# POLITECNICO DI TORINO

**Master in Automotive Engineering**

**Master Degree's Thesis**

# Market Research and Energy Efficiency Optimization Analysis for Small EVs


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# Abstract

With the acceleration of the global automotive industry shifting from traditional internal combustion vehicles to pure electric vehicles, the interconnection between energy efficiency, battery performance, and energy consumption has become a central focus for both market-driven policies and leading vehicle manufacturers. In particular, micro electric vehicles (micro-EVs), which are designed to contain compact dimensions, lightweight vehicle body structure, less space for passengers, and low cost on daily operation, have earned more attention and favor from global customers. Therefore, understanding how to downsize the vehicle and reduce the vehicle weight, while maintaining and compromising with the necessary driving range is essential. The study aims to extract available commercial vehicles data from various global markets to identify a vehicle model that aligns with market demands by featuring a compact size, low energy consumption, reduced battery capacity, and overall cost efficiency.

A cross-regional market survey was conducted, covering 46 vehicle models, which included vehicles with several specific versions released in the past 5 years from China, Europe, and Japan. The data collected includes essential specifications such as curb weight (kg), battery capacity (kWh), energy consumption (kWh/100 km), vehicle category, and certified range (km). To ensure classification consistency across regulatory regions, vehicles were labeled using a dual-category system: the Chinese industry standard (A00, A0, A, etc.) and the European standard (M0, M1, L6e, L7e). The market investigation methodology involves the combination of statistical correlation analysis and intuitive point distribution graphs. These comparative findings provide a comprehensive understanding of market demands, regional variations in

electric vehicle performance and energy efficiency, as well as classifications and regulatory requirements in different regions, including passive safety standards. Such insights offer valuable guidance for the subsequent optimization of EV dimensions, battery sizing, and related design considerations.

Based on the conclusions derived from the earlier parameter analysis, to investigate the impact of vehicle mass and driving cycles on the electrical efficiency of electric vehicles. Based on the MATLAB Simulink, using the representative case of the Fiat 500e, a longitudinal vehicle model is established to examine the effects of gradually reducing vehicle mass( from baseline 100% to 70%) on energy consumption. The results suggest that decreasing vehicle size and weight not only lowers energy consumption but also enables a reduction in battery capacity and the corresponding volume and mass of the battery pack, thereby contributing to cost reduction.

Finally, the analysis focuses on how the battery-related findings discussed above affect key aspects of automotive design and manufacturing, including vehicle structure, energy consumption, and production costs. Using relevant examples and modeling, provided a clear and insightful assessment and offered practical recommendations and strategies to help European manufacturers better tailor their vehicles and processes to the specific needs of the Chinese automotive market, ultimately improving their competitiveness.

The work presented in this thesis was a joint work carried out collaboratively with my colleague Jiahui Zhou (s312643).

# Contents

# Chapter 1

# Introduction

## 1.1 Background

Over the last 20 years, electric vehicles (EVs) have transitioned from an innovative technique to a milestone of the global automotive industry. Driven by growing environmental protection consciousness, improvement on battery technology both on unit energy density and quality under extreme working conditions, supporting from global countries' governments policies, EV adoption has accelerated significantly worldwide. Especially in regions with highly demand of customers, like China, Europe, USA and Japan, the development of EVs shows a diversified designs and development prospects:

• China has emerged as the world's largest commercial EV market, pushed by strong government incentives, substantial investment and highly speed of scaling in charging infrastructure. Also rapidly growing domestic industry led by companies like BYD, and NIO, Xpeng, SAIC, and people's increasing acceptance of new energy vehicles contribute to the current market environment. The Chinese government's "New Energy Vehicle" (NEV) policies have played a crucial role in encouraging both production and consumption of EVs. China now accounts for more than half of global EV sales annually and maintains a dominant position across the entire supporting chain, including battery manufacturing, raw materials processing, and powertrain technologies.

• Europe has also made substantial progress, especially in countries like Norway, Germany, and the Netherlands, the European Union has implemented ambitious climate targets under the European Green Deal, including a mandate to reduce greenhouse gas emissions by 55% by 2030 and to phase out new internal combustion engine (ICE) vehicles by 2035[1]. Many major cities including Paris, Amsterdam, and Barcelona have introduced low-emission zones and vehicle access restrictions, which have created a natural demand for vehicles suitable for urban environments.

• Japan, while initially a pioneer with hybrid technologies such as the Toyota, has gradually increased its focus on fully electric models, with companies now investing heavily in solid-state battery development and next-generation EV platforms.

Parallel to the expansion demand of standard-sized EVs, micro vehicles which characterized by small and lightweight were designed for urban mobility. These vehicles are typically characterized by their compact dimensions, low energy consumption, popular for short distance travelling, in case daily way and back to work, and suitable for passing through narrow street urban road or parking in tight resource parking area. One of the most iconic examples of this trend was the Fiat 500, introduced by the Italian automaker Fiat in 1957[2]. Measuring under 3 meters in length, the original Fiat 500 was designed as a "people's car" which is an inexpensive, reliable vehicle for the masses. Despite its minimal engine power and basic features, the 500 became a symbol of Italy's urban mobility and economic revival. It combined utility, affordability, and charm, making it one of the best-selling micro vehicles of its time, with over 4 million units sold before production ceased. In terms of regulation, Europe has created specific vehicle categories to accommodate micro vehicles while ensuring a balance between safety, environmental performance, and innovation flexibility. For example, the European Union classifies lightweight electric vehicles under the L6e (light quadricycles) and L7e (heavy quadricycles) categories. These classifications allow for streamlined approval processes and lower design complexity compared to full-sized cars, making them attractive for manufacturers developing compact electric urban mobility solutions. However, these vehicles are still subject to certain safety, emissions, and design requirements, particularly if they are intended for use on public roads. In China, regulation around micro vehicles originally developed as an informal solution to urban and rural mobility needs, in small cities and rural areas due to their low cost, ease of use, and minimal licensing requirements, for many years, this segment operated in a regulatory gray area, with vehicles often produced by local manufacturers without national certification and operating outside of standardized safety and technical frameworks. Because of both the market potential and the safety risks, the Chinese government began tightening regulation in the late 2010s. In recent years, national authorities have taken steps to phase out unregulated production and push manufacturers toward upgrading product standards to align with pure electric vehicles.

