Market and customer oriented design of electrified vehicle concepts
Vehicle Concepts & Engineering

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ABSTRACT: The development of electrified vehicles is in an extremely dynamic environment for years. The technology progress and differences in regional conditions make the design of a "world" and all purpose electrified vehicle impossible. In order to develop successful vehicle concepts, it is important to analyze the local requirements as well as the usage pattern of the potential customers. Consequently it is necessary to identify the main demand and challenges in the relevant markets before the developer can start the design of an electrified vehicle. Illustrated with the example of China, the appropriate vehicles are derived conceptually from market specific impact factors and different customer usage behaviors, which will be discussed and evaluated explicitly in this contribution.

Keywords: electrified vehicle concept, China, usage pattern, market influencing factor

1. INTRODUCTION

The rapid pace of urbanization and economic development over the past decades has improved the standard of living of millions in the world. However, this steady growth accelerates demand for mobility, especially for motorized individual mobility. Consequently rising energy consumption, increasing emissions of greenhouse gases and the deterioration of resources such as fossil fuels are creating serious and global challenges to sustainable development. Meanwhile, many countries face significant damage caused by the environmental impacts.

For this reason reducing CO_2 emissions becomes to be a major duty of today's society. Due to intensive public awareness about this topic a plurality of stringent government regulations to limit vehicles' CO_2 emissions and increase their fuel efficiency have been passed in many countries. To meet this challenge the automotive industry forces the development of alternative fuels as well as alternative propulsion concepts. Whereas alternative fuels such as CNG, LPG and biodiesel still emit CO_2, alternative propulsion concepts including plug-in hybrid (PHEV, also including Range Extender concepts) and battery electric (BEV) vehicles illustrate another possible solution to decrease local emissions significantly. Especially in megacities electrified vehicles with alternative propulsion can help to reduce local air and noise pollution.

Due to population growth and massive urbanization Chinas' megacities face exactly these environmental problems. Especially smog caused by energy production and the transport sector induces health problems. That leads China's government to stimulate the development of electromobility. In fact there is no other alternative for the government to satisfy the huge domestic energy demand. With about 5 million barrel crude oil import a day at the moment, China has already tripled the import volume within the past ten years [1]. According to IEA statistics, the transportation sector is accounted for over 40% of the oil demand in 2010. Until 2020 the daily import volume rises to 12.2 million barrel and to 15 million barrel in 2035 [2]. Concerning the rapid development of the Chinese automotive market the huge import volume is not economically and environmentally affordable anymore. Regarding to the economic policy in China, electromobility also makes sense. In order to launch electrified vehicles, almost every OEM has to start the development from scratch. Therefore the knowledge gap of domestic OEMs in the field of internal combustion engine (ICE) would not be relevant anymore. Overnight the Chinese automotive industry could be capable to compete.

With a large-scale plan including stimulus for private and public purchase and financial support for automotive manufacturers and related industries the policy attempts to force the development of the domestic electric vehicle market, and therefore to offer the best political and economic environment for electromobility. According to the "*12th Five-Years Plan*" China aims to be leading EV market by 2020. Despite this ambitious intention and current efforts of government consumers apparently remain unmoved. In fact only a fraction of government estimated sales volume was sold. The reasons are multifaceted. Limited offers, low awareness or negative preconception cause a lower consumer acceptance on one hand. The market complexity and rapid pace make product launches difficult for many foreign OEMs on the other hand. Furthermore the understanding about local usage patterns and customer requirements as one of the most important inputs for the design of electrified vehicles is not available yet. Consequently it is almost impossible to develop appropriate and successful vehicle concepts without the consideration of market and customer. Additionally, rapid market growth and quick, partially pragmatic adjustment of government regulations and guidance significantly increase the difficulty and uncertainty in the design of vehicle concepts.

In this contribution the most important influencing factors from the market side will be identified and evaluated for the derivation of relevant technical specifications for the design of electrified vehicle concepts. Furthermore background and motivations of different players on the market will also be explained for a better understanding. In order to analyze the customer requirements of the potential Chinese customers for electrified vehicles a mobility survey project was carried out. Concerning regional differences, the mobility and driving behaviour of 147 test subjects from five different cities in China (Beijing, Shanghai, Guangzhou, Chengdu and Wuhan) was recorded and evaluated. In this context the main potential customer groups will be identified. Driving requirements of different groups will be converted into representative use cases which will also be applied to the following simulation and calculation in the design process. At the end two appropriate electrified vehicle concepts will be designed for the related potential customer groups with regard to technical specifications from market side and use cases from customer side.

2. INSTRUCTIONS

2.1 Market Condition

Due to political condition, cultural characteristics, size and potential of its market, China is unique. Especially the automotive market, an important industry sector for the rapid economic development differs considerably from other automotive markets worldwide. For this reason vehicle developers, particularly with regard to electrified vehicles, have to take many influencing factors from different sectors into account. Subsequently the most important sectors such as policy and governmental guidance, economic development and infrastructural conditions will be discussed in this part for a better understanding of China's market condition, and evaluated for the impact on the design of electrified vehicle concepts.

