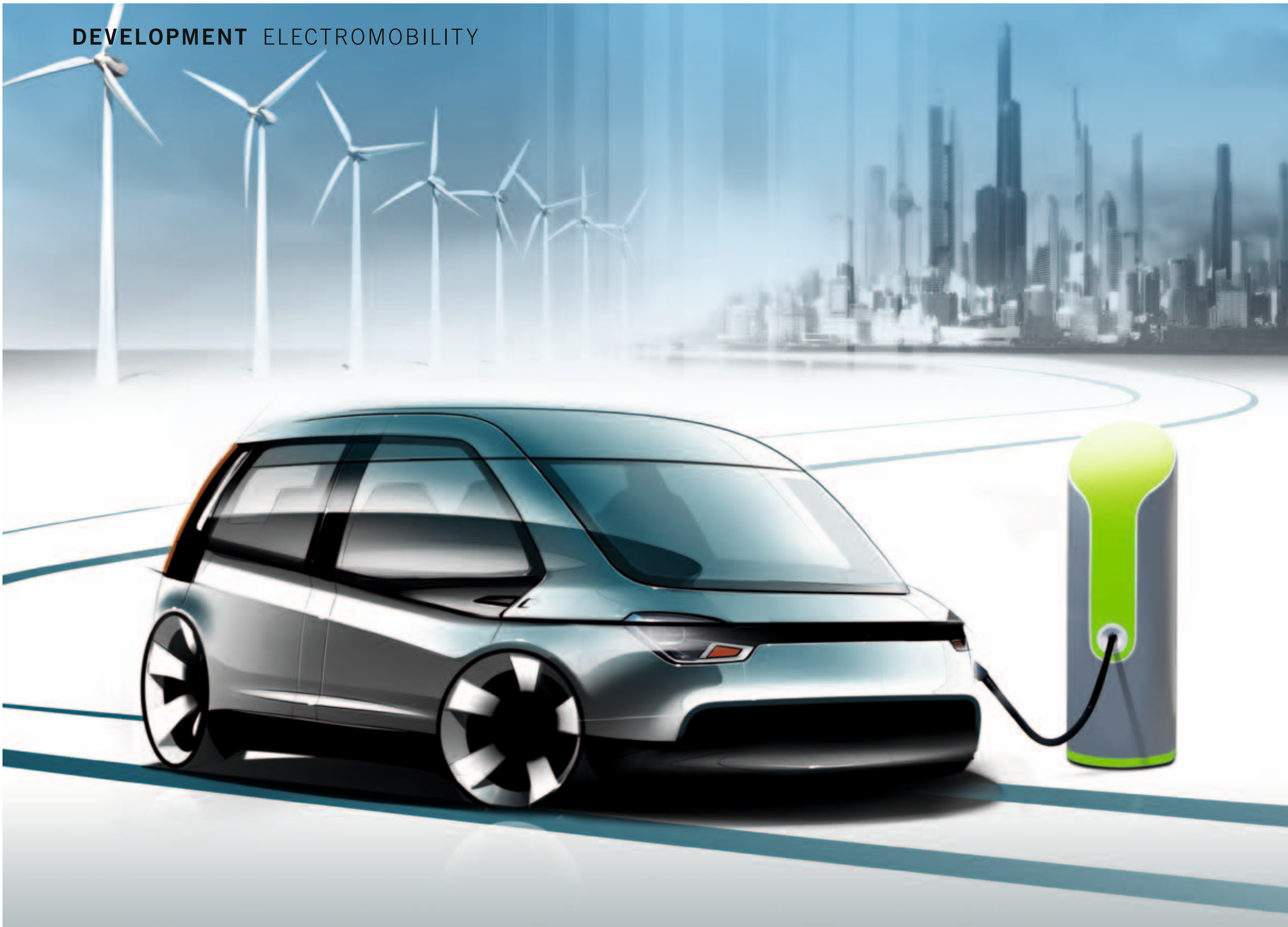

DESIGN OF ELECTRIC VEHICLE CONCEPTS FOR MEGACITIES IN ASIA

Electromobility can help to reduce the air and noise pollution, which is often very high in Asian megacities. Illustrated with the examples of Shanghai and Singapore, TUM Create and Technische Universität München show appropriate electric vehicles derived conceptually from specific usage and mobility patterns. Here the efficiency and sustainability are highly dependent on the regional conditions with regards to infrastructure, energy, climate and politics. This is demonstrated for a number of Asian cities using the example of one of the derived electric vehicles, Munich serves as a reference for a German city.