Based on both electric vehicles' innovation and highly commercial market requirement of micro-vehicles, the micro-EV models have been launched and becoming more popular to be consensus by global manufacturers. More advanced micro EVs, such as the Wuling Honguang MINI EV has been fully incorporated into China's national new energy vehicle framework. These vehicles comply with safety and emissions regulations required for passenger cars and are eligible for government incentives, subsidies, and simplified license plate access in many cities. Due to the fact that Europe makers have long period experience on micro vehicles manufacturing, proven technology and huge potential prospects of the Chinese market, European automakers are increasingly exploring ways to penetrate the Chinese micro-EV market.

## 1.2 Problem Statement

With the acceleration of urbanization, micro electric vehicles are emerging as a vital mode of urban commuting, and their market is expanding rapidly. Meanwhile, the potential for small commuter EVs in the Chinese market is significant. Although Chinese manufacturers have demonstrated clear advantages in lightweighting and cost control for micro-EVs, this does not mean that European companies should abandon this rapidly growing market. On the contrary, Europe’s strong engineering background and solid international reputation provide a valuable foundation. But to succeed, manufacturers must also confront and overcome several critical challenges.

the low-end segment in Europe is overly polarized; vehicles in the L-class often fall short in terms of functionality and safety, making it difficult to meet users' basic needs. From a functionality standpoint, Chinese consumers tend to prefer micro electric vehicles that offer greater practicality. designs such as that of the Renault Twizy, which features non-enclosed doors and lacks traditional window glass, designs as Microlino that has only two seats and special mechanism way to open the door, are perceived as highly impractical and even unacceptable by Chinese market. In addition, these vehicles frequently fail to comply with key regulatory requirements under China's road safety standards, which effectively prevents them from entering the Chinese market.

Meanwhile, most current European small EVs lie in the M class still follow conventional automotive design principles, leading to issues such as oversized battery configurations, excessive vehicle weight, and suboptimal energy efficiency. This "overengineering" is fundamentally misaligned with the actual needs of urban short-distance, low average speed travel, resulting in resource waste, increased costs, and poor market adaptability.

In addition, European manufacturers often face higher labor and material costs, as well as challenges related to regulatory complexity and policy issues such as legal and compliance requirements. Thus, many European brands struggle to localize their micro-EV products to fit the Chinese market.

There is currently a lack of a systematic framework that quantitatively evaluates and balances vehicle mass, energy efficiency, and performance across different markets. Therefore, we conducted extensive research, data collection, and simulation modeling with the aim of providing European companies with practical advices for the design and manufacturing of small EVs to maximize profits by reducing costs and expanding the market.

## 1.3 Motivation

The current micro-EV market in China remains in an early development stage, yet it offers considerable potential and opportunities for growth. This emerging sector represents a crucial window for European manufacturers to enter and establish a foothold. However, significant differences exist between China and Europe in terms of regional policies, road traffic conditions, and user behaviors, leading to notable disparities in key technical aspects of small commuter EVs—such as driving range, pricing, battery types, and performance expectations. This study is motivated by the need to clarify these technological and market differences, and to offer strategic insights for European manufacturers to design and produce micro electric vehicles aligned with the characteristics of the Chinese market. To this end, we conduct a comparative analysis focused on energy efficiency and test cycle standards, aiming to identify opportunities for cost reduction and to support a competitive positioning strategy in a market with long-term sustainable profitability.

## 1.4 Thesis outline

This thesis set out to investigate how the structural characteristics, energy configurations, and market-specific design parameters of micro electric vehicles can be optimized to reduce overall energy consumption. Considering the increasing global demand for sustainable transportation and the aggressive policy incentives supporting electric vehicle development, particularly in China, energy efficiency has emerged as both a technical and strategic imperative for vehicle manufacturers.

By conducting a comprehensive cross-regional analysis and comparison of small electric vehicles across China, Europe, and Japan, we observed that energy consumption tends to increase proportionally with vehicle curb weight. While European M-class vehicles are generally heavier, this added mass leads to higher energy consumption per unit distance unless substantial advancements are made in powertrain technology. On the other end of the spectrum, extremely lightweight vehicles—particularly those classified under Europe’s L6e/L7e categories—consume less energy overall, but with compromised performance, limited passenger space, and minimal safety features. This study, based on extensive investigation and data collection combined with simulation modeling, proposes a method for improving the energy efficiency of European electric vehicles by reducing vehicle size and weight—an approach aligned with the prevailing characteristics of small commuter EVs in the Chinese market to better balance among energy consumption, performance, and safety.

