electric vehicle, with one seat positioned behind the other. The ***Ha:mo*** navigation system promotes the use of transport services, taking into account available current public transport and individual transport options. In this way, intermodal mobility is promoted. An example of an ideal application of this concept is driving by private vehicle from home to a train station, continuing the journey by train, and then using the ***i-Road*** to reach the final destination. Following a successful test with four carsharing stations as of March 2014 in Toyota City, the ***Ha:mo*** concept was put into practice in late 2014 in a test phase in Grenoble (France) with 70 ***i-Road*** vehicles, as well as in Tokyo starting in April 2015.

Following the nuclear disaster in Fukushima in March 2011, Japan also committed itself to using renewable energy and further increasing energy efficiency. Within the framework of a decentralised electricity supply system and a "Smart Community Concept", the batteries of plug-in hybrids and electric vehicles play an important role as buffer storage for locally generated electricity from renewable energy sources. Electricity from the power grid is made available by incorporating the batteries of electric vehicles as buffer storage, *i.e.* as a reservoir for surplus green electricity as well as a source of energy during electricity shortages. The ***Nissan Leaf*** and fuel cell vehicles such as the Toyota ***Mirai*** provide systems with which electricity from the vehicle can be supplied to the household

Infobox 9: The Japanese test field "Goto Islands"

Since 2009, the Nagasaki Prefecture, within the framework of a consortium established specifically for this purpose, has been developing the southern Japanese Goto Islands into an application area and test field for electromobility (Nagasaki Prefecture, 2011). The main industries on the islands are agriculture, fishing and tourism (see Figure 34). Despite the agrarian and tourist orientation of the islands, the population and vehicle densities on the islands are relatively high. On average there are 100 inhabitants per square kilometre and 620 passenger cars per 1,000 inhabitants. The vehicle density is thus much higher than the Japanese average (approx. 453 passenger cars per 1,000 inhabitants), while the population density is well below the Japanese average (approx. 337 inhabitants per km²). Stimulated by the project, the density of electric vehicles is by now particularly high: In late 2011, there were around 55 electric vehicles per 10,000 households. By comparison, in nearby Nagasaki there were only around 5 electric vehicles per 10,000 households at that point in time (in Japan as a whole, there were 1.6 electric vehicles per 10,000 households). There are currently 177 electric vehicles in operation on the Goto Islands (World EV Cities & Ecosystems, 2014). In 2009, over half of the electricity consumed in Goto came from regenerative sources mainly produced locally (wind and solar power, biogas). In addition, there is an underwater power line that connects to the Japanese mainland. The aim of the test field is to facilitate the systemic interconnection of individual components and to test new vehicle, energy and telematics solutions. Specifically, the following targets have been identified (Suzuki, 2013):

- Achievement of maximum publicity as a testing ground for electromobility;
- Implementation of practical operations for vehicles and infrastructures;
- Integration of electromobility in tourism products ("Driving Tours of the Future");
- Establishment of a regional and decentralised application model.

The Goto Islands are an ideal site for pursuing these goals, as they have a relatively small-scale structure and enjoy considerable popularity as a tourist destination. In this context, electromobility is promoted as a sightseeing attraction under the motto "Driving Tours of the Future". This is intended to bring potential users into contact with the new technologies, while at the same time testing its suitability in practice. For the tours, 100 electric vehicles are available for use at publicly accessible parking areas. The in-car navigation system provides users with a wide array of technical information about the vehicles and parking and charging systems, as well as tourist information about sightseeing, restaurants and hotels. Sensors at the rental stations and selected points on the tour feed updated information into the system. Some 20 fast charging stations distributed across the islands are available for charging the vehicles and are evaluated with regard to utilisation behaviour. From a Japanese perspective, the information thus provided is particularly valuable, as this charging technology is a key component of the electromobility infrastructure in Japan (OECD, 2012). Data collected at the fast charging station at the main island's harbour showed that as many as 20 vehicles per day were charged. The average charging time at all fast charging stations was only 18 minutes, during which time drivers were able to engage in sightseeing activities close to the charging stations.

Fig. 34: *The Goto Island "eco system".* © Nagasaki Prefecture, 2011

mains (see Figure 35). This could supply an average household with electricity for around two days. The fuel cell vehicle *Toyota Mirai* supplies 200 kW-hr of electricity, which can power a small house for nearly a week.

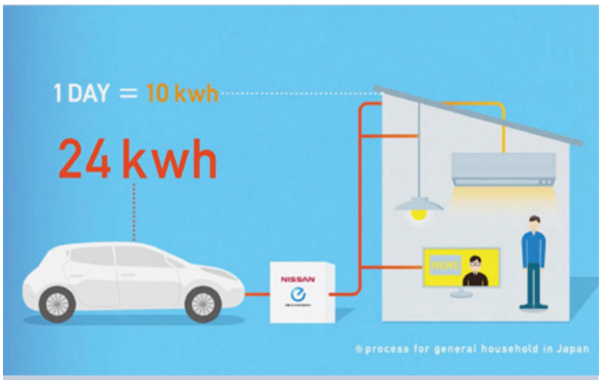

Fig. 35: *Principle of Nissan's smart home applications, 2015.*
© Nissan

These kinds of concepts are supported by the New Energy Promotion Council, which also operates a comprehensive information portal for the cities Yokohama, Toyota City, Keihanna and Kitakyushu under the name "Smart City Japan Portal". Numerous projects are underway in these cities that focus on different research areas; many of them incorporate aspects of electromobility. In Yokohama, for example, the controlled charging of electric vehicles is being tested within the framework of local carsharing services. In addition, the charging infrastructure, including fast charging stations, is coupled with solar power systems and storage units in an intelligent network. The objective is the efficient charging and feedback of electricity, taking into account various ancillary factors such as rental and return procedures, weather data and electricity prices. One of the participants in the project is the Nissan company.

From the Japanese point of view, electromobility is a holistic system in which the automotive industry, the electronics and software industries as well as battery manufacturers, energy providers and the service sector are closely intertwined (see Infobox 9).

5.2 The People's Republic of China

The People's Republic of China, with around 1.37 billion inhabitants, is the world's most populous country and the fourth largest country in the world by area. Because of its strong economic development, the PRC is increasingly considered an industrialised rather than an emerging economy. Since 2011, the People's Republic of China has been ranked as the world's second largest economy ahead of Japan, and within a few years the country is expected to surpass the United States as the world's largest economy. The vehicle stock has increased dramatically, going from 16 million in the year 2000 to 108 million in the year 2012. In particular in cities where the rapid expansion of motorisation is concentrated, this has led to high environmental impacts due to air pollution, traffic congestion and noise. The People's Republic of China has reacted with measures that include a tightening of the emissions standard (currently comparable with the Euro 4 standard) as well as the fuel standard (50 ppm sulphur content in petrol and diesel). The air quality, however, is still very poor, particularly in the country's megacities and metropolitan areas; this is due to the sharp increase in vehicle numbers and an energy supply system that is still based largely on coal (Shao/ Wagner, 2015).

The People's Republic of China has been active in the area of electromobility since the turn of the millennium, and the government sees electromobility as an important industrial policy issue. The People's Republic of China high dependence on foreign oil imports is a key driver in this development. In 2010, over 60 % of oil consumed in the People's Republic of China was imported; the transport sector accounted for around half of that amount. Another driving factor in the promotion of electromobility is air pollution, which particularly in major Chinese cities is creating considerable need for action. In the metropolitan areas of the country, up to 70 % of NO_x emissions result from internal combustion vehicles (Deutsche Bank Group, 2012). The most important motivation, however, is the desire to become both the leading supplier and the biggest market for electric propulsion technologies. According to estimates by the Mercator Institute for China Studies, there is a strong focus on protecting and securing the technological advantage of the domestic automotive industry (Meissner, 2014). The significant lag that Chinese manufacturers demonstrate compared to vehicle manufacturers from the United

States, Japan and Europe in the area of conventionally powered vehicles is to be offset by "leap-frogging" with electric vehicles. This means that certain stages in the automotive development process will be deliberately skipped in order to catch up to international competitors (Hillebrand/Hüging, 2015).

The current target of the Chinese Government is to achieve the registration of 300,000 electric vehicles in the People's Republic of China by the year 2015 and 2 million by the year 2020. Additionally, 10 million public charging points are to be built. In the public transport system, the aim is for an average of 30% of all vehicles to be equipped with an electric propulsion system by 2025. Government plans also set out the target of turning the People's Republic of China into the world's largest producer of electric vehicles by the year 2020.

The key instruments in the build-up of the Chinese electromobility industry are the following:

- Support for the formation of cooperative networks between various state-owned enterprises;
- The definition of national standards;
- Active industrial and control policies (including regulation of joint ventures; the Chinese partner has to take on expertise and key manufacturing processes in the fields of the electric motor, battery and power electronics);
- Local and national programmes for sales promotion (see Table 4).

Table 4: Promotion of electric mobility in selected cities of the PRC

	PHEV	EV
National Funding *)	50,000	60,000
Additional Regional Funding		
Beijing	50,000	60,000
Changchun	40,000	40,000
Hangzhou	30,000	60,000
Hefei	20,000	20,000
Shanghai	20,000	40,000
Shenzen	n. d.	60,000

*) Note: Maximum funding 2012

Source: Kühn, 2014

In 2009, the People's Republic of China made an initial selection of 13 cities (Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming and Nanchang) to be developed as model regions for the local promotion of electromobility. By the following year, 12 additional cities were added: Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan and Guangzhou (Representation of the Federal Republic of Germany, 2010). According to the "Development Plan for Energy-Saving and New Energy Vehicles (2011–2020)" presented in 2010, by 2020 electromobility is to receive subsidies of RMB 100 billion, or about EUR 11.5 million (Representation of the Federal Republic of Germany, 2010). In February 2014, the number of model cities was again increased to 25. In 2015, electric vehicles were promoted in 86 demonstration cities (Hillebrand/Hüging, 2015).

The Chinese Central Government provides support for all-electric vehicles, plug-in and fuel cell vehicles. In addition, there are also numerous local promotion programmes in place in individual metropolises (Kühl, 2014). With few exceptions, electric vehicles from non-Chinese manufacturers are excluded from the support measures.