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MOTIVATION

Increasing urbanisation coupled with steady economic growth lead to an increased demand for motorised individual transportation, especially in Asia. This aggravates locally the often already problematic environmental impact of fine dust and noise. The introduction of electric vehicles, particularly in megacities, can contribute to the reduction of pollution and thereby increase the quality of life in a city.

In the design of sensible and sustainable electric vehicles, a holistic consideration of the local context of mobility behaviour, energy supply, infrastructure and climate is needed. These sometimes differ significantly from the conditions in Central Europe and have a major impact on energy need. Focusing on Shanghai and Singapore, the market-specific vehicle concepts for Asia are derived, evaluated and then compared to Munich.

MOBILITY BEHAVIOUR

For the analysis of mobility and driving behaviour, two independent projects were carried out. In Shanghai, the driving behaviour of 30 test subjects was recorded, while in Singapore this was done by TUM Create for several taxis. As a comparative study for Munich, the fleet test "eFlott", carried out by Audi AG, Eon AG, Stadtwerke München and Technische Universität München, was used [1].

The test subjects in Shanghai used their own passenger cars for both private and business purposes. Besides recording the driving dynamics, surveys were carried out as part of the market research.

The participants, approximately 23 % of which were female, can be divided into the three following groups:

: New Social Generation (NSG)
: Ordinary Business (OB)
: Business Elite (BE).

The test subjects in the "New Social Generation" (NSG) are between 20–35 years old and as the youngest group with a medium-income, are very price-sensitive. They are open to new drive technologies and demonstrate a high willingness to purchase a battery electric vehicle (BEV) assuming comparable cost.

The 30–40 year olds, in the group "Ordinary Business" (OB), make use of their private vehicles for business purposes. They show interest in alternative drives only if it involves a possible reduction in their operating cost.

The "Business Elite" (BE) is 40 to 50 years old, wealthy and have the highest social status. Incentives for them to purchase an electric vehicle would be the possibility to showcase their environmental awareness and social responsibility. A willingness to pay more exists, but a loss of comfort will not be accepted.

❶ summarises the driving behaviour of the three groups in terms of average and maximum values. It is noticeable that with an increase in age and income level there is a rise in driving distance and therefore driving time, with the most frequent trips per day completed by the OB group. The records also indicate that the Chinese speed limit of 120 km/h is almost observed.

Singapore, due to its small size, offers good conditions for electric vehicles. For a successful introduction in the private sector, the government would have to make large investments and set up charging stations in the public housing estates where over 80 % of the population live. For the short-term however, the construction of a charging infrastructure for the taxi fleet is more feasible. Although these 27,000 taxis only make up 3 % of vehi-

		NEW SOCIAL GENERATION (NSG)	ORDINARY BUSINESS (OB)	BUSINESS ELITE (BE)
TRIP PURPOSE		Commute, eating out	Commute, business outing, pick up someone	Commute, business outing, eating out
DISTANCE [km]	Ø	29.2	41.5	93.5
	max	123.2	188.4	736.0
TRIP FREQUENCY	Ø	2.1	4.4	3.1
	max	7	13	16
TIME CONSUMPTION [min]	Ø	91.6	123.8	194.1
	max	154	191	659
SPEED [km/h]	Ø	19.1	20.1	28.9
	max	126	133	132

❶ Daily driving behaviour in Shanghai for the three population groups investigated cles in Singapore, they are responsible for 15 % of the total traffic in the city-state [2]. The study conducted by TUM Create has found that a taxi travels 260 km per shift and due to two shifts, are often constantly in use. Additionally, 95 % of all customer trips consist of a maximum of three passengers.