Chapter 1 presents the research background, the current status of the field, identifies key contradictions and challenges, and states the objectives of the study.

Chapter 2 focuses on comprehensive market research and preliminary analysis. It introduces the methodology used for the investigation and provides a detailed description of the database consisting of 46 vehicle models. By discussing the differing classification standards and safety testing requirements for small-sized EVs in China, Europe, and Japan, which analyzes how regional legislative frameworks influence vehicle performance, size, and safety features, revealing discrepancies driven by government-mandated classifications. Additionally, non-standard local classifications reflect consumers' differing demands and expectations across regions. And in section 2.4 we analyze several basic vehicle parameters that are directly accessible through public sources. This analysis aims to identify and explain the design, performance, and dimensional differences between existing vehicle models in the Chinese and European markets.

In Chapter 3, we first conducted a detailed analysis focusing on power density and energy density, which can be collected by simply calculating while effectively reflecting vehicle performance. The results revealed clear regional disparities: European vehicles exhibit a significant gap in performance distribution, whereas Chinese models tend to form a bridge to this performance divide. Additionally, we carried out a comparative analysis of energy efficiency across regions. These findings ultimately make us enabled the development of a three-dimensional estimation cube, mapping mass (650–1250 kg), energy efficiency (8.4–15.0 kWh/100 km), and PMR

(23–78 W/kg). This cube serves as a design space within which future micro-EV models can be optimized. Vehicles falling within the central triangular region of this cube showed the best balance between driving performance and energy efficiency. Notably, most of these vehicles were Chinese, but selected European and Japanese models—such as the Fiat 500e and Nissan Sakura—also occupied this optimal region. This convergence suggests that global manufacturers are increasingly aligning toward similar design philosophies, particularly in markets like China where urban density and short-distance commuting dominate consumer expectations.

In Chapter 4, we selected the Fiat 500e, one of the most popular small vehicles in Europe as a reference model to construct our model and simulation framework. By progressively reducing the vehicle's curb weight from 100% to 70%, the simulation demonstrated a corresponding decrease in energy consumption. Conversely, if the target driving range remains unchanged, battery capacity and therefore cost can be reduced accordingly. Moreover, we proposed that the most direct and effective approach to reducing vehicle weight is to minimize overall vehicle dimensions. Based on the safety considerations and vehicle specification dataset collected in Chapter 2, we identified a reasonable range within which vehicle size can be reduced without compromising essential functions. Finally, by conducting a driving range simulation under the CLTC, and characteristic data for CLTC, we infer that the CLTC may more accurately reflect real-world driving conditions for small urban commuter vehicles, and by using CLTC range, can significantly reduce the battery capacity. This suggests that if European vehicles aim to lower costs or enter cost-sensitive markets like China, they could flexibly downsize battery capacity by aligning with the CLTC-based range requirements.

In the final chapter of this thesis, we presented the overall conclusions of the study, outlined its limitations, and provided our personal insights.

# Chapter 2

# Market Research

Market Research is the process of gathering, analyzing, organizing information and interpreting what information has already obtained about a specific currently existing market or potentially established market with respect to the future. The research needs the analyzer to be provided with highly skill that is familiar with what necessary elements are required to build up the market. These elements include but are not limited to available products, brands of manufactures, target customers, competitors, etc. It helps companies or businesses runners to understand what products and products' conception is currently popular and with highly acceptance with the customers. Then start doing actions or modification on the future design or making adjustment to the currently existing process. Finally obtaining contribution and advantages to the profits of stockholders.

With respect to the automotive industry, especially the Micro-EV that we are interested in, market research plays a crucial role in developing new vehicles. Our research involves multiple available models currently in the markets, how the companies do the publicity work and sales point, specific parameters, and competitors' strategies.

## 2.1 Research Scope

### 2.1.1Geographical Scope

While the Chinese market is where the research mainly focusses on, but comparative analysis of European and Japanese market must also be included. This allows for a broader understanding of market maturity among the world and distinguishes the differences between the Western and Eastern vehicle market running modes.

**1. CHINA**

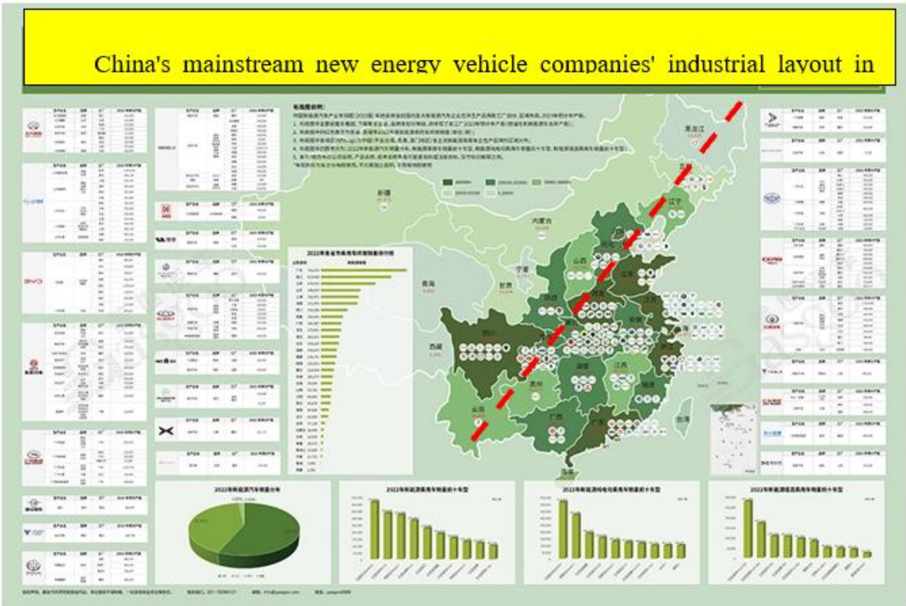



**Figure 2. 1 China's mainstream new energy vehicle companies' industrial layout in China**

The China's mainstream EV manufacturers' distribution layout in China is shown as Figure 2. 1, by making a glance following the red dashed line, it shows 90% of the