Due to local regulations, many European manufacturers work together with Chinese state-owned enterprises in joint ventures. The first electric vehicle made by Daimler and its Chinese partner BYD (Build Your Dreams) in the People's Republic of China, for example, was produced under the joint brand Denza. The car costs around RMB 369,000, or EUR 46,000. However, buyers of an electric vehicle are eligible for national and local state subsidies of up to RMB 120,000, or around EUR 16,700 (Handelsblatt online, 2014). For example, the purchase of the vehicle model *Dongfeng Fengshen E30*, which in 2014 cost around RMB 150,000 (around EUR 20,800) before subsidies, was supported by the Central Government and the respective city with subsidies amounting to approximately RMB 40,000, or EUR 11,000. The purchase premiums depend on the range of the vehicle. A comparable conventionally powered vehicle costs about RMB 70,000 (or around EUR 9,700). Already, the costs are thus comparable. In addition, electric vehicles are not subject to toll fees and are exempted from any local registration restrictions (for example through lottery or auction). Moreover, 17 models of all-electric passenger cars, 77 models of buses and 16 hybrid vehicle models manufactured in the

Table 5: Car sharing in the PRC – frequently with electric vehicles

Service	Operator	Founding year	Business model	Vehicles	Stations	Members	Cities	Website
Yi Dian Zuche (EduoAuto)	EduoAuto (Beijing) Technology Co., Ltd	2009	Station-based carsharing	1,000	769	278,419	Beijing, Changsha, Chengdu, Chongqing, Hangzhou, Nanjing, Shenzhen, Shijiazjuang, Suzhou, Wuhan	www.yidianzc.com
China Car Clubs	Hangzhou Cherry Intelligence Co., Ltd	2010	Station-based carsharing	200 (incl. 50 EV)	78	38,000	Hangzhou (Membership cooperation with Green Go in Beijing)	www.ccclubs.com
car2share	Daimler Greater China Ltd.	2013	Station-based corporate carsharing	90	3	Membership limited to pilot partners during initial phase	Guangzhou, Shenzhen	www.car2share.daihing.com
VRent	Volkswagen New Mobility Services Investment Co., Ltd	2013	Station-based carsharing	25	5	Membership limited to pilot partners during initial phase	Beijing	www.vrent.cn
Wei Gong Jiao	Zhejiang Kandi Electric Vehicles Co., Ltd (Joint Venture of Zhejiang Geely Holding Group and Kandi Technologies Group)	2013	Station-based carsharing	~2,500 (estimated, EV only)	34	n. d.	Hangzhou	No website available. Booking only via WeChat.
EVCARD	New Energy Vehicles Operating Services Co., Ltd	2013	Station-based carsharing	300 (EV only)	53	3,000	Shanghai	www.evcardchina.com
Green Go	Beijing Heng Yu New Energy Car Rental Co., Ltd (Joint Venture between BAIC New Energy Co., Ltd and Foxconn Technology Group)	2014	Station-based carsharing	700 (EV only)	26	15,000	Beijing (Membership cooperation with China Car Clubs in Hangzhou)	www.green-go.cn
GX Zuche	Car-sharing Rental Co., Ltd	2014	Station-based carsharing	100 (incl. 10 EV)	50	2,000	Yantai	www.gx-zuche.com

Source: Own compilation, based on China Auto Web, 2015a

People's Republic of China are exempted from paying value-added tax. The subsidy programme was recently extended to the year 2020, although the volume of the funding support measures is to be gradually reduced (Hillebrand/Hüging, 2015).

Because of strict quotas for new vehicle registrations as well as increasingly stringent driving bans, the purchase of new cars in cities such as Beijing and Shanghai is becoming increasingly unattractive. The availability of smart phones and mobile Internet, the shifting mentality among younger Chinese and a shortage of taxis in major Chinese cities is increasing the appeal of carsharing (see Table 5). Carsharing platforms are thus becoming ever more popular as an additional form of mobility. Roland Berger forecasts an 80 % annual market growth rate in carsharing in the PRC in the next few years, and a stock of around 18,000 carsharing vehicles by the year 2018. In addition to Chinese services such as the electric carsharing service provided by Kandi in Hangzhou, Chinese customers will soon also be able to use services provided by international providers. Daimler, for example, plans to introduce its carsharing product car2go to the market in the western Chinese megacity of Chongqing.

The People's Republic of China automotive industry is not committed exclusively to electric cars. In 2014, around 71 % of all vehicles sold were passenger cars, 27 % were buses and 1 % were lorries (China Auto Web, 2015a). In the same year, nearly 78,500 electric and hybrid vehicles were produced in the People's Republic of China (more than four times as many as in 2013). Nearly 75,000 electric and hybrid vehicles were sold in 2014 (more than three times as many as in 2013), of which over 45,000 were pure BEVs and around 30,000 hybrid vehicles. In the first six months of 2015, production and sales figures have seen another sharp rise. Production is currently at over 76,000 BEVs and over 72,500 hybrid vehicles. Sales figures are at approximately 30,000 BEVs and 20,000 hybrid vehicles (China Auto Web, 2015b). In terms of absolute sales figures, the People's Republic of China is currently the world's second-largest sales market for electric vehicles. The highest sales figures in the PRC have been achieved by the companies BYD, Zotye, BAIC EV, Chery and SAIC. Table 6 shows the ten most successful vehicle models in the 1st half of 2015.

Table 6: Sales of electric vehicles in H1 2015 in PRC

Rank	Vehicle Model	Vehicles Sold
1	BYD Qin (PHEV)	16,477
2	BAIC EV 150/160/200 (E Series, BEV)	5,803
3	Zotye E20 (Zhidou E20, BEV)	4,913
4	Zotye Cloud 100 (BEV)	4,347
5	SAIC Roewe 550 Plug-in (PHEV)	3,321
6	Chery QQ EV (QQ3 EV, BEV)	3,208
7	BYD e6 (BEV)	2,900
8	JAC iEV (BEV)	2,591
9	Geely-Kandi Panda (BEV)	2,547
10	Chery eQ (BEV)	2,129

Source: Own compilation, based on China Auto Web, 2015a

The People's Republic of China has also been very successful in the area of buses for urban public transport. Compared to European cities, electric vehicle fleets make up a significant share of the People's Republic of China public transport systems. In 2012, only 4,000 all-electric buses were produced (Ma Jian Yong, 2014); by comparison, around 2.7 million conventionally powered omnibuses are produced in the People's Republic of China each year (Destatis, 2014 (status 2012)). In the year 2014, over 20,000 electric buses (BEV and hybrid drive) were manufactured and sold. Moreover, by the year 2011, 39 % of the worldwide stock of public charging points for electric vehicles was to be found in the PRC; by late 2013, an additional 19,000 public charging points had been installed (Li Zoe, 2014). Today, the People's Republic of China is the global leader in the manufacturing of two-wheeled electric vehicles. Electric scooters enjoy particular popularity among the Chinese population. What is notable is that the development of these "low-speed electric-vehicles" in the People's Republic of China is largely unregulated. A number of Chinese local government administrations have instituted indirect support measures for electric scooters by exempting them from restrictions that apply to conventional scooters. In 2013, there were approximately 60 million electric scooters in operation in the People's Republic of China (Knoblach, 2013). In the year 2013 alone, around 9.4 million electric scooters were sold in the People's Republic of China (Pabst/Trentmann, 2014).

5.3 South Korea

The Republic of Korea is a high-tech industrialised nation. Many products from South Korea lead the market, in particular in the electronics segment. In the year 2011, the vehicle density in South Korea was 370 motor vehicles per 1,000 inhabitants (not including two-wheeled vehicles). That is significantly higher than the figure for the People's Republic of China (69/1,000), but below the figure for Japan (588/1,000) (World Bank, 2011). South Korea has a well-developed public transport system. The rail transport system comprises various categories, including commuter, long-distance and high-speed trains. In the major cities, there are also underground train systems, which form a central pillar of public transport. The underground network in the capital Seoul is one of the largest, busiest and most modern underground systems in the world. There is also a dense network of long-distance coaches which connects nearly all of the country's cities. The country has numerous toll-based motorways (expressways).

The economic boom that the country has experienced over the past 30 years also brought with it a sharp increase in motorised individual transport. From 1990 to 2012, the number of motor vehicles has approximately quadrupled. Since the turn of the millennium, however, the increasing motorisation has subsided. In 2012, the volume of traffic even declined for the first time in a long while (International Transport Forum/OECD, 2014). South Korea has only limited fossil fuel resources and is therefore particularly dependent on oil and coal imports. In order to reach to the climate objectives set out in the Kyoto Protocol, to which South Korea is a signatory, the country has committed to an expansion of renewable energies, for example through the construction of hydro and tidal power plants; at the same time, however, it still relies on nuclear power.

In the electromobility sector, South Korea's particular strengths lie in the areas of battery and cell manufacturing. The rapid process of industrialisation and the availability of government funding for research and development, including in the area of cellular chemistry, have made the country one of the global leaders in this industry branch, specifically for lithium-ion batteries. South Korea produces more battery cells for automobiles than the United States and European countries put

Fig. 36: *Explanation of Korean OLEV bus concept with inductive charging, 2014.* © http://olevtech.com

together. Only Japan has a higher production volume in this area. One of the attributing factors is the particular composition of the industry, which is characterised by a small number of often family-run conglomerates. This enables quick decision-making processes and a rapid transfer of technology from other industry branches (Roland Berger, 2014).

Although key technological foundations were laid for the manufacturing of electric vehicles, and the government is trying to achieve a balance between battery research and vehicle development, domestic production and sales have so far not taken off. Electric vehicles are being tested and employed in the context of bus fleets (Nicola, 2013). In the city of Gumi, for example, two electric buses are being tested on an approximately 24-kilometre route. The so-called OLEV buses (online electric vehicle) are charged by induction technology (KAIST, 2010). Induction coils installed in the surface of the road supply contactless charging for the buses with an efficiency level of approximately 85 %. The battery, which is located in the bus, can therefore be reduced to about 20 % of normal capacity with a correspondingly lower price (Pluta, 2013). After completion of the test phase in 2015, regular operations for up to 12 electric buses are planned (see Figure 36).

By the middle of 2013, there were 1,150 electric vehicles (most of them passenger cars) in use in South Korea, mainly by government agencies and public institutions. The country has over 1,500 charging stations, of which over 100 are fast charging stations. Only recently, with the ***Kia Soul*** and the ***Kia Ray***, have the first mass-produced South Korean electric vehicles become available on the market. Hyundai has announced its first battery electric vehicle, which will be available in 2016 (electric vehicle news, 2014).