2.1.1 Policy and Governmental Guidance

Nowadays China has become the world's No. 1 automotive market [3]. However, considering the car ownership per 1000 inhabitants China has not reached the proportion of industrial nations such as the US or Germany yet. The end of the growth has obviously not arrived. But as mentioned ancillary effects like pollution and traffic jams are the other side of the coin. Due to this tradeoff between economic development on one side, and foreign oil dependency and CO_2 emissions on the other side, electrified vehicles - so called New Energy Vehicles (NEV including BEV, PHEV, EREV and Fuel Cell Electric Vehicles) - have become a national priority to address these challenges. Consequently Chinese government embedded the development of NEV into the highest political national plan, the "*12th Five-Year Plan*". Therefore policy and governmental guidance are the most important and effective driving factors for electromobility and the development of NEV. For this reason the major influencing factors from policy and governmental guidance will be explained and analyzed.

Based on the special political landscape in China rules and regulations were enacted by several ministries during the last few years in this context. Due to different interests and targets of the related ministries, policies influence the development of NEV from different points of view and in a different way. One part of governmental activities regards the automotive industry. The other part of the activities tends to the customers.

On the side of industry Chinese government promotes and prompts electromobility. According to the drafted "*Development Plan for Fuel-efficient and New Energy Vehicles 2011-2020*" there will be an investment around 100 billion RMB (about 12 billion Euro) for the development of the whole industrial chain of NEV till 2020 [4]. The plan also mentioned the expectation of 5 million NEVs market volume until the end of this decade. In order to get this target the government forces OEMs to produce and sell NEV by limiting the consumption of all passenger cars in China. In the plan the new car corporate average fuel consumption (CAFC) should be reduced to 6.9l/100km till 2015, and this target will be below 5.0l/100km until 2020 [4]. The reduction of these targets is not just every five years. There is a defined step curve of the target reduction which the OEMs have to fulfil every year. The calculation of CAFC is defined in [5].

$$CAFC = \frac{\sum FC_i * V_i}{\sum V_i} \qquad (1)$$

In order to discuss the effect of the CAFC targets Eq. (1) shows the CAFC calculation method. The CAFC of an OEM in a certain year shall be calculated as the total product of the fuel consumption of each vehicle type (FC_i) and its sales volume (V_i) divided by the total sales volume of the year. The CAFC targets are obligatory for every OEM, that produces or sells in China. In case of being off target there will be a high penalty payment, even when the amount of the payment is not published yet. Especially for foreign OEMs with premium or high consumption cars in their product range the CAFC target and the penalty could be very challenging. However there is an incentive for NEV to compensate the CAFC, since BEV or FCEV would be counted as five cars with zero consumption, and PHEV with fuel consumption lower than 2.8 L/100 km would be counted as three cars. Therefore it is important to launch NEVs for the possibility to achieve the CAFC target.

In order to get the above mentioned target electrified vehicle concepts need to reach the NEV homologation. That means they have to fulfil the national technical specifications. Table 1 shows the most important specifications for BEV.

Table 1: National Standard for BEV [6]

GB/T 28382-2012	**Battery electric passenger cars - Specifications**
Performance	Top speed ≥ 80km/h (at least for 30 min) Acceleration 0-50km/h ≤ 10s Acceleration 50-80km/h ≤ 15s
Gradeability	Gradient 4%: vehicle uphill speed ≥ 60km/h Gradient 12%: vehicle uphill speed ≥ 30km/h Max. grade ability: 20%
Range	Min. Range ≥ 80km at New European Driving Cycle (NEDC)
Mass distribution	Weight ration of battery system and vehicle curb mass ≤ 30%
Trunk capacity	Volume ≥ 0.3m³ for vehicle with more than 4 seats
Cold starting property	Normal operation by -20°C ± 2°C
Reliability	Min. mileage ≥ 15000km

Until now, technical specifications for PHEV have not been published yet. But technical requirements of other regulations such as financial subsidy, calculation method of CAFC and exemption of vehicle usage tax already point out some technical specifications, which are definitively a challenge from conceptual point of view. For example the electric range of PHEV has to exceed 50km at NEDC. The minimum battery capacity is 10kWh. The maximum ratio of electric machine power should be more than 30% of the whole drive system. This multiplicity of all the relevant regulations makes the design of electric vehicle concepts very complex. Hence the main challenge here is to consider all relevant regulations and to keep information up to date.