EV producer mainly concentrate on the eastern side of the mainland of China, with specific focus on large cities like Beijing, Shanghai, Guangzhou, Wuhan, Chongqing that all cities will populations exceed 10 million. Based on this evidence, in our selection of brands for analysis, we excluded those that are based in less populated regions of China and operate on a relatively small scale. The rationale behind this exclusion is to focus our study on manufacturers with broader market sharing, more established operations, and with a high number of potential customers.

## 2. EUROPE

The distribution of electric vehicle manufacturers across Europe is closely linked to the regional concentration of battery production capacity. High logistical and economic interdependence between EV assembly and battery supply chains defines the region of developed manufacturers. Based on this relationship, our research selects several European countries that host significant battery manufacturing facilities as reference. From these countries, we identify the micro-EV models produced by local brands.

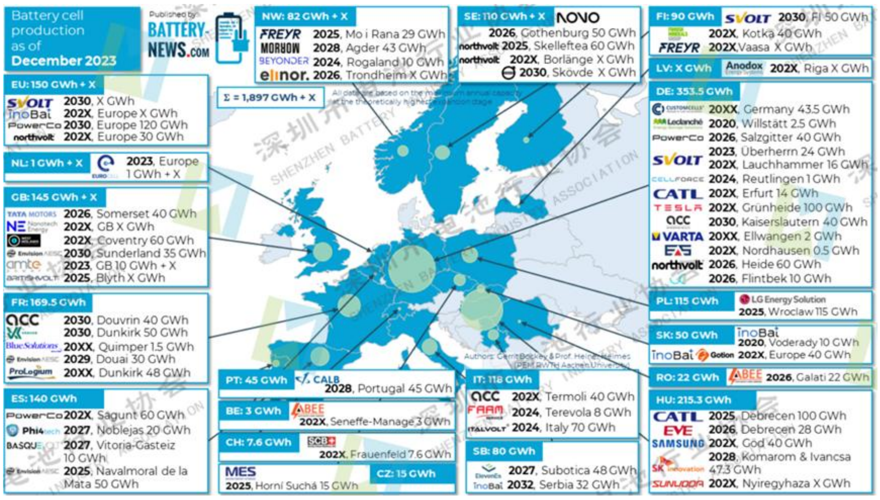



**Figure 2. 2 The enlarged circles in the battery manufacturer distribution map**

As illustrated by Figure 2. 2, Italy, France, and Germany are main pioneer for power battery production in Europe. In line with this observation, we have selected leading micro-EV brands that operate under major manufacturers based in these countries as the primary subject of our investigation.

**3. Japan**

Since the number of available micro-EV brands in Japan is smaller compared to those in China and Europe, we have decided to include all micro vehicle models that are currently available on the commercial market in Japan as part of our investigation. This comprehensive inclusion ensures that the analysis reflects the full range of options within the Japanese market, despite its relatively limited scale.

## 2.1.2 Vehicle Type Covered

The vehicle types covered in this research include micro-EV that are fully battery-powered, with two to four seats, designed primarily for short-distance urban transportation, and currently available on the commercial market.


**Figure 2. 3 Vehicles examples from research**

The vehicles shown in Figure 2. 3 all fall in the criteria of micro-EV with specific characteristics. Firstly, they are compact in size and dimension, making them compatible with daily usage for urban environments with limited parking space. Secondly, all of them are fully electric, designed to provide eco-friendly and less energy-consuming compared to conventional cars. Most of these vehicles are with limited speed, with limited range. In terms of capacity, these models are typically able to hold 1~4 passengers, emphasizing personal mobility or paired travel. Their exterior designs tend to be playful (It should be emphasized that the exterior design of many European cars of this type is a significant factor contributing to their market selling point, attracting consumers who value both performance and visual sophistication. But in contrast, the design of similar Chinese cars tends to be relatively conventional. This disparity in design quality may influence consumer perception.) that often attracts younger generation customers. To be concluded, the common characteristic of these micro-EV is highly practical for usage and less economically consuming for urban mobility.

### 2.1.3 Time period

The research covers the EV that is on sale or used to during the period from 2018 to 2024, based on market trends history, current available product. And the data was collected in October 2024 when our research work started. This time frame allows for the assessment of the recent market situation and the anticipation of future market development trends.

### 2.1.4 Purpose of the Survey

The objective of this preliminary survey is to gain a fundamental understanding of the current market landscape for micro-EVs. As a preparatory phase for more in-depth analysis, the survey focuses on collecting key information such as vehicle classifications, safety standards, performance indicators, dimensions, and pricing. By conducting an initial analysis of this data, the study aims to establish a clear and comprehensive view of the market status, thereby ensuring that subsequent research is grounded in accurate and relevant market insights.