Korean OEMs pursue a safety-oriented and diversified path that is similar to the position of German OEMs when it comes to electromobility (Roland Berger, 2014). In addition to the fully electric drive, part electric and fuel cell based propulsion systems are also considered. On the demand side, there have so far hardly been any of the "early adopters" who encourage acceptance of electromobility; one of the reasons for this is that in South Korea, innovations tend take a different path and there is a high degree of social cohesion. Moreover, the fact that the South Korean charging infrastructure is oriented to the CHAdeMO standard has so far proven to be an obstacle. There is so far no reason to assume that western OEMS will retrofit their vehicles for the Korean-Japanese market, so that a harmonisation with the global Combo standard is likely (Bernhart *et al.,* 2014). Comparable to the Japanese trials on the Goto Islands, South Korea also uses an island as a testing ground and promotion area for electromobility and the related infrastructure. In this case it is the island of Jeju, south of the Korean Peninsula. In spring 2014 there were close to 360 electric vehicles in operation on the island (versus around 300,000 conventional vehicles). The island's electric vehicle fleet is set to grow to 29,000 by 2017 and 94,000 by the year 2020. With approximately 500 easily accessible 240-volt charging stations, Jeju's charging infrastructure has one of the highest densities in the world (electric vehicle news, 2014). Jeju is the most popular destination for Korean tourists and especially suited as a testing ground since the vast majority of tourists on the island choose to rent a car during their stay.

In the South Korean capital Seoul, a significant expansion of electromobility is also planned. By the year 2018, the city government plans to put 50,000 electric vehicles on the roads of the metropolis and to build 500 charging stations. There is also a financial incentive of KRW 20 million (around EUR 16,000) planned for private car park operators who install additional charging stations. Buyers of electric vehicles are to receive tax relief to the amount of KRW 6 million (nearly EUR 5,000) (Korea IT Times, 2015).

5.4 India

The Republic of India, which accounts for 18 % of the world's population, is the most populous country on earth behind the People's Republic of China. There is a precarious balance between the Indian transport infrastructure and the country's population growth, rapid urbanisation and increasing commuter traffic; increasingly, the expansion of the infrastructure system is unable to keep up with these developments. In many places, there is virtually no development planning according to Western standards; instead, development often takes a spontaneous and uncontrolled path. Congested roads and overcrowded trains and buses are the most visible expression of this constant pressure. Particularly in the metropolitan areas, the imbalance between available space for transport and parking and the growing, mobile population is clearly evident. Furthermore, 13 of the 20 most polluted cities in the world are located in India (Pandit/Kapur, 2015). Although the Indian vehicle market is largely dominated by two-wheeled vehicles and scooters, the vehicle density per square kilometre is in some cities higher than in Europe. The high cost of fuel, low average speeds on Indian roads and short average driving distances are among the challenges faced by the automotive industry in India.

A central motive of the Indian Government's promotion of electromobility is energy security. Whereas the country's own extraction of oil has nearly reached its limit, demand continues to grow at a rapid pace. This is why possibilities are being explored to reduce the dependency on oil, which in the transport sector is particularly high. India expects that by the year 2020 the cumulative effect of the promotion of electromobility will achieve economic profit through the savings in fossil fuel (Government of India, 2012). The relatively low speeds and driving distances also make India an interesting market for electric microcars and compact vehicles. The existence of qualified engineers, relatively low labour costs and access to both hardware and software make India ideally suited to be a production location for electric vehicles.

The Central Government, however, wants to ensure that the growing domestic vehicle industry is not jeopardised in the process. In light of the low vehicle density in India, a wider potential for growth is seen in the domestic market. But the export business is also considered to be of relevance for the national economy. Domestic vehicle production increased from a total of 2 million vehicles in the year 1991 to 20 million within 20 years. Today, the automotive sector accounts for about 6 % of the GDP, it contributed 22 % of the industrial output in 2011 and employs more than 13 million people (Ministry of Heavy Industries and Public Enterprises, 2012). According to experts, the external costs of motorised individual transport in India, including the extremely high accident rates, local air pollution and, as a result, reduced life expectancy, as well as noise and congestion, amount to more than 6 % of the GDP.

For this reason, the promotion of alternative fuels and propulsion technologies within the national automotive industry is an obvious measure that must be taken. Despite the fact that individual Indian states or regional governments – *e.g.* Delhi, Bangalore and Chandigarh – incentivise the purchase of electric vehicles (including two and three-wheelers) through tax relief and subsidies, the effects have remained for the most part fragmented and short-lived.

The Central Government is also involved in encouraging the demand for electric vehicles. Notable in this context is the "Alternate Fuels for Surface Transportation Programme" (AFSTP), which was launched by the "Ministry of New and Renewable Energy". This programme provides state subsidies for the purchase of electric vehicles, although it is conspicuous that the majority of such support was provided primarily for two-wheelers: Between 2011 and 2012, 130,000 two-wheeled electric vehicles received subsidies of INR 4,000 to 5,000 per vehicle, which at today's exchange is equal to around EUR 51–64. A purchase premium amounting to the equivalent of approximately EUR 769 to 1,282 per vehicle was

Table 7: Volume targets and financial support from the Indian Central Government (2011/2012)

Type	Vehicle characteristic	Units		Support per vehicle	
		2011	2012	INR	% of purchase price
Two-wheelers	Low speed	20,000	80,000	4,000	20
	High speed	10,000	20,000	5,000	20
Three-wheelers	7-seater	100	166	60,000	20
Passenger car	4-seater	140	700	100,000	20
Bus/minibus	>10 seats	-	-	400,000	20

Source: Klötzke *et al.*, 2013

instituted for three- and four-wheeled vehicles; due to the lower numbers of vehicles on the road, however, the overall scope of this support is much smaller (see Table 7).

The Indian Central Government recognised that previous support measures were not yet sufficient to help bring about a breakthrough in the area of electromobility. In 2011, India established the "National Mission for Electric Mobility", which at the three levels of "Ministers and eminent representatives of economics and industry", "Secretaries of state" and "Experts" developed a plan for electromobility to the year 2020. Due to the particularities of the Indian vehicle market (high proportion of two-wheelers and compact cars, high cost sensitivity and shortage of space in cities) the consensus was that products and solutions from other markets were not necessarily applicable to the situation in India (Department of Heavy Industries and Public Enterprises, Government of India, 2012).

The "National Electric Mobility Mission Plan 2020", which was published in 2013, set out the target of building an electric automobile industry by the year 2020. According to this plan, the entire range of electric vehicles is eligible for support, from "mild hybrids" to fully electric vehicles. This is meant to ensure that the market for electric and hybrid vehicles can grow to as many as seven million vehicles by the year 2020. TCO calculations were used to determine the expected demand potential for India in 2020. Indian buyers of new cars are very sensitive to costs and are more interested in a robust and reliable car than in technological innovation. The demand for all-electric vehicles is predominantly seen in the two-wheel segment (up to five million units) (Venugopal Sampath, 2012). For three- and four-wheeled vehicles, more demand is assumed to exist for hybrid vehicle types (1.3 to 1.4 units). The demand for other fully electric vehicles outside of the two-wheel segment is estimated to be relatively limited, at only 200,000 to 400,000 units (Hüging/Koska, 2015). Attainment of the planned target of 400,000 electric vehicles (BEVs) will help save 120 million barrels of oil and 4 million tonnes of CO_2.

The Indian government plans to spend around USD 3 billion to reach this goal. Given the significantly divergent potential variables in the different vehicle segments, the Indian Government wants to institute specific government contracting and procurement measures. These will apply to the both the part-electric and all-electric vehicle segments:

- ***Two-wheel segment***: Significant demand is assumed to exist in this segment, so that no public contracts are necessary to reach the planned mid-level target of 4.8 million vehicles by the year 2020.
- ***Three-wheel segment***: In this segment, current demand is estimated to be insufficient to meet the future planned target of 20,000 to 30,000 vehicles by the year 2020. The proposed incentive, however, is

Fig. 37a, b: *Tricycles with solar roof, being used as rickshaw.* © SIKCO, 2015 limited to additional licences for local vehicle registration (see Figure 37a, b).

- ***Four-wheel segment***: In this segment as well, current demand is estimated to be below the required 2020 level. The recommendation in order to stimulate the market is to institute state procurement measures, for example with regard to public or municipal vehicle fleets. However, the government recently instated purchasing incentives in this area as well.
- ***Bus segment***: Here the assessment of the situation is similar to that in the four-wheel segment: The current demand of 2,600 to 3,000 vehicles does not correspond to the prospective needs in the year 2020. A recommended incentive is the procurement of electric and hybrid buses for public transport companies within the framework of pilot projects. Another recommendation is to launch cooperation ventures between international companies and domestic industry to jointly develop buses that are tailored to local needs. In Bangalore, the first pilot project with electric buses was launched in 2014. A project with hybrid buses was carried out in Mumbai as well (Pandit/Kapur, 2015).
- ***Van and light lorry (van) segment***: Here too, the authors estimate that additional contracts and procurement are necessary to meet the future requirements and reach the target of 30,000 to 50,000 vehicles that has been set for urban vehicle fleets (see Figure 39a, b).

Within the individual vehicle segments, recommendations are made for further priorities regarding the degree of electrification (with the exception of two-wheeled vehicles). At least three quarters of investment funds are to be applied to hybrid vehicles (including plug-in

Infobox 10: Mahindra BEV E2O

The *Mahindra E2O* is the first all-electric vehicle produced in India; it has been available on the market since early 2013. The car can fit four people and has a range of around 100 to 120 kilometres (see Figures 38a, b). With a 240-volt charging system, its battery can go from nearly empty to fully charged overnight. The car also has a fast charging feature, with which a range of around 25 km can be charged within 15 minutes. It also supports innovative charging systems such as "*Sun2Car*", which through a solar charging device enables charging while the vehicle is parked, for example.

The BEV is based on a replaceable battery system. In this case, the battery is not purchased, but rather leased in the context of an energy service contract (Goodbye Fuel Hello Electric – GFHE). The purchase price of the car is the equivalent of approximately EUR 7,000. In addition, there is a monthly fee of approximately EUR 40 for the energy supply and usage of the battery. This is limited to five years or 50,000 kilometres. So far, the BEV has remained far behind sales expectations (500 vehicles per month), with 1,000 units sold within the first 15 months (Mahindra, 2015).

Fig. 38a, b: *Mahindra/Reva BEV E2O.*

hybrids), leaving only a maximum of one quarter for investment in all-electric vehicles. Based on the dominance of two-wheeled and three-wheeled vehicles, many hybrids are also available in very small versions (hybrid scooters, for example). Considerable potential is also seen in merging the electric generator and starter into one unit, which can simultaneously serve as an automated starter (start&stop), power generator (recuperation) and power support unit (booster) for the conventional engine. The hybrid scooter can be operated either in conventional, all-electric or hybrid mode. The options are separated so that in the case of a malfunction of any of the subsystems, the full operation of the other systems is still maintained. Plug-in hybrid scooters have been developed and deployed with parallel hybrid architecture and wheel hub drive in the rear axle to support the internal combustion engine (Klötzke *et al.,* 2013).