Beside various industry policies increasing purchase incentive is the other way of the government to push electromobility. Due to different conditions local agencies implement different actions to rise the attractiveness of NEVs. In Beijing for instance, the NEV buyer is able to receive the license plate without lottery procedure, which is a big benefit in the context of the strong license restriction there. At the same time there is no one day ban of driving for NEVs drivers. In a mega city like Shanghai, there is also a monthly restriction of license plate registration via auctions. Currently the price for a license plate soared to about 70.000 RMB (about 8500€) [7], which reduces the user costs for NEV significantly. It can be assumed that many other cities will enact similar regulations soon. Further possible regulations could be the increase of driving restrictions for conventional vehicles or to implement zero or low emission zones, where just NEVs are allowed to drive through. Such regulations will impact mobility, driving behavior of Chinese customers and consequently also vehicle concepts significantly. Due to political motivation NEVs will be more than just an attractive alternative for new car buyers in the future.

From technical point of view the bottle neck of NEV are basically high battery costs. Therefore financial support on the customer side such as subsidy for purchase or tax exemption can bring the main impact on the market success. Currently NEV buyers are exempt from vehicle usage tax. Depending on the cubic capacity of the vehicle, the amount of this tax could rise up to the amount of 5400RMB (about 650€). In order to make the purchase of NEVs more attractive there are very high subsidies both from government and from local agencies.

In the participating pilot cities of "*Ten Cities, one thousand Vehicles Program*", which has been introduced by several ministries, NEV buyers could receive a maximum financial subsidy to the amount of 60000RMB (about 7060€), which is basically depending on the capacity of the battery and propulsion concept [8]. Meanwhile more than twenty-six cities joint the program. In eight of them local financial subsidy up to the amount of 60000RMB is also possible. This means a significant reduction of the total cost of ownership (TCO) of a NEV. For the design of NEV concepts it is not enough just to fulfill the requirements from customers usage.

The technical characteristics such as battery capacity or electric motor power also have to be considered in order to receive the maximum or meaningful financial support for reducing TCO. Table 2 shows different types and possible amount of financial subsidy depending on the participant cities or the technical characteristics of NEV.

Table 2: Overview of state and local subsidies for NEV purchase [8]

	Specification	State subsidy	Local Subsidy (eight pilot cities)
PHEV/ EREV	Battery ≥ 10kWh	3000RMB per kWh	20000 – 50000RMB per car
	Electrical range ≥ 50km (NEDC)	30000 – 50000RMB per car	
	5 year / 100000km warranty		
BEV	Battery ≥ 15kWh	3000RMB per kWh	30000 – 60000RMB per car
	5 year / 100000km warranty	45000 – 60000RMB per car	

In summary policy and governmental guidance exert a major influence on the success and the attractiveness of NEVs. Consequently they are the most important input factors for the design of electrified vehicle concepts in China.

2.1.2 Economic Development

The next important sector is economic development. The influence of GDP on a person's income is unquestioned. Due to improving living standards Chinese customers spend more money on mobility. On average they spent more than 10% of their gross income in 2011 [1]. Especially the middle and high income customers invest extensively in their motorized individual mobility. Results are increasing vehicle density on one hand, and rising trips and kilometers traveled on the other hand [1]. That also means the range within a day, which is important for the decision about capacity of the battery, has changed a lot in the last decade. Although due to the characteristics of the customer groups their mobility pattern and driving behavior are completely different .

Beside personal and household income several economic factors also have deep impact on the characteristics of NEVs and consequently on the design of the concepts. Particularly the development of fuel and electricity prices affect the operation cost significantly. Therefore the NEV concepts have to be designed with an optimal dimension of all relevant components. This increases the difficulty in the design process due to the necessity of considering of TCO.

2.1.3 Infrastructural Conditions

Infrastructural conditions also have a very strong impact on the mobility and driving behavior of customers. Especially the level of urbanization plays an important role. Factors such as population growth, extension of built up areas, improvement of public transport systems and development of urban structure have strong impacts on each other and also on the mobility pattern of people. Hence in the design process it is obligatory to take influences of these factors into account. In fact the quantification of the real impact of every single factor is not feasible due to the complexity of the market dynamics and the unpredictability of customer behavior. For this reason the most relevant factors are analyzed and evaluated for the derivation of relevant technical requirements.

Regarding climate, geographical, historical and urban structural diversities, Chinese cities have their own development speed and direction. There are approximately 655 cities in China. Thereof about 160 have a population of one million or more people [1]. They differ in many ways. For a deeper understanding it is important to classify them. In fact there is an official classification of the cities. Depending on criteria such as demographic distribution, city GDP and level of urbanization, China's cities are ranked into tiers based on the five levels of local government. For instance mega cities like Beijing, Shanghai and Guangzhou are typical first tier cities. Developed provincial cities like Chengdu or Wuhan are typical second or third tier cities. Due to the level of their development second and third tier cities will have more potential for the growth of passenger car market. Figure 1 shows the market development of typical first and second tier cities.