DERIVATION OF VEHICLE CONCEPTS

With an electric vehicle, fulfilling all the wishes of the customer, is technically and economically unachievable. Therefore, in the following, the vehicle requirements are derived explicitly from the real customer behaviour. Presented in ❷ are the requirements for 95 % of all trips made and 95 % of the higher accelerations. As the very long journeys and extreme accelerations are now excluded, the maximum range requirements in Shanghai for the group NSG is very low with 47 km, while the BE group demands 218 km.

For economic reasons, electric vehicles for the group OB are not of interest at this time. A taxi for Singapore requires a design for a long range and long battery life. For this purpose, a low maximum speed is sufficient. For the purpose of comparison, the characteristics of the Mute electric passenger car, which was developed by Technische Universität München as an ideal second car for use in Central Europe, are shown in ② [3].

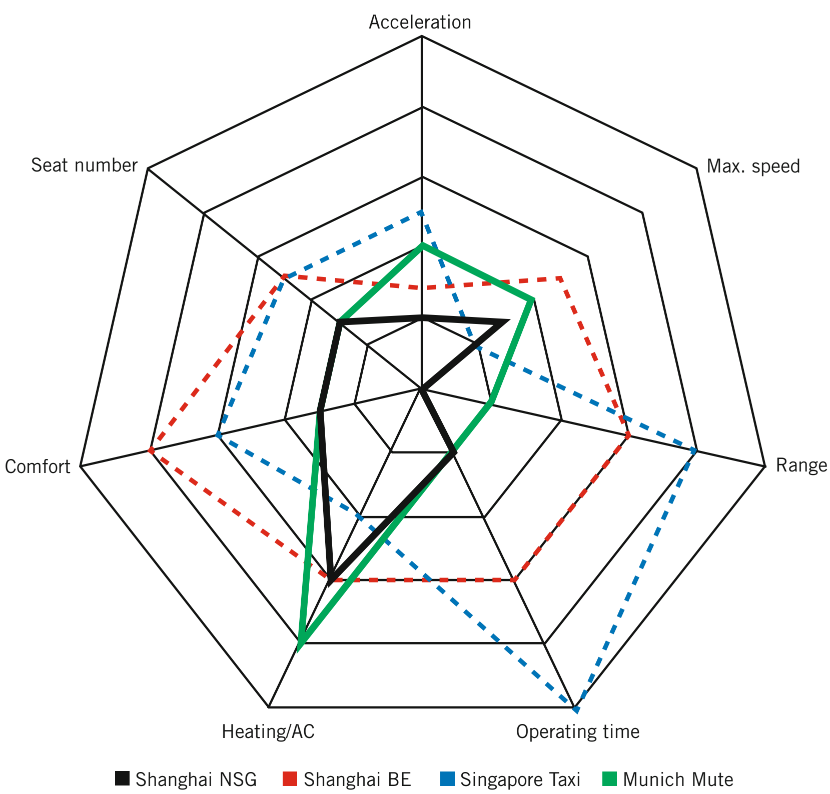
The Institute of Automotive Technology at the Technische Universität München, in cooperation with Audi AG, developed the "Eigenschaftsorientierte Konzeptentwicklungstool, Eoket" [engl. "Characteristic-oriented Concept Development Tool"] [4]. The aim of this tool is the design of an optimal electrified vehicle concept of user-dependent characteristic objectives. The result includes all vehicle dimensions and interprets the drive technology and energy storage. Having used Eoket, ❸, provides the appropriate vehicle concept to the presented requirements. The TCO calculation is carried out separately and makes use of current cost and subsidies.