Additional incentive measures introduced should be designed as technology-neutral as possible, and implemented in a gradual process that is reproducible for later purposes. Beyond the state contracting and procurement measures, there are, within the individual vehicle segments, differentiated purchase incentives in the form of subsidies for the first vehicles purchased: Support is to be made available for the first 1 million two-wheelers, the first 20,000 three-wheelers vehicles, the first 200,000 four-wheeled vehicles and the first 50,000 vans and light lorries. Starting around the year 2016, the volume of funding is then to be gradually decreased (Department of Heavy Industries and Public Enterprises, Government of India, 2012). Until now, there is hardly any notable charging infrastructure in place, which is why funding for expansion in this area is planned as well. By now there are initial pilot projects in place to develop a charging infrastructure, for example in Delhi or Bangalore (Praveen/Kalyan, 2013).

In 2014 India joined the Electric Vehicles Initiative and redoubled its efforts in the promotion of electromobility. In early 2015 the Indian Government announced its intention to invest a total of INR 10 billion — the equivalent of around EUR 120 million — in electromobility over the next two years. In 2015 the FAME programme (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) was initiated to pay out purchase premiums, develop charging infrastructure and promote pilot projects, amongst other things. Buyers of electric vehicles receive a refund of 15 % of the vehicle's purchase price within two months of purchase. In addition, the vehicle purchase is not subject to value-added tax, so that the buyer receives another 12.5 % in savings. Moreover, buyers of an electric vehicle receive a 50 % discount on road use charges (Pandit/Kapur, 2015).

5.5 Indonesia

The Republic of Indonesia has the fourth largest population in the word, behind the People's Republic of China, India and the United States. The vehicle density in 2011 was at around 60 motor vehicles per 1,000 inhabitants (not including two-wheelers), which is approximately the

Fig. 39a, b: *E-tricycle as transport vehicle and the electric light lorry Maxximo.*

same as that in the People's Republic of China, but higher than the vehicle density in India (41/1,000) (World Bank, 2011). The typical Angkot minibuses (informal transit) operate in many towns that are connected by road, while in larger cities there are also bus services of different categories ranging from small-scale informal transit to the "TransJakarta" BRT system in the capital Jakarta. As a result of the population's increasing purchasing power, private passenger cars are becoming increasingly common, especially in urban areas. This is causing considerable congestion, especially in Jakarta, where even by global standards the traffic situation is particularly problematic (see Figure 40).

Indonesia has significant fossil fuel resources, and up to a few years ago was among the oil-exporting countries (it had been the only Asian OPEC member outside of the Middle East). Since then, however, the energy consumption has significantly increased, while domestic oil production has fallen relative to 1990 levels. In addition to fossil fuels, geothermal energy also plays an important role. Indonesia is the world's third-largest producer of geothermally generated electricity (after the United States and the Philippines).

Indonesia's activities in the area of electromobility are, accordingly, primarily driven by energy and industrial policy motives. In recent years, the government has undertaken initial efforts to develop — from the ground up — a domestic production capacity for electric vehicles. The state-owned power company PLN has committed to building the country's first charging stations. Dahlan Iskan, the Indonesian Minister for State Enterprises, is considered to be a supporter and advocate of a national electromobility initiative. His view is that although local automobile manufacturers may not be able to compete with foreign companies in the area of the internal combustion engine, they can do so in the field of electromobility.

Although the industry in Indonesia has so far developed various electric vehicle prototypes (passenger cars and buses), it has not taken them to the production stage. At the same time, the Indonesian entrepreneur Dasep Ahmadi has for several years been working on developing electric cars, although so far without achieving a breakthrough (Patoni, 2012). Legal regulations, component manufacturing and infrastructure development are key factors here. According to Edy PutraIrawady, Minister for Industry and Technology, Indonesia needs electromobility in order to create a broad energy base for the country's mobility. The electricity for electric vehicles can be generated from fossil, geothermal, solar or other sources (Nugraha/Hasanah, 2014).

Fig. 40: *Traffic in Jakarta, one of the most congested cities in the world.*

5.6 Singapore

Almost nowhere else in the world is the population density as high as it is in Singapore, where 4.6 million inhabitants live in an area of 650 square kilometres. The effects of such overcrowded conditions put the transport systems to a serious test. The government in Singapore has shown that efficient and sustainable traffic management is possible even in a growing metropolis. With its resolute implementation of innovative concepts, Singapore has proven to be a model city for sustainable mobility in the entire Southeast Asian region. Singapore can even serve as a model when compared to European cities: 60 % of its road users make use of the public transport system, while in European cities, by contrast, 30 % is considered to be a successful rate of public transport usage. Such a high level of public transport use is primarily the result of the tough restrictions on new car registration, as well as the world's highest fees for motor vehicles. To even own a car, a driver in Singapore needs a special licence, which can cost up to USD 40,000 and is valid for ten years. In addition to this, there are very high import duties. A simple hybrid vehicle such as the ***Toyota Prius*** costs over USD 150,000 in Singapore (Jaffe, 2015). Furthermore, the annual increase in new vehicle registrations is currently limited to 0.5 %. On weekdays, all motor vehicles in the inner city area are subject to a city toll, which since 1989 has been collected electronically.

These transport policy concepts have a clear effect in Singapore: The ratio of cars to inhabitants is 1 to 10, compared to 1 to 2.7 in Hamburg, Germany. The exhaust emissions of older cars are regularly checked. Leaded petrol is also prohibited, and the sulphur content in diesel fuel is restricted by law to 0.05 %. Tax relief measures provide incentives for the purchase of electric and hybrid vehicles.

Due to its manageable size and its highly developed infrastructure, Singapore is considered an ideal testing ground for electromobility. It will still take a while, however, before the necessary charging infrastructure is implemented and electric vehicles become a real success on the market in Singapore. In the year 2011, the "Electric Vehicle Task Force" (EVTF) was founded. This initiative by the Land Transport Authority is intended to promote the introduction of electric vehicles as well as the development of charging technology.

In 2011, the company Bosch Software Innovations began a test project to develop its first charging stations, which will also serve as charging points for Singapore's first electromobility test applications. The charging stations are linked to each other by way of an Internet platform. Other companies can also offer their products and services on this platform, or can connect their own charging infrastructure with the network, for example. Once they have registered using the widespread ID card NETS CEPAS, customers can then use the platform to locate the next available charging station. Bosch evaluates the customer utilisation of the charging infrastructure in order to gain relevant information for further network expansion (Bosch, 2011).

After over four years, the use of electric vehicles is still largely limited to research purposes. Over 50 organisations participated in the first test phase, in which 89 electric vehicles were tested on the streets of Singapore – including the models ***Mitsubishi iMiEV***, ***Daimler smart fortwo electric drive***, ***Nissan Leaf*** as well as the ***Renault Fluence Z.E.*** (eco-business, 2014). The vehicles were operated by test users, who drove an average of 41 kilometres per day. This is just short of the average daily distance driven with conventional vehicles in Singapore (55 km), and it confirms that the existing range limits do not pose a problem for the kind of driving mostly done in Singapore. The test drivers gave high marks in particular for the cars' low noise levels and rapid acceleration. Outside of the test fleets, however, there are very few privately registered electric cars in Singapore. In early 2013, there were only three electric cars among the approximately 618,000 cars on the road in Singapore: one converted ***BMW***, one ***Tesla Roadster Sport*** and a three-wheeled ***Corbin Sparrow*** (SG Carmart, 2013).

In the area of research and development, however, Singapore is making significant progress: The Nanyang Technological University (NTU) has carried out initial tests with a driverless vehicle in Singapore and has been testing it on the road since 2013. The electric vehicle that goes by the name ***NAVIA*** can accommodate eight passengers, driving at a speed of 20 km/h on pre-programmed routes between NTU and an industrial park. In early 2014, a fully automated driverless vehicle was presented by the National University of Singapore and the "Singapore-MIT Alliance for Research and Technology". The name of the vehicle is ***Shared Computer Operated Transport***, or ***Scot*** for short. It is a ***Mitsubishi i-MiEV*** equipped with USD 30,000 worth of supplemental electronics, and it can reach speeds of up to 130 km/h. Built-in remote

Fig. 41: *Driverless electric cars being tested in Singapore.* © NTU, 2014

sensing technology, specifically a laser with a range of 30 metres, enables the car to be used even without satellite navigation capability (straits times, 2014) (see Figure 41).

The government in Singapore has high expectations for autonomous electric vehicles, which are to help make Singapore an even more sustainable and liveable city. There are currently plans to expand the test with the autonomous ***Mitsubishi I-MiEV***; the reliability and acceptance of an autonomous taxi service will be tested over a six-month period in the district "One North". An initial study indicates that there is enormous potential for an autonomous taxi system in Singapore. Calculations show that a fleet of 300,000 autonomous taxis would be sufficient to ensure that, even in rush hour, nobody would have to wait longer than 15 minutes for a taxi. In today's Singapore, there are around 800,000 cars on the streets, and these cars occupy a correspondingly large amount of space for parking. This is one of the reasons behind plans to further automate the city's public transport system, thereby enhancing its reliability and increasing the capacity of the urban modes of transportation (Jaffe, 2015).

5.7 Sri Lanka

The island nation of Sri Lanka has a population of slightly over 20 million. In the year 2012, there was a vehicle density of approximately 76 motor vehicles, 18 of them private cars, per 1,000 inhabitants (not including two-wheelers). With over 1.7 million motorcycles, the Sri Lankan transport sector is, similar to that of India, very much dominated by two-wheeled vehicles. There are also nearly 700,000 three-wheelers in operation on the island's roads (Central Bank of Sri Lanka, 2013). Additionally, there is a national railway company and a national bus company, both of which are state owned. The vast majority of the population (around 90 %) relies on the public transport system for their daily transportation needs, using trains, buses or smaller vehicles such as three-wheelers (see Figure 42).