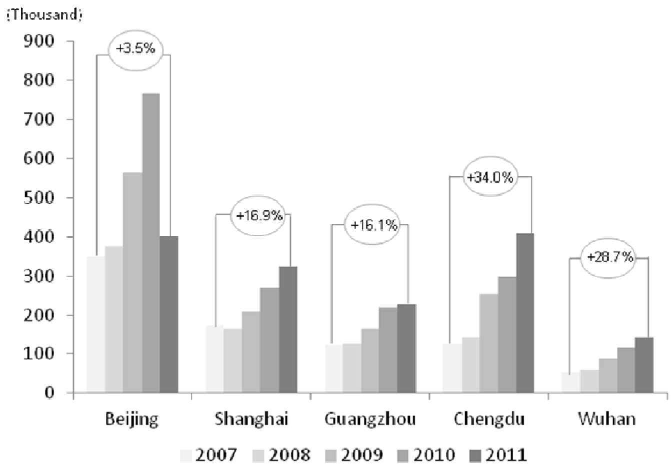

Figure 1: Car registration number in five cities in recent years [1]

Beijing tightened its lottery policy from 2011. In the same year, the car registration number dropped down to almost 50% compared to 2010. In contrast to first tier cities the development speed of Chengdu and Wuhan is significantly higher. Due to market growth speed a major part of future potential NEV customers will be from these cities. Therefore it is important to take second tier cities into account for the medium term. For this reason the above mentioned five cities are chosen for a deeper analyzing of the customer mobility in the project of mobility survey.

Due to different mobility maturity of the chosen cities the mobility pattern of local customers also differs in many ways. Figure 2 gives an overview of the mobility maturity of these cities in comparison to a reference big city from Europe [11].

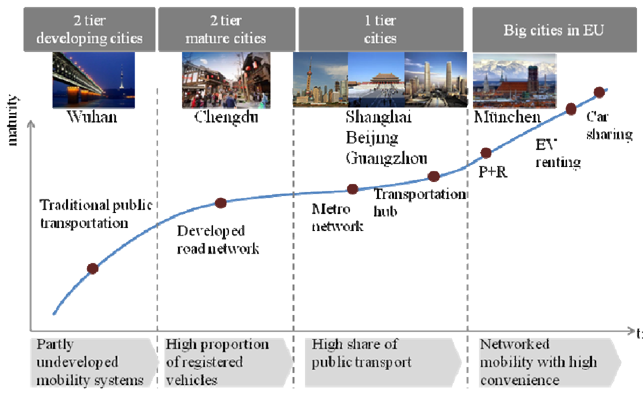

Figure 2: Mobility mature of typical Chinese cities

With a population of 9.8 million (2010) Wuhan is one of the biggest cities in central China. The built up area with about 408 km² and the vehicle density with 128 per thousand inhabitants are comparatively low. Due to the low efficiency of the traditional public transportation system the increasing share of private transport is the only solution to fulfill the mobility demand. The modal split of public transport is about 24% in 2010. Based on the small built up area and the single center city structure the distance of private driving trips is relatively short. In comparison to Wuhan, Chengdu has a similar built up area dimension (406km²) and vehicle density (150 per thousand of inhabitants) [1]. But the road network is developed and in a good condition. Also here the traditional transportation system cannot meet the requirements of growing mobility demands. Therefore vehicle quantities raised rapidly, and the modal split of public transportation is kept on a low level. Like Wuhan the average trip distance in Chengdu is short as well.

Guangzhou with its population of about 12.7 million people is in the most developed economic and one of the most densely urbanized regions, the Pearl River Delta in southern China. The built up area of 1049 km² is already twice as big as Wuhan or Chengdu. But the vehicle density is on as similar level as the other two second tier cities. The public transport system is developed, but still less on numbers and capacities. With its multi center city structure the mobility demands of the inhabitants are high, which can just be met by private transport on a relatively well developed road network. Based on the densely urbanized Pearl River Delta people usually travel between several cities. Consequently the average distance of the trips is long. The next first tier city is Shanghai, the most important economic and financial center in China. It has the biggest built up area, about 1563km², of all cities. Due to the auction of private license plates since 1996 the car ownership (84 per thousand inhabitants) is kept on a very low level. At the same time the public transport system is well developed. This causes the increase of the public transportation to nearly 50% of the modal split until 2015 [1]. The mobility maturity in Beijing is almost the same. But the vehicle density about 236 per thousand inhabitants is the highest value in China. Frequent traffic jams during rush hours caused by huge amount of vehicles raised the share of public transportation to 41% in 2010. Therefore it is obvious, that the growth of vehicle market in the first tier cities will remain static, and the main potential for NEV is offered basically by the second tier cities.

Beside the mobility mature of the cities the energy availability is also basic requirement for the use of NEV. On one hand there has to be enough energy production in order to cover the additional energy demand caused by NEVs. On the other hand the energy infrastructure has to be well developed, so that drivers of NEVs have the possibility to charge the vehicle both at home and at public places. Only in case of completion of both preconditions a market success is possible.