For the NSG group in Shanghai, a compact two-seater BEV with a power of 43 kW is sufficient. A nominal battery capacity of 20 kWh more than sufficiently fulfils the range requirements. Here, this will be consciously accepted, as the vehicle gets a state subsidy of 13,750 Euro [5]. With this support, a vehicle with mileage of 10,000 km per year, a holding period of four years and assumed battery cost of 300 Euro per kWh, will cost only 0,16 Euro/km, significantly less than a comparable conventional vehicle with combustion engine (internal combustion engine vehicle, ICEV). Without this subsidy, there exists no purchase incentive for the NSG group.

In terms of driving behaviour, the Mute fits the profile of this group. However, the Mute comes with no subsidy in China, as the required minimum battery capacity of 15 kWh is not met [5]. In addition, an air-conditioning system would have to be fitted in.

The requirements of the BE group are fulfilled by a Plug-in hybrid vehicle (PHEV) as a sedan. The electrical power of 45 kW covers the inner city requirements. Including a subsidy of 5714 Euro when purchasing a PHEV [5], the electrified vehicle with an annual mileage of 25,000 km and a holding period of five years is somewhat cheaper than an ICEV. Without a subsidy, the PHEV would have additional cost of 750 Euro annually, which is a price the wealthy clients would be willing to pay for the positive image effect.

For Singapore, designing the vehicle for only four passengers allows a reduction of the weight and "consumption". With the premise to realise a local emission-free taxi, the vehicle will still be



	SHANGHAI NSG	SHANGHAI BE	SINGAPORE TAXI	MUNICH MUTE
ACCELERATION 0–60 km/h [s]	9	8	6	7
MAXIMUM SPEED [km/h]	105	126	100	120
RANGE [km]	47	218	260	100
OPERATING TIME [min/d]	122	221	600	120
OPERATION AREA FOR HEATING/AC (T_∞) [°C]	1–35	1–35	25–32	-5–30
COMFORT	Satisfactory	Excellent	Very good	Satisfactory
SEAT NUMBER	2	4	4	2

❷ Market-specific requirements for the design of the vehicle concepts – seven points from acceleration to seat number (spider network is spanned by technical feasible maximum values)

	SHANGHAI NSG	SHANGHAI BE	SINGAPORE TAXI	MUNICH MUTE
CONCEPTS (DRIVETRAIN)	BEV, compact car (front drive)	PHEV, sedan (front drive)	BEV, minivan (front drive)	BEV, micro car (rear drive)
CURB WEIGHT [kg]	1230	2100	2130	500
c_D VALUE	0.30	0.33	0.34	0.27
FACE SURFACE [m²]	2.0	2.4	2.5	1.7
WHEELBASE [mm]	2530	2900	2610	2100
POWER $P_{TOTAL}/P_{ELECTRICAL}$ [kW]	43/43	120/45	104/104	15/15
BATTERY (NOMINAL) [kWh]	20	17	88	12.5
ELECTRICAL RANGE$_{NEDC}$/ELECTRICAL RANGE$_{CUSTOMER}$ [km]	106.1/72.1	54.1/47.6	282.6/260.1	113.6/100.5
TCO FOR BEV OR PHEV WITHOUT/WITH SUBSIDY [EURO/km]	0.40/0.16	0.40/0.37	0.24/0.23	0.26 (ex subsidy)
TCO FOR ICEV WITHOUT/WITH SUBSIDY [EURO/km]	0.31 (without subsidy)	0.38 (without subsidy)	0.23/0.20	0.26 (without subsidy)

❸ Resulting vehicle concepts for Shanghai and Singapore in comparison with the electric car concept Mute for Munich

very heavy, because the battery pack designed for 260 km – assuming an energy density of 150 Wh/kg – weighs 590 kg. The starting cost of the electric taxi is higher than that of a conventional taxi. However, due to the extremely high mileage, should the price of diesel fuel no longer be subsidised for taxis, the total cost of this electric taxi will even out.