Sri Lanka's electricity supply is based primarily on hydropower (which accounted for approximately 28 % of electricity generation in the year 2012) and on thermal power plants generated by fossil fuels (diesel, natural gas, oil and coal). In addition to hydropower, another form of renewable energy that is slowly gaining significance is solar power. Wind power, by contrast, still plays a minor role. In 2010, President Mahinda Rajapaksa, who held office until early 2015, formulated the goal of developing domestic sources of energy such as oil and natural gas. For now, new coal-fired power plants are contributing to the security of supply and driving the continuing electrification of rural regions. In 2014, Sri Lanka's first solar power plant, with a capacity of 500 kW, was connected to the grid; increasingly, private households are also producing their own solar power. For affluent home owners, this inexpensive, decentralised and environmentally friendly method of generating energy contributes to the appeal of electromobility (Goonewardene, 2015).

Fig. 42: *Ceytros electric three-wheeled taxi, manufactured in Sri Lanka.* © Alibaba, 2015

Due to its relatively small size, Sri Lanka seems fundamentally well suited for applying electromobility solutions. Individual initiatives taken by the Lanka Electric Vehicle Association (LEVA) for the electrification of the transport sector have even received funding from the international community. In 2003, an initial test of electromobility applications was launched in order to promote both the introduction of local pollutant-free vehicles and the creation of jobs through new industries and services. The focus in this context was on electric three-wheelers. Their use in the urban public transport system as well as in a botanical garden was deemed to be useful, and the company Ceytro Lanka was founded with the involvement of partners from Australia. Among the company's plans is the production of electric three-wheelers for use as taxis in Sri Lanka. Key potential customers that were identified include the Ministry of Tourism, shopping centres and private hotels (UNDP, 2005).

Until late 2013, however, electromobility had not played a significant role in the Sri Lankan transport sector. At the beginning of 2014, only about 60 all-electric vehicles were in operation on the island state (Silva, 2014). The company E-Lanka Automotive, an importer of electric vehicles, only sold an average of six electric vehicles per month during that period; however based on political statements, the company estimates the market in Sri Lanka to be somewhere in the range of 100,000 electric vehicles for the next two years (Loveday, 2014). The hope is that change will be brought about through the reduction of import taxes on electric cars (previously 100 %) and the expansion of the charging infrastructure (LeSage, 2014). In the spring of 2015, the focus of support measures was placed on all-electric vehicles (Admin, 2014). Taxes were increased for hybrid vehicles, while for BEVs they were lowered from 25 to 5 %. However, after the significant decrease in taxes on BEVs led to the import of a large number of premium electric cars and a major decline in tax revenues, this was corrected at the end of 2015. Currently, electric vehicles are subject to a tax rate of 50 % (economynext, 2015). At the same time, charging stations are to be built at filling stations, supermarkets and even in residential neighbourhoods across the entire island (Goonewardene, 2015). In the capital Colombo, electric scooters and foreign-made electric cars are available, including the *Nissan Leaf*, but also models by Chinese manufacturers like *Leopard*. Many of the taxis on the roads in Colombo are Japanese hybrid vehicles.

5.8 Bhutan

The Kingdom of Bhutan in the Himalayas is one of the few countries in the world that does not pursue an economic model which is primarily growth-oriented. In Bhutan, the public transport system is very limited. The country's total population is approximately 700,000. The vehicle density in Bhutan is around 70 motor vehicles per 1,000 inhabitants (figures from 2011/2012), which is higher than that of India but lower than the vehicle density in the People's Republic of China. In terms of energy and economic policy, hydropower plays an important role, and so far its potential has only been partially exploited. The country generated approximately 99 % of its electricity in 2010 from hydropower, with the remaining one % coming from fossil fuels (World Factbook, 2010). Since on the whole Bhutan produces more power than it consumes, electricity exports to India and Bangladesh are an important source of foreign currency and a major factor in the state budget. The price of energy in Bhutan, approximately one fifth of what it is in India, is among the lowest in the world (Banerjee 2014). By the year 2020, Bhutan's fossil fuel demand is to be reduced in this way by 70 %.

In recent years the Government of Bhutan has been engaged in talks with Asian automotive companies regarding the shift in the transport sector to electromobility. To this end, in early 2014 representatives of Bhutan and of the Indian company ***Mahindra*** signed a memorandum of understanding for a strategic partnership to promote electromobility (Gopalan, 2014). ***Mahindra*** has already tested its vehicles under the climactic and topographical conditions in Bhutan, which form a demanding testing ground for the electric compact car ***Mahindra e20*** (formerly ***REVA NXR***). At the same time, the ***Nissan Leaf*** was introduced in the capital Thimphu. Nissan is granting a 50 % discount for the first 77 ***Nissan Leaf*** cars purchased. One year after the launch, 50 of the cars have been sold in Bhutan, and orders have been placed for 22 more. This discount makes the ***Nissan Leaf*** cheaper than the ***Mahindra e20***, of which so far not one has been sold (Sundas, 2015) (see Figure 43).

An increase in the use of electric buses and taxis is also planned. Currently, there are about ten electric taxis in the capital Thimphu. There are, however, more far-reaching plans in place in conjunction with the introduction of electromobility. Bhutan's entire vehicle stock

Fig. 43: *E-Taxi in Thimphu, Bhutan, 2016.* © Manfred Breithaupt

comprises only approximately 80,000 vehicles. Against this background, the prospect of a blanket electrification of the transport system, provided that corresponding support programmes are instituted, does not seem unrealistic. In the coming years, to up to 8,000 electric cars are to be imported into the country. The general import ban on passenger cars does not apply to electric cars. According to the Bhutanese Prime Minister Tobgay, it is the task of the government to create an overall concept that will facilitate measures such as purchasing incentives, tax relief and infrastructure funding. As Tobgay explains, however, success is ultimately dependent on supply and demand (Dema, 2014).

Since the entire length of the country's paved roads is only 5,000 kilometres, it is also realistic to meet the need for infrastructure in the form of charging stations. There are currently five charging stations in the capital and one at the airport in Paro. By the year 2018, 150 charging stations are planned across the country (Tshering, 2014). Thanks to the large share of hydroelectric power, the electricity could come almost completely from regenerative sources. However, the low purchasing power of the Bhutanese population is an inhibiting factor. The coming years will show whether or not Bhutan can seize its opportunity to become the first territorial state with a fully electric motorised individual transport system.

6. Recommendations for Electromobility

The descriptions and examples detailed above illustrate the wide range of electrically powered vehicles for the transport of persons and goods which are already being used in different applications, some of which are only in the testing stage. Larger scale funding programmes can often be found in countries where the interest in electromobility is rooted in industrial policy, primarily in the People's Republic of China, India and Japan. These countries often implement projects employing large fleets of vehicles with daily mileage amounts of fewer than 100 km and high annual mileage amounts. In many cases, central stakeholders are involved (*e.g.* large companies and governmental authorities) that can implement vehicle and charging infrastructure solutions from a single source and can afford to conduct larger-scale tests than smaller private companies.

With the emergence of the first series production models of hybrid vehicles, and increasingly of BEVs, private users are also able to profit, albeit to varying degrees, from the purchase incentive programmes established by their respective national governments and city administrations.

In places where the overall conditions have been significantly altered in favour of electromobility, for example when the People's Republic of China banned conventional scooters, we have seen the development of proper mass markets for electromobility.

Electromobility applications, however, have also been successful in the two-wheeled vehicle segment, even without support measures or regulatory intervention. The same applies for certain segments of electric utility vehicles.

The range of uses, locations and countries where electromobility can be implemented is extremely heterogeneous. The first distinction that must be made is between rural and urban usages of electromobility:

1. In ***rural areas*** there are fewer processing and supply structures for goods and services, and the level of prosperity is generally lower than in industrial or urban metropolitan areas. Furthermore, the transport infrastructure is often less developed and public transport services do not exist or are less widespread. As a rule, the distances to be covered are longer (medium to long distances), and users often have to transport heavier loads than is the case in cities. The key challenge here lies in the creation of additional, affordable and environmentally friendly mobility services and a basic infrastructure, while environmental impacts play a relatively small role.
2. In ***urban areas*** there are jobs in industry and in the service sector. Here, people who have a relatively high level of prosperity (by national standards) have a diverse range of supply structures, as well as educational and cultural possibilities at their disposal. Metropolitan areas generally offer a well-developed road infrastructure and in many cases a range of public transport services. The distances travelled are often shorter than in rural areas. In metropolitan areas, the transport density and emissions levels are generally high. The key challenge in metropolitan areas lies in dealing with increasing traffic volume and often poor air quality.

Furthermore, there must be a differentiation between places with highly developed and less developed infrastructures. This pertains in particular to the scope, quality and stability of the transport, electricity and data networks.

- ***Less developed infrastructures*** are characterised by intermittent supply and a high susceptibility to disruptions of transport, data and energy networks. The central challenge in the integration of electromobility is initially the development of basic energy and transport infrastructures, which then form the basis for subsequent development.
- ***Well developed transport, energy and data networks***, on the other hand, are characterised by a high degree of robustness and stability. A wide range of interfaces and interconnection points ensures a variety of mobility, energy and communications services which electromobility can build upon. The central challenge in the integration of electromobility consists of interlinking the existing transport systems, organising the resulting complexity (energetic load management) as well as ensuring data protection and protection from abuse of data.

Combining these two criteria produces four clusters which must be examined. Given the acute adverse effects to health and the environment resulting from the use of fossil fuels and their finite supply, in particular with regard to the transport sector, it is clear that additional measures and approaches are needed.

And in the medium to long term, factors such as the high efficiency of electric motors ALT electromobility. Electromobility, however, should not be understood as the mere electrification of the propulsion system and a "stand-alone" solution. Instead, it represents individual components of overarching transport solutions in passenger and freight transport and must be fitted into a holistic concept of transport and energy.