## 2.2 Data Sources and Collection Method

Since most manufacturers' technical information is classified due to business competition, the data and methods available for collection are relatively limited. While the data may not reach the level of precision typically found in experimental studies, it remains sufficiently robust for statistical analysis and drawing meaningful conclusions. The following is a detailed explanation of the channels through which we obtained information, which can be used as a reference for subsequent research on the Chinese market.

### 2.2.1 Primary Data Sources

As part of our primary data collection, we conducted on-site observations in the cities of Beijing and Tianjin. Specifically, we observed the frequency and presence of micro-EV on public roads during busy hours. These observations were carried out in high density urban areas, including business districts and residential zones, to assess the level of public adoption in daily usage scenarios, aims to gain insight into how commonly these vehicles appear in actual China's developed city urban traffic environments.

**Figure 2. 4 Real-World Examples of Micro-EVs Observed in Urban China**

### 2.2.2 Secondary Data Sources

Secondary data sources refer to information that has already been collected, processed, and published by other individuals or organizations for purposes other than the current research. In our research study, secondary data played a critical role in providing necessary information that we required. It helps us to save time, provide a wide range of resources and compare large datasets that would be otherwise difficult or expensive to collect independently. The sources that we used are shown as follows:

**1. Official websites of automotive manufacturers**

The official website of the automobile manufacturer can provide relatively complete information and parameters of the models on sale, but it should be emphasized that these information parameters may be exaggerated in order to achieve the purpose of publicity and thus increase sales. Taking the official website of SAIC Motor as an example, shown as Figure 2. 6 and Figure 2. 7, the website provides intuitive and comprehensive information about vehicle models, which is also one of the main sources of information we collect.

| Style | 203km Light Enjoyment | 333km Enjoyable model | 333km Lingxi Internet Model | 333km Lingxi Premium Edition |
|---|---|---|---|---|
| official guide price | 56,800 | 70,800 | 75,800 | 80,800 |
| Dimensions | | | | |
| Length(mm)*Width(mm)*Height(mm) | 3950*1708*1580 | 3950*1708*1580 | 3950*1708*1580 | 3950*1708*1580 |
| Wheelbase(mm) | 2560 | 2560 | 2560 | 2560 |
| Curb weight(kg) | 1010 | 1155 | 1155 | 1155 |
| body structure | 5 door 4 seat car | 5 door 4 seat car | 5 door 4 seat car | 5 door 4 seat car |
| Performance parameters | | | | |
| Power battery type | Lithium Iron Phosphate | Lithium Iron Phosphate | Lithium Iron Phosphate | Lithium Iron Phosphate |
| Power battery capacity (kWh) | 17.3 | 31.9 | 31.9 | 31.9 |
| Cruising range (km, CLTC method) | 203 | 333 | 333 | 333 |
| Drive motor type | [illegible] | [illegible] | [illegible] | [illegible] |
| Maximum power of driving motor (kW) | 30 | 50 | 50 | 50 |
| Maximum torque (N·m) | 85 | 125 | 125 | 125 |
| Maximum speed (km/h) | 100 | 130 | 130 | 130 |

Figure 2. 5 Parameter list of SAIC

| | | | | |
|---|---|---|---|---|
| official guide price | 56,800 | 70,800 | 75,800 | 80,800 |
| Performance parameters | | | | |
| AC charging time (at room temperature, AC charging pile, SOC 20%~100%) | 5.5h | 9.5h | 9.5h | 9.5h |
| DC fast charging | ● | ● | ● | ● |
| Fast charging time (at room temperature, SOC 30%~80%) | 35 minutes | 35 minutes | 35 minutes | 35 minutes |
| energy recovery | ● | ● | ● | ● |
| Battery heating and intelligent insulation | ● | ● | ● | ● |
| Low voltage battery intelligent charging | ● | ● | ● | ● |
| Comfortable chassis | | | | |
| Drive form | Front wheel drive | Front wheel drive | Front wheel drive | Front wheel drive |
| Brake type | Front disc and rear drum type | Front disk and rear disk | Front disk and rear disk | Front disk and rear disk |
| Parking brake type | Mechanical handbrake | EPB electronic parking | EPB electronic parking | EPB electronic parking |
| front suspension | McPherson independent suspension | McPherson independent suspension | McPherson independent suspension | McPherson independent suspension |
| rear suspension | Torsion beam non-independent suspension | Torsion beam non-independent suspension | Torsion beam non-independent suspension | Torsion beam non-independent suspension |

Figure 2. 6 Parameter list of SAIC

The obtained information includes but is not limited to length, width, height, wheelbase, curb weight, body structure type, power battery type, power battery capacity, cruising range, drive motor type, drive motor maximum power, maximum torque, maximum vehicle speed, AC charging power, AC charging time (at room temperature, SOC 20%~100%), fast charging time (at room temperature, SOC 30%~80%)[3], driving mode, brake type, parking brake type, front suspension, rear suspension, wheel material, tire specifications, and other auxiliary driving systems..

## 2. Government and Public Sector Data

The government's public information was not used to collect information about specific brands or models, but more as a reference for our laws and regulations parts in our research. In particular, the dual regulations for micro-car and EV manufacturing, as well as the safety testing of micro-EV. We found the requirements for automotive manufacturing in the Implementation Rules of Compulsory Product Certification issued by China's Ministry of Industry and Information Technology, and the China Electric Vehicle Safety Guidelines issued by the Electric Vehicle Industry Association established by several large automotive manufacturing groups, from which we collected the necessary information and came up with our summary of China's micro-electric vehicle safety regulations.