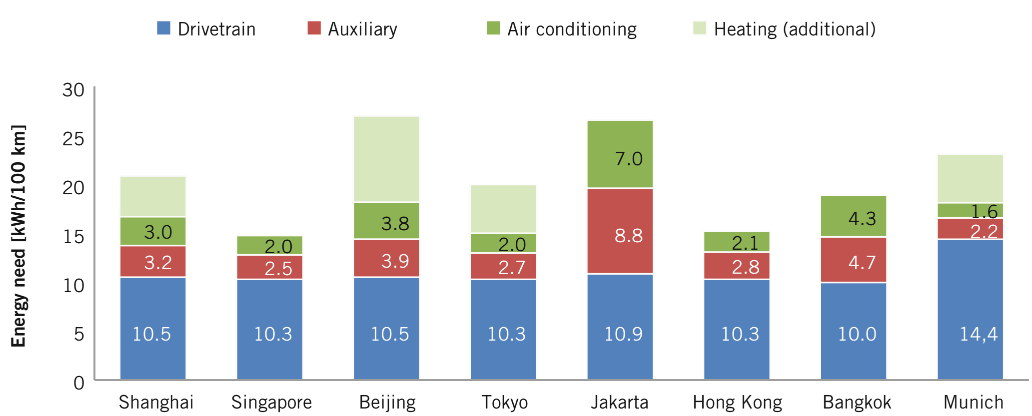
ENERGY DEMAND

In the following, the influence of local conditions on energy consumption and CO_2 emissions of electric vehicles is presented. Here, the usage locations will be expanded to several Asian megacities and Munich. The previously defined small car for Shanghai, first column in ③, serves as a reference vehicle. ❹ shows the results of a simulation for an estimation of energy need. Here, driving cycles were used, which have been created from real data measured in Shanghai, Singapore and Munich. These were transferred to Beijing, Tokyo, Jakarta and Hong Kong. For Bangkok, the test procedure New York City Cycle (NYCC [6]) has been used since the characteristics are similar.

While the required energy for driving differs only slightly between the compared Asian cities, the proportion of the current consumption of auxiliary units and the heating/air-conditioning show major differences. The energy consumption per auxiliary unit and travelled distance increases inversely proportionally to the respective average speeds, resulting in an extremely high value in cities with very bad traffic jams such as in Jakarta.

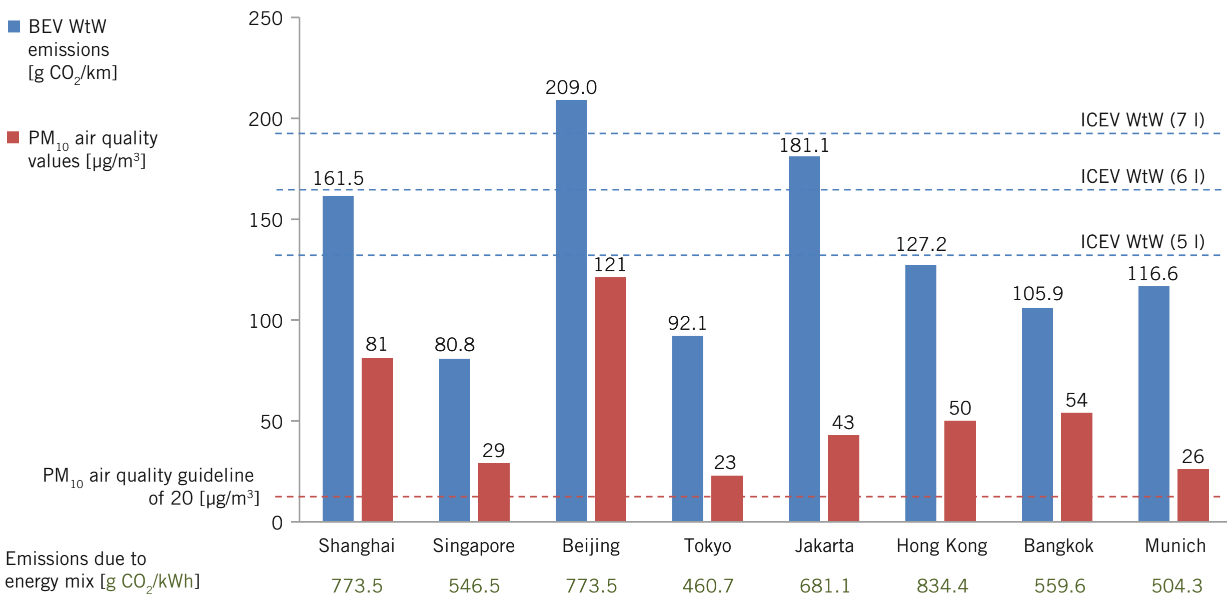
Likewise, the average speed has a large influence on the conditioning of the interior. Hence, even though Singapore and Jakarta show nearly identical climates, there is a difference of 5 kWh per 100 km on energy demand for the air-conditioning system. However, a constant power requirement of 2.3 kW for heating in cities with very cold winters, for example in Beijing, nearly doubles the demand and therefore halves the range. The use of an auxiliary heater (fed by fuel) decoupled from the battery is highly recommended here, even if this means that the car is no longer locally emission-free.