Electromobility should therefore always be understood as part of a larger systemic solution. Charging solutions and energy production and supply in particular should always be integrated into a comprehensive planning process. Initially, viable operating and business models must be developed for individual components, and administrative and political parameters must be created or adjusted. With regard to supported charging standards, particular attention must also be given to the issue of compatibility with local electricity networks and load capacity, since fast charging technology for example can place high demands on network capacity and stability. Not least, the successful implementation of solutions must also take account of societal factors. This includes the availability of affordable products and services for the general public, and also the image and symbolic value of the vehicles for their users. (see Table 8)

Considering the diversity of possible applications for electromobility, and the heterogeneity of the specific challenges, development stages and framework conditions found in different countries and cities, only general recommendations can be given for each cluster:

Areas with low population density and a rudimentary infrastructure offer only limited possibilities for an immediate and comprehensive implementation of electromobility. In most cases the energy and transport networks are not developed enough to allow a reliable and comprehensive infrastructure for electromobility solutions to be built up. If shares of renewable energy generation in the electricity mix are low, electromobility applications are of little environmental benefit. That is why it is fundamentally important to initially promote the development of a decentralised electricity supply based on regenerative energy sources – for example through photovoltaic systems – in order to create the infrastructure foundation for an electromobility that is ecologically sustainable. The use of all-electric vehicles is restricted to small-scale applications. And in that

Table 8: Typical of electromobility application cases according to different parameters

	Metropolitan area ■ High traffic density, air pollution, short transport distances	**Rural municipality** ■ Low traffic density, low air pollution, longer transport distances
... advanced infrastructure ■ High capacity power network, data network needed	**Cities** Tokyo (Japan), Shanghai, Beijing (China), Singapore, Gumi (Korea) **Examples** e-carsharing, e-car rental, inductive e-busses	**Places** Goto Islands Nagasaki (Japan), ports/airports **Examples** e-car rental, electric load carriers, e-busses
... basic infrastructure ■ Low load capacity of power network and no data network needed	**Cities** Manila (Philippines), Delhi (India) **Examples** e-jeepney/e-busses, e-tricycles, e-scooters, e-bikes	**Places** countryside **Examples** utility vehicles with battery change system, e-tricycles, e-load carriers, e-bikes

Source: Own data

context, the connection of a household photovoltaic system with an electric vehicle also provides stability for the household power supply. Otherwise, it is the hybrid vehicle, with its compatibility with conventional supply infrastructures, which offers the range necessary to be able reach surrounding cities and supply centres. Under these circumstances, charging stations should first be built at decentralised power generation facilities in order to avoid putting a further strain on the already unreliable electricity grid.

Unlike regions with less developed infrastructures, it is areas with a low population density and a well developed infrastructure — tourist developments for example — which exhibit the necessary prerequisites for the effective use of electromobility. The electricity grids here normally have a higher capacity and reliability, thus enabling fast charging with higher loads, for example. Here too, the environmental benefit of electromobility depends on the share of electricity that comes from renewable energy sources. The development of a charging infrastructure in this case is relatively inexpensive, since the individual charging stations do not require large-scale stationary batteries for the storage of decentralised generated power. The promotion of electromobility could take the form of a purchase of a fleet of electric vehicles by city government and the first installation of public charging stations. Beyond support measures to promote the use of electric vehicles at municipal level, there are other electromobility applications to be considered: A programme to promote the use of electric shuttles, rental cars and delivery vehicles in tourism or in local hotels and restaurants is another possible application.

In Asia it is common to find areas of high development with only rudimentary infrastructure. The expansion of a regenerative system of electricity supply and the creation of a charging infrastructure present a particular challenge for these regions. For this reason, the installation of decentralised, autonomous electricity generation and charging systems is advantageous. In the context of an expansion of the regenerative electricity generation system, there could be an interlinking of buildings and facilities, for example into "smart grids", which would in this way be developed into islands with supply-side stability that can eventually incorporate electromobility applications through controlled charging and vehicle-to-grid functions. Such a step offers benefits for infrastructural development, increases energy autonomy and can create the infrastructure foundations for the implementation of electromobility solutions. In comparison with North American and European cities, Asian cities have a much higher population density per square kilometre. Older diesel buses and delivery vehicles, motorcycles and scooters, and other contributing factors have led to high levels of air pollution. The use of electric vehicles, particularly as buses and delivery vehicles, rickshaws and taxis, is an important step towards reducing pollution. Since these kinds of uses often employ centrally managed fleets, fixed routes or parking areas, there is initially only a limited need to build new charging infrastructures. Corresponding procurement programs seem to be a useful approach in such cases. In the two-wheeled sector, electromobility can likewise contribute to significant improvements; in this case comprehensive infrastructure programmes are not necessary, although regulations to restrict the use of internal combustion vehicles — *e.g.* environmental zones — are recommended. Individual motorised transport, in particular the use of passenger cars, is quickly reaching its limits, alone due to the space it requires in high-density areas with underdeveloped infrastructure. However, while the use of electric vehicles can help mitigate air pollution, it will not on its own completely solve the problems of congestion and shortage of parking space. The promotion of private electric cars does not appear to be useful in this respect, unlike restrictive parking management does. Carsharing models will tend to be successful in more affluent cities with higher security standards, as the vehicles in use can otherwise be the target of theft and vandalism.

High-density areas with highly developed transport, data and energy infrastructures present an arena for integrated transport systems. Long-term spatial and transport planning is complemented by an efficient system of traffic management. An optimal presentation of intermodal real-time information, possibly supplemented by price systems based on load and pollution levels, could already create a steering effect which is favourable to electromobility. The integration of electromobility solutions can be carried out in a first step through the introduction of electric buses in the public transport system, which would provide an initial reduction of pollution levels. This could be followed by publicly available services such as e-taxis, e-carsharing, e-scooter sharing, e-bike sharing, etc. However, these steps must be taken in parallel with the expansion of electricity generation from renewable energy sources, if climate protection targets are to be met. The introduction of electrically powered taxis, and to an even greater degree of e-carsharing models, will provide the impetus for building and developing a public charging infrastructure that can later be used for private transport as well. Moreover, publicly available services also allow broad sections of the population to test new modes of transport based on electromobility. Any possible isolated economic disadvantages arising from the operation of electric transport systems must be seen in the context of broader societal benefits. Particularly worthy of support measures are resource-efficient and space-saving solutions in high-density metropolitan areas. If the societal benefit outweighs the drawbacks, then funding measures and/or restrictions and price increases for less desirable conventional alternatives are appropriate.

Precisely what kind of electromobility applications should be actively promoted today, and what specific mix of measures local governments should implement is a matter for national decision-makers to determine. Possible measures range from funding instruments and funded pilot applications to legislative restrictions (*e.g.* driving bans and requirements for manufacturers) and financial policy incentives (*e.g.* taxing or toll systems). It is important that the measures are sustainable and scalable, and that they are the starting point for both long-term and short-term initiatives. The entry into the post-fossil mobility era, on the one hand, requires staying power, since in the process renewable energy sources must be developed, infrastructure built and barriers to purchase and utilisation eliminated. On the other hand, short-term success is also important in order to remove the most urgent development bottlenecks and to gain the support of the population, and also to recognise and correct any misguided developments at a sufficiently early stage.

Countries that already have high shares of environmentally friendly electricity generation and that are continuing to expand the use of regenerative energy should promote the study, testing and operation of combined, systemic solutions. This could benefit a variety of different industries (automobile industry, vehicle manufacturing sector, and also the electronics and energy and recycling industries). The framework conditions should be designed in such a way that private sector actors are able to easily implement necessary business models. However, a permanent, purely supply-side subsidy system should be regarded critically, as in the long run this would put a strain on state budgets and could reduce the incentive for implementing self-sustaining business models. The Chinese funding strategy is currently undergoing a transformation from financial subsidies to market-based incentive systems. For example, a loan programme based on a model used in the US state of California is currently being discussed: This would require large car manufacturers to provide a certain number of so-called zero emission vehicle credits. State loans would only be provided to those manufacturers who sell low-emission vehicles. However, manufacturers would be able to trade those credits between each other, leading to the creation of a ZEV credit market (China Observer, 2015).

Just as important as industrial policy support in the form of push-measures is the setting of social incentives as pull-measures to stimulate demand for sustainable electromobility solutions. What it comes down to is how people on the ground accept electromobility and utilise it in their daily lives. Integrated comprehensive concepts that can compete with conventional solutions in terms of their relative costs will determine if there is long-term success or not. The reduction of import taxes and import restrictions for electric vehicles, *i.e.* an exception for electric vehicles from taxation as “luxury articles” could be a promising way to promote electromobility.

One European country that is successfully implementing a broad mix of pull-measures is Norway (exemption from the import tax, waiving of 25 % value-added tax and motorway fees, possibility of using bus lanes, free parking on municipal car parks, free charging). As a result of these combined measures, 20 % of new vehicle registrations in Norway are now electric vehicles (dpa, 2015). But demand-side incentives would not be enough of a stimulus if it weren’t for the overall positive public reception of electric vehicles. In order to ensure that transaction costs and the necessary changes in routine for users are kept to a minimum, the access to transport services should be designed to be simple and uniform with regard to intermodal use.

With a view to developing and emerging economies, the following points should be identified as necessary prerequisites for a successful and intelligent implementation of electromobility solutions:

State funding is required for the initial development of electromobility. Here there must be a consistent and integrated approach incorporating both transport and energy policy measures.

Energetic requirements:
- A high proportion of regenerative energy in the national electricity mix;
- A clear and long-term political framework for the expansion of renewable energy generation capacities;
- Establishing stable electricity networks to cover generation, transmission and distribution needs efficiently and stably, also in the case of load fluctuations;
- Creating buffer capacity for fluctuations from renewable energy generation (*e.g.* pumped storage facilities, stationary storage systems, etc.);
- Support for building and expanding a standardised charging infrastructure (plugs, services, access and payment systems).

Transport requirements:
- Countries with import restrictions and tariffs on means of transport should consider easing or lowering relevant regulations for all-electric vehicles or parts and components of such vehicles.
- National and local authorities should actively support demonstration, research and pilot projects in the area of electromobility through technical, financial and regulatory measures (including vehicle registration, privileges for use of streets and parking areas), as well as communication measures, and should lead the way by advancing the electrification of public vehicle fleets.
- In addition to the promotion of electromobility, measures to regulate or restrict less environmentally friendly means of transport should be considered. This could entail the removal of subsidies for conventional fuels, bans on high-contaminant fuel blends, internal combustion engines and vehicles, as well as the introduction of parking management and road pricing systems that exclude electromobility.
- Under certain conditions, electrically operated vehicles have both environmental and economic advantages, for example when used in public transport fleets, as taxis or as delivery vehicles. In these scenarios, electromobility solutions are directed at the general population (e-buses, two- and three-wheelers) rather than having relevance only for the upper class. The introduction of electromobility should keep a focus on this aspect.
- In particular in urban areas, electromobility should be defined as part of an integrated mobility system and accordingly integrated into networked multimodal solutions.