Due to rapid economic growth the electricity demand in China has tripled from 1347.2 to 4193.5 billion kWh in the period between 2000 and 2010 [1]. For meeting this increasing demand Chinese government invests extensively in the energy sector. So the extension of power supply lines and the boost of the energy production in terms of building up power plants are important elements of Chinese energy policy. According to the World Nuclear Association (WNA) there are 51 planned nuclear power plants in China [9]. Regardless of the discussion about danger and the environmental impact of nuclear energy China has to push the CO_2 neutral energy production even more, so that a significant reduction of the share of coal based energy production in its power mix can be reached. Currently coal fired power plants produce more than 77.8% of the whole electricity [1]. So it is not surprising that in the recent past the indicated values of particulate matter, the PM_{10} values in Beijing raised to 700µg/m³, which is a more than alarmingly high level of particulate pollution. [10].This also explains the political motivation in the field of electromobility for reducing the local CO_2 emissions. However it should not neglect the overall energy balance. Due to the high proportion of coal power about 836.7g CO_2 per kWh is produced on average [11]. For instance a small BEV with an electric consumption of 16kWh/100km at NEDC would emit about 134g CO_2 per kilometer. In comparison, a similar ICE vehicle in the same segment with a fuel consumption of 5l/100km emits about 117g CO_2 per kilometer. This simple calculation example underlines the inefficiency of the electrified vehicle with the current power mix in China. The use of NEV could only be considered as meaningful when a significant reduction of CO_2 emissions during the energy production process is achieved.

Not only energy production, but also the power supply represents a huge challenge. A sufficient charging infrastructure is essential for the use and the possible dissemination of NEVs. High charging availability shall be realized both at home and at public places. Whereas the first charging station and pillars are already installed for demonstration purposes in all pilot cities [8], the effort for building up a private charging infrastructure is much higher. Currently the share of urban population in China is about 51% [1]. Most of them live in residential complexes, so called living compounds with hundreds of apartments in tower buildings. Due to high population density the free base area in these compounds is expensive and limited. Because of that just relatively few people own their private garage or parking space. This makes the installation of private charging pillars difficult, and reduces customers' willingness to buy. Furthermore the additional power supply lines have to be laid within the compounds, which requires a massive investment on the electricity supplier side. At the moment the overall energy supply network in China belongs to State Grid Corporation of China (SGCC) and China Southern Power Grid Co. (CSG). Both are state owned enterprises and support the government for the implementation of the electromobility strategy. However to prevent supply shortages they prefer the battery change technology. In this context a strategic agreement was signed between CSG and Better Place in 2011 [11]. But the practice of the battery changing system for private passenger car sector is difficult to enforce. Missing technical standards, high necessary conceptual adaptation and thereby a low degree of distinctiveness make the technology unattractive for OEMs. It remains to be seen whether the important energy infrastructure challenges can be met by the government. There is no other alternative to the electromobility in sight at the moment.

2.2 Customer Behavior

Beside the market impact the customer and his using behavior represent the primary requirements for the electrified vehicle concept. This relates in particular to the decision of the propulsion concept as well as the dimension of the related components. For this reason the knowledge about the mobility and driving behavior of the potential customer is essential for the design of the appropriate electrified vehicle concept. So a mobility study was carried out in the five chosen cities in China. In this project four potential customer groups have been identified based on the given customer structure at the start. Though a multi level survey 150 representative test subjects were selected. Equipped with GPS logger the complete mobility patterns have been recorded. The movement data have been analyzed with regards to the electrification of drive system. The results are prepared in terms of representative use cases for the following concept design.

2.2.1 Customer Structure

In the past a major part of Chinese customers were first buyers, and the vehicle ownership was a status symbol in the society. With the rising mobilization the proportion of private and second buyers increases, although the second hand car market is still under development. This leads to conscious and rational purchase decisions [11]. Due to additional diversity of regional conditions the customers from different cities differ quite considerably. Most customers from first tier cities pay special attention to individuality and the cost benefit ratio of the vehicles, whereas customers from second tier cities continue to prefer the image and the related status of the vehicle. For this reason a deeper analysis of the Chinese customer structure is necessary for the following mobility data record, in order to select the representative and potential customers.

In the analysis and selection phase the participants from the chosen cities were interviewed and clustered according to demographic criteria such as age, family status, career stage, personal and household income, as well as vehicle using behavior like driving purpose, distance and frequency. The questions about the consumer expectation, acceptance and amortization time are also integrated into the interview, in order to take life style and the values of the customers into account. The analysis of the interviews provides four potential customer groups. Figure 3 gives an overview of the identified customer groups.