Source website

Non-English version available:

*https://www.cqc.com.cn/www/chinese/upload/resources/file/2025/02/21/62594.pdf*

English version available:

*https://www.scribd.com/document/632414788/Electrical-Vehicule-Safety-Guide*

Using the same method, we found a safety article on four-wheeled light electric vehicles published by the New Zealand Transport Industry Association, which details the regulations and safety collision requirements for such vehicles.

Source website

https://www.trl.co.uk/uploads/trl/documents/XPR123-safety-of-four-wheeled-lightweight-electric-vehicles.pdf

## 3. New Media and Trade Publications

We have collected new media industry evaluations of micro-EV currently available on the market, as well as interviews with some users' feedback, including Douyin, Weibo, Rednote, and the automotive sections of major news consulting platforms. To a certain extent, the information on these platforms is updated closely in line with market changes, directly reflecting the current market demand of the general publics and users' feedback. However, this information is published by the media and individuals, is not authoritative. It is only used to strengthen the integrity of our investigation report and is not used as the main reference.

## 4. E-commerce Platforms

E-commerce platforms can provide relatively comprehensive information. Some brand products are not widely promoted due to their low popularity and small market scope, and their parameters cannot even be searched on the manufacturer's official website. However, these cars have maintained stable sales in the sinking market of second- and third-tier cities with low prices and small-scale word-of-mouth. For such products, large-scale automotive e-commerce and used car platforms have detailed information and can be directly compared horizontally on the platform.

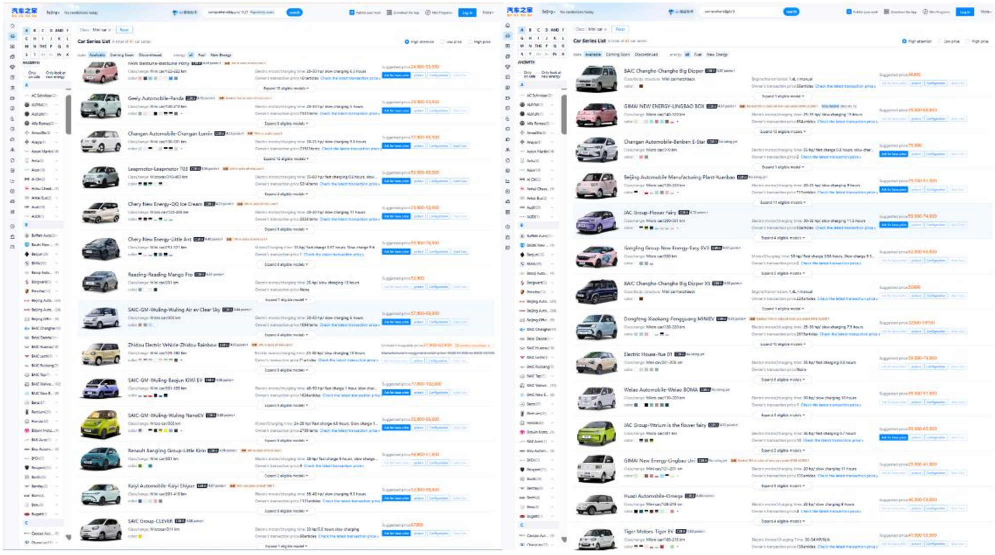


**Figure 2. 7 List of E-commerce platforms page**

### 2.2.3 Data Collection Method

**Table 1: Percentage distribution of each division**

| Region | Official Websites | E-commerce Platforms | New Media |
|---|---|---|---|
| China | 50% | 40% | 10% |
| Europe | 80% | 10% | 10% |
| Japan | 50% | 20% | 30% |

### 2.2.4 Processed Dataset for Comparative Analysis

In the market research phase, we collected a wide range of data on small urban commuter EVs from China, Europe, and Japan. The dataset as shown in Table 2 and

Table 3 includes information such as seating capacity, maximum power, top speed, driving range, and battery capacity. This data serves as the foundation for subsequent comparative analysis across different vehicle categories, sizes, and performance characteristics in various regional markets. The detailed dataset and examples of data processing are presented below. The collected vehicle data are collectively referred to as the database. We performed several processing steps on the vehicles within the database, including categorization according to various standards, conversion of CLTC and NEDC ranges into WLTC-equivalent ranges, and the calculation of key performance indicators such as power-to-mass ratio (PMR) and energy efficiency. The specific classification criteria, conversion formulas, and calculation methods are described in detail in Section 2.3.4.