7. Online Sources

ADB, 2009	http://www.adb.org/sites/default/files/publication/27519/electric-bikes-ind-vie.pdf
ADB, 2014	http://www.adb.org/sites/default/files/publication/42808/sustainable-urbanization-asia-and-latin-america.pdf
ADFC, 2015	http://www.adfc.de/pedelecs/elektrorad-typen/elektrorad-typen
AECOM, 2011	http://ec.europa.eu/transport/themes/urban/studies/doc/2011-smartcards-final-report.pdf
Admin, 2014	http://www.adaderana.lk/bizenglish/electric-cars-in-sri-lanka-too-will-be-cheaper
Alibaba, 2015	http://ceytrolanka.fm.alibaba.com/product/11121370-10773674/Ceytro_Electric_Three_Wheeler.html
Asian Development Bank, 2012	http://www.adb.org/news/300-million-green-transportation-revolution-philippines-adb
Avda, 2013	https://commons.wikimedia.org/wiki/File:Berlin_-_Potsdamer_Platz_-_E-Mobility-Charging.jpg
bcs, 2007	http://www.carsharing.de/alles-ueber-carsharing/studien/wirkungen-und-entlastungspotenziale-neuer-verkehrsdienstleistungen
Berlin Institut, 2007	http://www.berlin-institut.org/online-handbuchdemografie/bevoelkerungsdynamik/regionale-dynamik/lateinamerika.html
Berhart *et al.*, 2014a	http://www.rolandberger.de/media/pdf/Roland_Berger_Index_Elektromobilitaet_Erstes_Quartal_2014_20140301.pdf
Bernhart *et al.*, 2014b	http://www.rolandberger.de/media/pdf/Roland_Berger_Index_Elektromobilitaet_3_Quartal_2014_20140919.pdf
Bierau *et al.*, 2014	http://www.japan.ahk.de/fileadmin/ahk_japan/Publikationen/PDF/Trendbericht_Elektromobilitat_in_Japan_Februar_2014_Klein.pdf
blogspot, 2013	http://newsandfeaturesonindonesia.blogspot.de/2013/01/the-entire-national-electric-car.html
Böhler-Baedeker/Hüging, 2012	http://www2.giz.de/wbf/4tDx9kw63gma/SUT_module5h.pdf
Bosch, 2011	https://www.bosch-si.com/solutions/mobility/our-solutions/test-bed-singapore.html
Brown, 2014	http://wallstreetpr.com/the-car-share-program-of-kandi-technologies-group-inc-nasdaqkndi-32695
Bulut, 2013	http://www.busplaner.de/aktuelles/omnibus-news-touristik-nachrichten/9665/Bogota-setzt-auf-Elektromobilitaet/Volvo-erhaelt-Hybridbus-Grossauftrag-in-Sue
BYD, 2013	https://bydcompany.wordpress.com/2013/03/22/56-reduction-anticipated-in-hong-kong-vehicle-emissions-through-electrified-public-transportation
BYD, 2015a	http://www.byd.com/news/news-305.html
BYD, 2015b	http://www.byd.com/news/news-316.html
Chademo, 2016	http://www.chademo.com/wp
Chamon/Mauro/Okawa, 2008	http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1108502##

Central Bank of Sri Lanka, 2013	http://www.cbsl.gov.lk/pics_n_docs/10_pub/_docs/statistics/other/econ_&_ss_2013_e.pdf
China Observer, 2015	http://www.china-observer.de/index.php/2015/10/09/forderung-von-elektromobilitat-in-china
China Auto Web, 2015a	http://chinaautoweb.com/2015/01/2014-ev-sales-ranking
China Auto Web, 2015b	http://chinaautoweb.com/2015/07/chinese-ev-sales-ranking-in-the-first-half-of-2015
CIA Factbook, 2010	https://www.cia.gov/library/publications/the-world-factbook/geos/bt.html
Dalkmann/Brannigan 2007	http://star-www.giz.de/dokumente/bib/07-1296.pdf
Disgnmind, 2014	https://designmind.frogdesign.com/2014/01/chinas-electric-bike-charging-cultures
Drewitz/Rommerskirchen, 2011	http://www.internationalesverkehrswesen.de/fileadmin/user_upload/pdfs/www.internationalesverkehrswesen.de_1_2011_Progtrans.pdf
GDV, 2013	http://www.gdv.de/2013/04/pedelec-ist-nicht-gleich-pedelec
Government of India, 2012	http://dhi.nic.in/NEMMP2020.pdf
Destatis, 2014	http://de.statista.com/statistik/daten/studie/222155/umfrage/herstellung-von-omnibussen-in-china
DNAindia, 2014	http://www.dnaindia.com/bangalore/report-bangalore-to-get-quick-charging-stations-for-electric-cars-1963458
Doll/Tauber, 2014	http://www.welt.de/wirtschaft/article132561785/Daimlers-indische-Geheimwaffe-gegen-China-Trucks.html
dpa, 2015	http://www.handelsblatt.com/auto/nachrichten/norwegen-elektroauto-boom-dank-staatlicher-foerderung/12211510.html
eco-business, 2014	http://www.eco-business.com/news/singapore-concludes-electric-vehicle-test-bed-may-conduct-further-trials
Economynext, 2015	http://www.economynext.com/Sri_Lanka_tax_hike_prompted_by_$100,000_electric_cars_coming_at_2.5_pct__Ravi-3-3590-1.html
Edelstein, 2015	http://www.greencarreports.com/news/1085908_one-new-york-cabbie-loves-his-nissan-leaf-electric-taxi
Electric car news, 2015	http://electriccarsreport.com/2015/01/kandi-deliver-5000-electric-vehicles-chengdu-city
Electricvehicle news, 2010	http://www.electric-vehiclenews.com/2010/05/byd-e6-electrictaxis-hit-roads-in.html
Electricvehicle news, 2013	http://www.electric-vehiclenews.com/2013/01/indonesian-official-breaks-speed-limit.html
electricvehiclenews, 2014	http://www.electric-vehiclenews.com/2014/04/electric-car-sales-set-to-take-off-in.html
Emobil-umwelt.de, 2015	http://www.emobilumwelt.de/index.php/projektergebnisse/gesamtbilanzen/batterieelektrische-pkw
Fan, 2014	http://usa.chinadaily.com.cn/world/2014-11/10/content_18891185.htm
Goonewardene, 2015	http://www.ft.lk/article/433871/Is-Sri-Lanka-ready-for-electric-mobility?
Gopalan, 2014	http://www.thehindubusinessline.com/companies/mm-to-steer-bhutans-electric-mobility/article5732334.ece

Gunasekara, 2014	http://www.ceylontoday.lk/90-75800-news-detail-await-vega-sls-first-electric-lamborghini.html
Hamiltion, 2009	http://www.technologyreview.com/news/415773/next-stop-ultracapacitor-buses/?a=f
Handelsblatt online, 2014	http://www.wiwo.de/unternehmen/industrie/chinesisches-elektroauto-daimler-beginnt-mit-produktion-von-denza/10674266.html
Hillebrand/Hüging, 2015	http://www.dlr.de/dlr/presse/Portaldata/1/Resources/documents/2015/DLR_Stuttgart_STROMbegleitung_Abschlussbericht.pdf
Hubject, 2015	http://www.hubject.com
ICLEI, 2011	http://www.ecomobility.org/fileadmin/template/project_templates/ecomobility/files/Publications/Case_stories_EcoMobility_Hangzhau_PDF_print.pdf
IEA, 2013	https://www.iea.org/publications/globalevoutlook_2013.pdf
Ifeu, 2010	http://www.ifeu.de/verkehrundumwelt/pdf/Helms%20et%20al.%20(2010)%20Electric%20vehicles%20(TAP%20conference%20paper).pdf
India Today, 2011	http://indiatoday.intoday.in/story/a-single-travel-card-for-all-public-transport-on-cards/1/163126.html
INSG Insight – No. 23, 2014	http://www.insg.org/docs/INSG_Insight_23_Global_Ebike_Market.pdf
International Transport Forum/OECD, 2014	http://internationaltransportforum.org/Pub/pdf/14IrtadReport.pdf
Jaffe, 2015	http://www.citylab.com/tech/2015/06/singapore-is-already-planning-for-a-future-of-driverless-taxis/396707
Jing, 2015	http://www.globaltimes.cn/content/900877.shtml
Jung, 2015	https://sustainabletransport.org/fewer-cars-more-mobility-can-carsharing-work-in-china
KAIST, 2010	http://olev.kaist.ac.kr/en/olevco/2.php
KAIST, 2015	http://www.smfir.co.kr
Kandi Technologies, 2012	http://uk.reuters.com/article/2012/08/13/idUS104247+13-Aug-2012+MW20120813
Kandi Technologies, 2014a	http://en.kandivehicle.com/ProductDetail.aspx?kid=72
Kandi Technologies, 2014b	http://en.kandivehicle.com/NewsDetail.aspx?newsid=145
Khandelwal, 2015	http://thetechportal.in/2015/02/14/meet-vega-supercar
Klötzle *et al.*, 2013	http://elib.dlr.de/87884/1/14%20STROMbegleitung%20Arbeitspapier%202013%20-%20Ergebnisse%20Forschungsreise%20Indien_anonym.pdf
Knoblach, 2013	http://www.berliner-zeitung.de/wirtschaft/elektromobilitaet-e-scooter-statt-e-auto,10808230,23700954.html
Korea IT Times, 2015	http://www.koreaittimes.com/story/44319/seoul-city-introduce-50000-evs-2018
Korea Transport Institute, 2014	http://english.koti.re.kr/board/report/index.asp?code=research_report&cate=2&mCode=040200
Kühl, 2014	http://www.manager-magazin.de/unternehmen/autoindustrie/analyse-chinas-neue-foerderungen-stuetzen-absatzboom-bei-elektroautos-a-993067.html