In comparison with Munich, it shows what a significant impact the infrastructure and consequently the driving behaviour has on energy demand. The high proportion of highways and motorways



	Shanghai	Singapore	Beijing	Tokyo	Jakarta	Hong Kong	Bangkok	Munich
$T_{\infty,\,summer}$	35 °C	32 °C	31 °C	30 °C	31 °C	31 °C	35 °C	30 °C
$T_{\infty,\,winter}$	1 °C	30 °C	-10 °C	-2 °C	29 °C	13 °C	31 °C	-5 °C
$Øv_{traffic}$	22 km/h	28 km/h	18 km/h	26 km/h	8 km/h	25 km/h	15 km/h	32 km/h

❹ Simulated energy need for summer and winter in seven Asian cities and in Munich



❺ Actual CO_2 emissions and PM_{10} air quality values in selected megacities (WtW = Well-to-Wheel)

that are not found in megacities, together with the rapid driving style of the test subjects lead to a 40 % increased energy demand for the drive as compared to that in Asia.

SUSTAINABILITY

In order to improve the air quality in cities, the World Health Organisation (WHO) defines the PM_{10} Air Quality guideline for particulate matter (PM) with an annual mean of 20 µg/m³ with intermediate milestones of 30, 50 and 70 µg/m³ [7]. ❺ shows the current PM_{10} values in some Asian megacities as compared to the value in Munich. Apart from Singapore and Tokyo, the metropolises exhibit more than twice the guideline value. Especially the Chinese cities show an alarmingly high level of particulate matter, which could be alleviated by the use of emission-free electric vehicles. More stringent emission standards for conventional vehicles (ICEV) may achieve the same effect.

The global CO_2 emissions are dependent on the respective energy mix [8] and are reflected in the well-to-wheel (WtW) emissions in ⑤ for the NSG compact vehicle. Here the Chinese cities also show, due to the almost 80 % coal portion in the current mix, the highest values. The result in Beijing is therefore a global CO_2 emission, which is higher than that of a conventional vehicle with a fuel consumption of 7 l per 100 km. Nevertheless, from an environmental point of view, electric vehicles should be promoted here to improve the local air quality. In Jakarta however, where the PM_{10} value is interpreted as still acceptable, with the current energy mix and prevailing traffic chaos, the introduction of electric vehicles is not sustainable.

CONCLUSION

Electric vehicles can help to alleviate one of the major problems in megacities – the air and noise pollution. The extreme temperatures and high traffic densities often found in Asia greatly influence the energy demand. The economic feasibility of electric vehicles and sustainable emission reduction can only be achieved through a conscious choice of the usage locations and precise design of the vehicle concepts with regards to real customer requirements and local conditions. When this happens, competitive electromobility may even be offered today.

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