# Table 2: Collected Specifications of Compact Urban EVs in China

| Brand | SGMW | SGMW | SGMW | SGMW | SGMW | SGMW | SGMW | SGMW | CHANGAN | CHANGAN | CHANGAN | BAOJUN | BAOJUN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | MiniEv(120) | MiniEv(170) | MiniEv(215) | Air Ev (2 seats) | Air Ev(4 seats) | Bingo(203) | Bingo(333) | Bingo(410) | Lumin(130) | Lumin(205) | Lumin(301) | Kiwi Ev(40) | Kiwi Ev(50) |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Standard Catalogue in Europe | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 |
| Standard Catalogue in China | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 |
| Extended Classification in Europe | M0 | M0 | M0 | M0 | M0 | M1 | M1 | M1 | M0 | M0 | M0 | M1 | M1 |
| Industry Classification in China | A00 | A00 | A00 | A00 | A0 | A | A | A | A0 | A0 | A0 | A0 | A0 |
| Characteristic Tech. | | | | | | | | | | | | | |
| Passenger N. | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Top speed(km/h) | 100 | 100 | 100 | 100 | 100 | 100 | 130 | 130 | 101 | 101 | 101 | 105 | 115 |
| Max Rang(km) | 120 | 170 | 215 | 300 | 300 | 203 | 333 | 410 | 130 | 205 | 301 | 305 | 305 |
| TEST TYPE | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | NEDC | NEDC |
| Max range convert to WLTC | 96 | 136 | 172 | 240 | 240 | 162 | 266 | 328 | 104 | 164 | 241 | 260 | 260 |
| Maximum power(kW) | 20 | 20 | 30 | 30 | 50 | 30 | 50 | 50 | 30 | 35 | 35 | 40 | 50 |
| Kerb weight(kg) | 685 | 715 | 777 | 818 | 888 | 1010 | 1125 | 1185 | 840 | 870 | 930 | 1040 | 1052 |
| PMR(w/kg) | 29.200 | 27.970 | 38.610 | 36.670 | 56.310 | 29.700 | 44.400 | 42.190 | 35.710 | 40.230 | 37.630 | 38.460 | 47.530 |
| Wheelbase(mm) | 2010 | 2010 | 2010 | 1635 | 2010 | 2560 | 2560 | 2560 | 1980 | 1980 | 1980 | 2020 | 2020 |
| Length(mm) | 3064 | 3064 | 3064 | 2599 | 2974 | 3950 | 3950 | 3950 | 3270 | 3270 | 3270 | 2894 | 2894 |
| Width(mm) | 1493 | 1493 | 1493 | 1505 | 1505 | 1708 | 1708 | 1708 | 1700 | 1700 | 1700 | 1655 | 1655 |
| Height(mm) | 1614 | 1614 | 1614 | 1631 | 1631 | 1580 | 1580 | 1580 | 1545 | 1545 | 1545 | 1595 | 1595 |
| Battery Voltage(V) | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Capacity(KWh) | 9.3 | 13.4 | 17.3 | 26.7 | 28.4 | 17.3 | 31.9 | 37.9 | 13.41 | 17.65 | 28.08 | 31.7 | 31.7 |
| Battery Tech. | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiMO2/LiFePO4 | LiMO2/LiFePO4 |
| Battery swap | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Acc Time 0-50km/h(sec.) | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Acc Time 0-100km/h(sec.) | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Price (€) | 4650 | 5300 | 6100 | 7500 | 8970 | 7280 | 9080 | 10872 | 4740 | 6013 | 8500 | 11250 | 13200 |
| version | min | | max | min | max | min | | max | min | | max | min | max |
| Energy density(Wh/kg) | 13.577 | 18.741 | 22.265 | 32.641 | 31.982 | 17.129 | 28.356 | 31.983 | 15.964 | 20.287 | 30.194 | 30.481 | 30.133 |
| Energy efficiency in their cycle | 7.75 | 7.88 | 8.05 | 8.9 | 9.47 | 8.52 | 9.58 | 9.24 | 10.32 | 8.61 | 9.33 | 10.39 | 10.39 |
| Energy efficiency in WLTC | 9.69 | 9.85 | 10.06 | 11.13 | 11.83 | 10.68 | 11.99 | 11.55 | 12.89 | 10.76 | 11.65 | 12.19 | 12.19 |