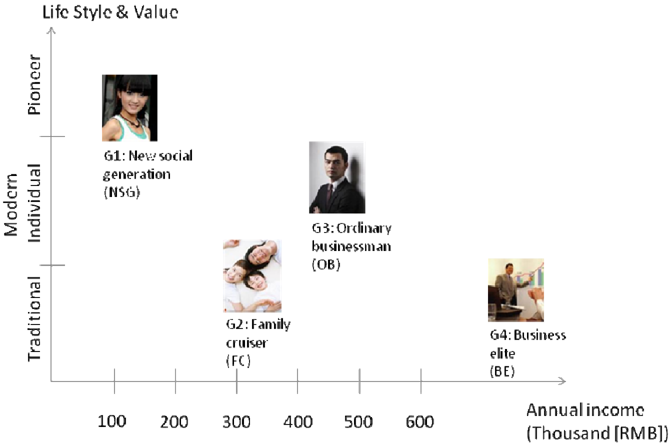

Figure 3: Four potential customer groups

The test subjects in the "New Social Generation" (NSG) are 20-35 years old and the youngest group with a medium income. Most of them are very price sensitive. At the same time they are open to new technologies and demonstrate a high willingness to purchase a BEV assuming affordable costs.

A part of the respondents - 30-45 years old - can be assigned to the group "Family Cruiser" (FC). About 84% of them are married and have children. The families in this customer group are in the middle household income bracket. This leads to a high price awareness. Due to the relatively conservative and traditional way of life customers in the group FC would only conceivably consider purchasing a NEV, if there is a clearly felt reduction of TCO.

The 30-40 year olds, in the group "Ordinary Business" (OB), are successful in their career and therefore have a comparably high income. Most of the respondents in this group are married, and they do not have children (yet). For their mobility they also make use of private vehicles for business purposes. At the moment they refuse the purchase of NEV, because of missing relevant infrastructure and product offerings. This is basically resulting from the strong comfort and image awareness of the OB customers.

The oldest and most prosperous participants are from the group "Business Elite" (BE). The group members are 40-50 years old and have highest income. Due to highest social status and financial possibilities there is purchase motivation and interest for NEV in this group. Incentives for them to purchase a NEV 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.

2.2.2 Customer Mobility

All in all, the overall mobility of the selected test subjects has been recorded by GPS logger for three weeks. At the same time the test subjects kept an additional logbook in order to register the means of transport used, the number of passengers, the driving purpose and the destination. By using the GPS data both the vocational and private trips can also be considered. It was found that the weekdays and the weekend have a major impact on the general mobility behavior of all test subjects.

On weekdays, business affairs take large proportion of trip purposes. In contrast, the trips for private affairs are much less, both from the aspect of frequency and number participants. On average, customers went out 2.04 times per day for business affairs. It occupied 73% of average daily frequency. For private affairs customers went out 0.76 times per day. Shopping, eating and meeting friends are the main private purposes, which cover 86% of the whole private outing. In general about 66% trips take no more than 40 minutes. Mostly business affairs have longer distance and time consumption than personal affairs, which are basically optional for customers. Therefore they tend to control the time consumption less than 40 minutes. About 65% of average daily distances is between 20km and 60km. Business outing is the most important purpose when daily distance is more than 40km.

At the weekend business affairs still play a role in mobility. The difference of frequency among the purposes is not significant. On average, customers went out 0.91 times per day for business affairs. It occupies 44% of average daily frequency. For private affairs customers went out 1.14 times per day. Traveling is a main purpose, which is specific for purpose at the weekend. About 8% of customers had no trip at weekends. Compared to weekdays almost all the trips (excluding business trip and traveling) can be finished in 40 minutes and their average distances are lower than 20km. In total 42% of average daily distances are within 20km and 67% within 40km. So short trips are more common on weekend.

There are also differences between the four customer groups. Figure 4 reflects the diversity of the mobility of the groups. Therein all the participants are clustered by the trip frequency per day and the average distance per day. Remarkable above all is the rising mobility demand with increasing age. The NSG is the group with the lowest mobility demand. On average, NSG went out 2.1 times per day. About 80% of all daily distances are less than 34.1km. A particularly interesting point is the comparison between FC and OB. Although most of the demographic criteria of these two groups are very similar, due to the differences in career and attitude towards life the trip frequencies varies widely. On average FC went out 2.5 times per day. About 75% of all daily distances centralized in 35-65km. The daily average trip frequency of OB is considerably higher, with about 4.4 times per day. 80% of all daily distances of OB are concentrated between 20km and 60km. The group BE has the highest mobility demand of all test subjects, although it just went out 3.1 times within a day on average. Allocation of average daily distance, due to the large proportion of business affairs BE has the longest daily distance.