Kuther, 2012	http://www.elektromobilitaet-praxis.de/e-antriebe/technologie-und-forschung/articles/377747
Leonzon, 2010	https://www.devex.com/news/as-adb-shifts-gears-a-new-lending-focus-on-urban-transport-67408
LeSage, 2013	http://green.autoblog.com/2013/12/27/kandi-ev-vending-machine-carsharing-china
LeSage, 2014	http://www.autoblog.com/2014/01/09/sri-lanka-wants-to-import-more-evs
Leuphana Universität, 2013	http://www.leuphana.de/news/meldungen/titelstories/oekobilanz-von-elektroautos-untersucht.html
Li Zoe, 2014	http://edition.cnn.com/2014/04/24/world/asia/china-electric-vehicles
live mint, 2015	http://www.livemint.com/Politics/noBxmpkbhRAqTKP60sBI8M/Govt-earmarks-Rs1000-crore-to-boost-electric-vehicle-sales.html
Lockström/Callarman/Lei, 2011	http://www.ide.go.jp/English/Publish/Download/Jrp/154.html
Loveday, 2014	http://insideevs.com/ceo-e-lanka-automotive-sri-lanka-will-100000-electric-vehicles-road-just-2-years
Luan, 2015	http://news.xinhuanet.com/english/china/2015-02/25/c_134016535.htm
Ma JianYong, 2014	http://www.cev-pc.or.jp/event/pdf_n/japanese/7-2.pdf
Marchán/Viscidi, 2015	http://www.thedialogue.org/wp-content/uploads/2015/10/Green-Transportation-The-Outlook-for-Electric-Vehicles-in-Latin-America.pdf
Mahindra, 2015	http://mahindrareva.com
Marchetti, 2013	http://earthtechling.com/2013/11/100000-electric-cars-target-of-chinese-car-sharing-project
Mein Elektroauto, 2012	http://www.mein-elektroauto.com/2012/02/batterien-fur-elektroautos-werden-laut-tesla-motors-immer-gunstiger/4683
Meissner, 2014	http://www.merics.org/fileadmin/templates/download/china-monitor/China_Monitor_No_17.pdf
Ministry of Heavy Industries and Public Enterprises, 2012	http://planningcommission.nic.in/aboutus/committee/wrkgrp12/wg_auto1704.pdf
Mishra, 2014	http://forbesindia.com/article/auto-expo/electric-cars-hit-by-poor-infrastructure-and-government-inaction/37123/1
MYrapid, 2015	http://www.myrapid.com.my/projects/brt-sunway-line/about-project
Nicola, 2013	http://kojects.com/2013/02/08/namsan-e-bus-first-commercial-electric-bus-worldwide
Neubert, 2012	http://www.urbanophil.net/urbane-mobilitat/chinas-road-to-e-bike
Nugraha, 2014	http://en.voi.co.id/voi-editorial/6507-indonesian-electric-cars-cannot-be-mass-produced
OECD/IEA, 2015	http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf
Öko-Institut, 2011	http://www.oeko.de/fileadmin/pdfs/oekodoc/1283/2011-413-de.pdf
Omnibusarchiv, 2009	http://www.omnibusarchiv.de/include.php?path=content&mode=print&contentid=269

Pabst/Trentmann, 2014	http://www.welt.de/print/die_welt/wirtschaft/article131357139/Gegen-den-Strom.html
Pandit, Kapur; 2015	http://khub.niua.org/wp-content/uploads/2015/05/Electric_Vehicles_-_Policies_Opportunities_Scenario_1-SPandit.pdf
Patoni, 2012	http://blogs.wsj.com/indonesiarealtime/2012/07/24/indonesia-powers-ahead-with-electric-car-plans/?mg=blogs-wsj&url=http%253A%252F%252Fblogs.wsj.com%252Fsearealtime%252F2012%252F07%252F24%252Findonesia-powers-ahead-with-electric-car-plans%252F
Pedelec-portal, 2011	http://www.pedelec-portal.net/was-bedeutet-watt-ampere-und-kwh/0059
Pflanzelt, 2014	http://www.spiegel.de/spiegel/spiegelwissen/d-130025982.html
Pluta, 2013	http://www.golem.de/news/elektromobilitaet-suedkoreanische-stadt-elektrifiziert-nahverkehr-1308-100839.html
Präfektur Nagasaki, 2011a	http://www.pref.nagasaki.jp/ev/ev&its/en/eng_ev&its5.pdf
Präfektur Nagasaki, 2011b	https://www.pref.nagasaki.jp/ev/ev&its/en/index.html
Praveen, Kalyan; 2013	http://www.ripublication.com/aeee/61_pp%20%20%20471-476.pdf
Rogowski, 2013	http://www.forbes.com/sites/markrogowsky/2013/12/28/kandi-crush-an-electric-car-vending-machine-from-china-could-upend-the-auto-industry
Roland Berger, 2013	http://www.rolandberger.com/media/studies/2013-10-29-rbsc-pub-Are_we_running_out_of_oil.html
Roland Berger, 2014a	http://www.rolandberger.de/pressemitteilungen/Car_Sharing_in_China_2014.html
Roland Berger, 2014b	http://www.rolandberger.de/media/pdf/Roland_Berger_Index_Elektromobilitaet_3_Quartal_2014_20140919.pdf
Roland Berger, 2015a	http://www.rolandberger.de/media/pdf/Roland_Berger_E_Mobility_Index_Q1_2015_e_20150325.pdf
Roland Berger, 2015b	http://www.rolandberger.com/media/pdf/Roland_Berger_e_mobility_index_Q3_2015_20150911.pdf
S2R Consulting, 2009	http://www.trolleymotion.eu/www/uploads/tx_sbdownloader/DLR_062009_asm.pptx
Saving-volt, 2015	http://www.saving-volt.de/2015/01/geschichte-der-elektromobilitaet-bei-nissan-zukunft-mit-tradition
Scherf, 2008	https://bibliothek.wzb.eu/pdf/2008/iii08-103.pdf
Schiffer, 2015	http://www.et-energie-online.de/AktuellesHeft/Topthema/tabid/70/NewsId/1518/Bedeutung-der-Wasserkraft-fur-die-weltweite-Stromerzeugung.aspx
Schwarzer, 2014	http://www.zeit.de/mobilitaet/2014-11/alternative-antriebe-elektroautos-induktives-laden
Schwarzer, 2015	http://www.zeit.de/mobilitaet/2015-02/elektroauto-bosch-batterie
SG Carmart, 2013	http://www.sgcarmart.com/news/article.php?AID=7482
Shao, Wagner; 2015	http://www.theicct.org/sites/default/files/publications/ICCT_China_MVEC_benefits-costs_20150629.pdf
Silva, 2014	http://www.thesundayleader.lk/2014/04/06/100000-e-cars-in-two-years
Sirap bandung, 2015	https://commons.wikimedia.org/wiki/File:RapidKL_electric_bus.jpg

SloCat, 2014	http://www.slocat.net/climatesummit
Sorge, 2014	http://www.manager-magazin.de/unternehmen/artikel/niedrigpreise-schwaechen-chinas-monopolstellung-fuer-seltene-erden-a-998373.html
Statista, 2016	http://de.statista.com/statistik/daten/studie/244999/umfrage/weltweiter-pkw-und-nutzfahrzeugbestand
straitstimes, 2014	http://www.straitstimes.com/singapore/transport/driverless-vehicles-take-to-the-tarmac-three-examples-in-singapore-and-overseas?page=47
Sundas, 2015	http://www.wheels24.co.za/News/Tiny-kingdom-chasing-clean-cars-lead-20150610
Teslamotors, 2015	http://www.teslamotors.com/findus/list/superchargers/China
Thai PBS, 2015	http://englishnews.thaipbs.or.th/bangkok-ranked-among-worlds-top-10-cities-worst-traffic
THECRWODFUNDING-CENTER, 2015	http://thecrowdfundingcentre.com/?page=project&id=XRAK8P
The dep. of national Planning, 2010	http://www.treasury.gov.lk/publications/mahindaChintanaVision-2010full-eng.pdf
TomTom, 2014	http://www.tomtom.com/en_gb/trafficindex/#/list
Terra Motors, 2015	http://www.terra-motors.com/ph/tricycle/y6
Trentmann, 2015	http://www.welt.de/wirtschaft/article139707971/Jetzt-entdecken-auch-Chinesen-das-Carsharing.html
Tshering, 2014	http://www.uncrd.or.jp/content/documents/22548EST-P2_Bhutan.pdf
UNDP, 2005	https://sgp.undp.org/index.php?option=com_sgpprojects&view=projectdetail&id=423&Itemid=205
UNFCCC, 2010	http://unfccc.int/secretariat/momentum_for_change/items/7102.php
UTIP, 2015	http://www.rupprecht-consult.eu/uploads/tx_rupprecht/FINAL_UITP_brochure_trolleybus_DIGITAL_mail.pdf
VDMA, 2014	http://www.forum-elektromobilitaet.de/assets/mime/-UTQ3ZSydci,2IhxsCWJpIRWnyTp-w0eicET+TsD2iIPmIljtC/Roadmap-Batterie-Produktionsmittel-2030.pdf
Venugopal/Sampath, 2012	http://mnre.gov.in/file-manager/akshay-urja/november-december-2012/EN/24-26.pdf
Vertretung der Bundesrepublik Deutschland, 2010	http://www.china.diplo.de/Vertretung/china/de/03-wi/verk/elektromobilitaet/120104-02-elektromobilitaet-in-ch-s.html
VDA, 2013	https://www.vda.de/de/services/Publikationen/tatsachen-und-zahlen-2013.html
VDI/VDE, 2016a	http://www.erneuerbar-mobil.de/de/schlagwortverzeichnis/battery-electric-vehicles-bev
VDI/VDE, 2016b	http://www.erneuerbar-mobil.de/de/schlagwortverzeichnis/plug-in-hybrid-electric-vehicle-phev
VDI/VDE, 2016c	http://www.erneuerbar-mobil.de/de/schlagwortverzeichnis/range-extended-electric-vehicle-reev
Weißenborn, 2015	http://www.welt.de/motor/article136100544/Sie-kennen-SUV-aber-was-ist-ein-FCEV.html
World Bank, 2011	http://data.worldbank.org/indicator/IS.VEH.NVEH.P3

WWF, 2008	http://assets.panda.org/downloads/plugged_in_full_report___final.pdf
ZSW, 2015	http://www.zsw-bw.de/infoportal/aktuelles/aktuelles-detail/mehr-als-740000-autos-welt-weit-fahren-mit-strom.html

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
GIZ Bonn and Eschborn, Germany

Sector Project ‘Transport Policy Advisory Services’
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
Tel. +49 (0) 6196 79-2650
Fax +49 (0) 6196 79-802650
transport@giz.de
www.giz.de/transport

Authors
Christian Scherf, Dr Frank Wolter

Manager
Manfred Breithaupt

Design and layout
Klaus Neumann, SDS

Photo credits
Cover photo: Electric Taxis in Mexico City © Manfred Breithaupt, 2012

As of
May 2016

GIZ is responsible for the content of this publication.

On behalf of
Federal Ministry for Economic Cooperation and Development (BMZ)
Division Water; Urban development; Transport

Addresses of the BMZ offices

BMZ Bonn
Dahlmannstraße 4
53113 Bonn, Germany
Tel. +49 (0) 228 99 535 – 0
Fax +49 (0) 228 99 535 – 3500

BMZ Berlin
Stresemannstraße 94
10963 Berlin, Germany
Tel. +49 (0) 30 18 535 – 0
Fax +49 (0) 30 18 535 – 2501

poststelle@bmz.bund.de — www.bmz.de