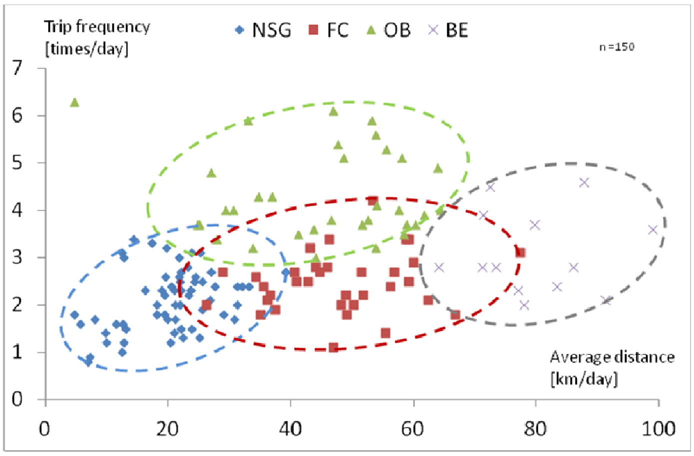

Figure 4: Mobility pattern of four customer groups

For the design of NEV it is necessary to analyze the specific driving behavior of the potential customer groups. It is not enough just to consider the average mobility pattern. Therefore Table 3 summarizes the driving behavior of the four groups in terms of average and maximum values. It is noticeable that all four groups have comparably low average velocity. Especially NSG shows the lowest value. This is basically due to a high proportion of urban trips. The group BE has the most share of motorway trips. Therefore the average velocity of BE is high in comparison to other groups. The records also indicate that the Chinese speed limit of 120 km/h is almost observed.

Table 3: Driving behaviour of four customer groups

		NSG	FC	OB	BE
Distance	Ø	25.5	42.1	45.0	97.9
[km/day]	max	235.3	188.7	218.4	736.0
Frequency	Ø	2.1	2.5	4.4	3.1
[time/day]	max	7	6	13	16
Travel	Ø	72.6	118.0	128.6	168.8
time [min]	max	170	267	411	659
Velocity	Ø	17.8	20.8	22.1	26.0
[km/h]	max	126	122	133	132

2.2.3 Customer Use Cases

In order to derive the technical requirements for the design of NEV it is not sufficient only to consider the average and maximum values in the driving behavior of the customers. Reasonably the recorded driving data has to be used for the dimensioning of the components with the regard to the power demand and energy consumption. So it is not enough just to consider the drive system relevant figures like velocity, acceleration and distance. The energy relevant using behavior of comfort systems such as heating and climate control beside the drive system also has a big impact on the overall energy consumption of the vehicle. But due to the GPS logger the study is only personal specific, thus the vehicle specific information about the use of comfort systems is not possible. For this reason the energy demand of comfort systems are reliably estimated.

For the design of drive train components and the decision about propulsion concepts the specific use cases are prepared. A use case consists of several trips within a certain period. Normally a period can contain one day or the time between two charging possibilities. All the trips within a period are ordered chronologically and they can be displayed in a VT-diagram for the following simulation and calculation. The clustering and the selection of an appropriate use case are made by analyzing the percentage cover of the energy and power demand in the overall database. The evaluation criteria are the period distance (PD) and driving style (DS) of the customers. PD is the whole range within a period. In this contribution DS is defined as the speed and acceleration selection of the driver. The indicator for DS is the normalized positive kinetic energy (PKE), which is shown in Eq. (2).

$$PKE = \frac{1}{PD} * \sum \left| (v_{i+1}^2 - v_i^2) \right| \qquad (2)$$

Due to the technical restrictions of the battery technology it is never reasonable and economical to design an electrified vehicle, especially BEV as an all purpose vehicle. Therefore use cases with reasonable cover ratio have to be selected for developing a rational vehicle concept. Presented in Table 4 the requirements for 95% of all trips and 89% of the higher accelerations are made.

Table 4: Use case with 95%PD and 89%DS

	NSG	FC	OB	BE
Acc 0-60km/h [s]	8	8	5	6
Max Velocity [km/h]	105	119	128	121
Distance [km]	56	93	97	261
Operation time [min]	164	197	203	297
Nr. passengers [-]	2	4	3	2

2.3 Derivation of vehicle concepts

Based on the technical requirements from the market side and the selected use case, electrified vehicle concepts including BEV, PHEV and EREV concepts are roughly designed by using some functionalities of the tool “Eoket” [engl. “Characteristic-oriented Concept Development Tool”] [12], which is developed by the Institute of Automotive Technology at Technische Universität München, in cooperation with Audi AG. 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. The whole calculation and simulation environment is Matlab/Simulink. The major design steps are shown in a flow chart in Figure 5.

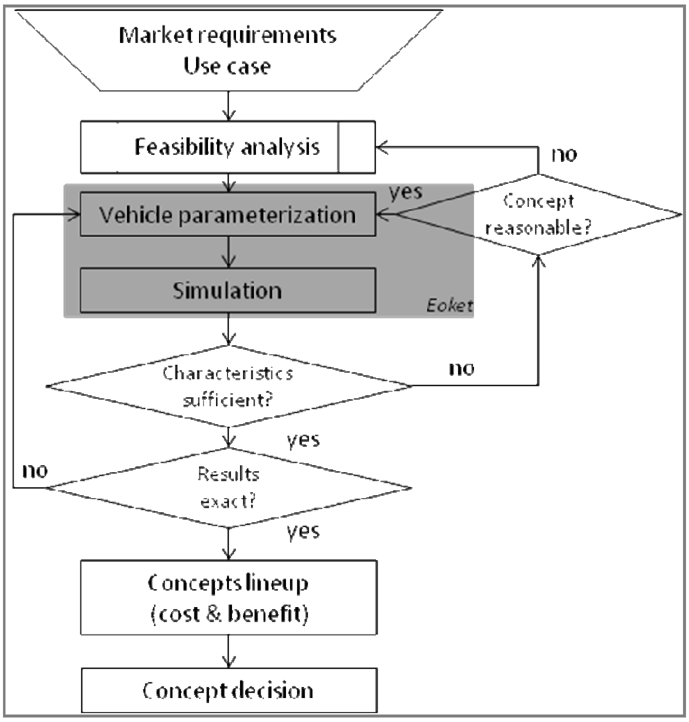

Figure 5: Design approach of NEV

By using an implemented graphical user interface (GUI) the existing technical market requirements in terms of database can be entered and considered for the following design steps. Within the GUI it is possible to adjust and change the stored data of market requirements. Subsequently a certain use case with any cover ratio can be selected in the second GUI. Even prior to start the simulation there is a feasibility analysis, which checks for the technical feasibility and economical reasonability of each concept. Implausible propulsion concepts can be excepted for the following process by using simple criteria such as PD, the proportion of motorway and the maximum velocity in the selected use case. This also increases the computing power of the whole approach. Currently PHEV concept is not considered for the use cases with 90% proportion urban trips. On the other side the feasibility analysis excepts BEV concept for use cases with a higher PD value than 200km/day. BEV and EREV concepts are excluded for the use cases with a maximum velocity more than 130km/h, which is already more than the speed limit on motorways in China.

After the feasibility analysis depending on the selected vehicle segment and derivative the left concepts are parameterized geometrically and weight based by the tool “Eoket”. Especially the weight based parameters are initial values or minimum requirements, which are adjusted in the following quasi-stationary simulation. Beside the use case oriented design, there are also possibilities to give additional technical requirements manually, such as maximum velocity or acceleration of minimum range at standard test driving cycles. In the simulation the manual given requirements can also be checked, and influence the dimension of the components. When all the requirements are fulfilled the selected use case will be simulated again, till the consumption of the vehicle is not impacted noticeably by the weight change anymore. The next step is to check the mass distribution of the vehicle and the available volume for the calculated components. Concepts with insufficient volume and illegal weight ratio are also excluded for the final cost benefit comparison. Therein the TCO calculation is carried out separately and makes use of current costs and subsidies from the market database.

After the initial interview for economic and comfort reasons, for the group FC and OB NEVs are not of interest at this time. Table 5 provides two appropriate NEV concepts to the presented requirements for the group NSG and BE by using the above mentioned approach.

Table 5: NEV concepts for NSG and BE

	NSG	BE
Concepts (drive train)	BEV compact car (front drive)	PHEV sedan (front drive)
Curb weight [kg]	1250	2150
C_d value	0.3	0.33
Face surface [m²]	2.0	2.4
Wheelbase [mm]	2530	2900
P_{TOTAL} / $P_{ELECTIRICAL}$ [kW]	75/ 75	135/ 45
Battery (nominal) [kWh]	20	17
Electrical range$_{NEDC}$ / Electrical range$_{CUSTOMER}$ [km]	101.4 / 70.2	52.6/ 44.2
TCO NEV ex / with subsidy [€/km]	0.40/ 0.16	0.40/ 0.37
TCO ICEV [€/km]	0.31	0.38

For the NSG group, a compact two seater BEV with a power of 75kW 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 full state and local subsidy. With this support, a vehicle with mileage of 10000 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 ICE. Without this subsidy, there exists no purchase incentive for the NSG group.

The requirements of the BE group are fulfilled by a PHEV as a sedan. The electrical power of 45 kW covers the inner city requirements. Including the subsidy the electrified vehicle with an annual mileage of 25000 km and a holding period of five years is somewhat cheaper than a vehicle with ICE. 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.

3. CONCLUSION

For Chinese government there is no other choice than electromobility to solve the trade off between economic growth and local environmental pollution at the moment. This explains its high motivation to support the development and stimulate the purchase of NEVs. The strategy of promotion on one side and prompt on the other side could be a step to the right direction to realize the future individual mobility in the country. However it also brings plurality of technical and nontechnical challenges for the design of NEV. The new propulsion concepts can help to alleviate one of the major problems in Chinese cities – the air and noise pollution. But regarding to the overall energy balance with the coal intensive energy mix the use of NEVs is not efficient und economically reasonable. Therefore the improvement of the energy sector has the highest priority. The results of customer analysis demonstrates that there is an existing demand by distinct customer groups in China’s cities. Already today NEV concepts designed for the real customer requirements seem to be affordable to potential customers. The results of this contribution underline this fact. However sufficient charging infrastructure both at home and at public places is the main challenge for the success of NEV in China.

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