| Brand | BENTENG | BENTENG | BENTENG | GEELY | GEELY | LEAPMOTOR | LEAPMOTOR | LEAPMOTOR | CHERY | CHERY | CHERY | CHERY | CHERY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Little Horse(122) | Little Horse(170) | Little Horse(222) | Geometry panda mini(120) | Geometry panda mini(200) | T03(200) | T03(310) | T03(403) | Ice cream(120) | Ice cream(170) | Ice cream(205) | Little Ant(251) | Little Ant(321) |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Standard Catalogue in Europe | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 |
| Standard Catalogue in China | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 | M1 |
| Extended Classification in Europe | M0 | M0 | M0 | M0 | M0 | M0 | M1 | M1 | M0 | M0 | M0 | M0 | M0 |
| Industry Classification in China | A0 | A0 | A0 | A00 | A00 | A | A | A | A0 | A0 | A0 | A0 | A0 |
| Characteristic Tech. | | | | | | | | | | | | | |
| Passenger N. | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Top speed(km/h) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Max Rang(km) | 122 | 170 | 222 | 120 | 200 | 200 | 310 | 403 | 120 | 170 | 205 | 251 | 321 |
| TEST TYPE | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | CLTC | NEDC | NEDC | NEDC | CLTC | CLTC |
| Max range convert to WLTC | 97.6 | 136 | 177.6 | 96 | 160 | 160 | 248 | 322.4 | 102 | 144.5 | 175 | 200 | 257 |
| Maximum power(kW) | 20 | 20 | 30 | 20 | 30 | 40 | 55 | 80 | 20 | 20 | 30 | 36 | 36 |
| Kerb weight(kg) | 685 | 715 | 750 | 715 | 815 | 995 | 1102 | 1190 | 699 | 715 | 778 | 920 | 960 |
| PMR(w/kg) | 29.200 | 27.970 | 40.000 | 27.970 | 36.810 | 40.200 | 49.900 | 67.200 | 28.610 | 27.970 | 38.560 | 39.130 | 37.500 |
| Wheelbase(mm) | 1953 | 1953 | 1953 | 2015 | 2015 | 2400 | 2400 | 2400 | 1960 | 1960 | 1960 | 2150 | 2150 |
| Length(mm) | 3000 | 3000 | 3000 | 3065 | 3065 | 3620 | 3620 | 3620 | 3008 | 3008 | 3008 | 3200 | 3242 |
| Width(mm) | 1510 | 1510 | 1510 | 1522 | 1522 | 1652 | 1652 | 1652 | 1496 | 1496 | 1496 | 1670 | 1670 |
| Height(mm) | 1630 | 1630 | 1630 | 1600 | 1600 | 1605 | 1605 | 1605 | 1637 | 1637 | 1637 | 1550 | 1550 |
| Battery Voltage(V) | - | - | - | 12 | 12 | - | - | - | - | - | - | - | - |
| Capacity(KWh) | 9.4 | 13.9 | 18.11 | 9.61 | 17.03 | 21.6 | 31.9 | 41.3 | 9.4 | 13.6 | 17.4 | 25.05 | 29.23 |
| Battery Tech. | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 | LiFePO4 |
| Battery swap | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Acc Time 0-50km/h(sec.) | - | - | - | - | - | 6 | 5 | 4.1 | - | - | - | 6 | 6 |
| Acc Time 0-100km/h(sec.) | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Price (€) | 3200 | 4090 | 5000 | 4500 | 5500 | 6410 | 7680 | 8900 | 3200 | 4600 | 6000 | 7500 | 8200 |
| version | min | | max | min | max | min | | max | min | | max | min | max |
| Energy density(Wh/kg) | 13.723 | 19.441 | 24.147 | 13.441 | 20.896 | 21.709 | 28.947 | 34.706 | 13.448 | 19.021 | 22.365 | 27.228 | 30.448 |
| Energy efficiency in their cycle | 7.7 | 8.18 | 8.16 | 8.01 | 8.52 | 10.8 | 10.29 | 10.25 | 7.83 | 8 | 8.49 | 9.98 | 9.11 |
| Energy efficiency in WLTC | 9.63 | 10.22 | 10.2 | 10.01 | 10.64 | 13.5 | 12.86 | 12.81 | 9.22 | 9.41 | 9.94 | 12.53 | 11.37 |

# Table 3: Collected Specifications of Compact Urban EVs in Europe and Japan

| Brand | Microlino | Microlino | Microlino | XEV | Renault | Renault | Citroen | Axiam | Tazzari | Tazzari |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Microlino(1) | Microlino(2) | Microlino(3) | yoyo | Twizy(45) | Twizy(80) | Ami | e city | Zeromax(45) | Zeromax(80) |
| |  |  |  |  |  |  |  |  |  |  |
| Standard Catalogue in Europe | L7E | L7E | L7E | L7E | L6E | L7E | L6E | L6E | L6E | L7E |
| Standard Catalogue in China | - | - | - | - | - | - | - | - | - | - |
| Extended Classification in Europe | L7E | L7E | L7E | L7E | L6E | L7E | L6E | L6E | L6E | L7E |
| Industry Classification in China | A00 | A00 | A00 | A00 | - | A00 | - | - | - | A00 |
| Characteristic Tech. | front door open | front door open | front door open | | | | | | | |
| Passenger N. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Top speed(km/h) | 90 | 90 | 90 | 90 | 45 | 80 | 45 | 45 | 45 | 80 |
| Max Rang(km) | 91 | 177 | 228 | 150 | 120 | 100 | 75 | 75 | 213 | 213 |
| TEST TYPE | *Maximum | *Maximum | *Maximum | *Maximum | *ECE-15 | *ECE-15 | *WMTC | NEDC | WMTC | WMTC |
| Max range convert to WLTC | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 64 | N/A | N/A |
| Maximum power(kW) | 12.4 | 12.4 | 12.4 | 15 | 4 | 13 | 6 | 6 | 10 | 15 |
| Kerb weight(kg) | 596 | 613 | 630 | 525 | 446 | 474 | 471 | 425 | 400 | 400 |
| PMR(w/kg) | 20.800 | 20.230 | 19.680 | 28.570 | 8.970 | 27.430 | 12.740 | 14.110 | 25.000 | 25.000 |
| Wheelbase(mm) | - | - | - | 1680 | 1686 | 1686 | - | 1795 | - | - |
| Length(mm) | 2591 | 2591 | 2591 | 2530 | 2338 | 2338 | 2410 | 2762 | 2129 | 2129 |
| Width(mm) | 1473 | 1473 | 1473 | 1500 | 1381 | 1381 | 1390 | 1500 | 1200 | 1200 |
| Height(mm) | 1501 | 1501 | 1501 | 1560 | 1454 | 1454 | 1520 | - | 1668 | 1668 |
| Battery Voltage(V) | 48 | 48 | 48 | 86 | 48 | 48 | | 220 | 230 | 230 |
| Capacity(KWh) | 5.5 | 10 | 15 | 10.4 | 6.1 | 6.1 | 5.5 | 5.54 | 16 | 16 |
| Battery Tech. | Li-ion(NMC) | Li-ion(NMC) | Li-ion(NMC) | LiFePO4 celle cilindriche | Li-ion(NMC) | Li-ion(NMC) | LiFePO4 | Li-ion(NMC) | LiFePO4 | LiFePO4 |
| Battery swap | - | - | - | Yes | - | - | - | - | - | - |
| Acc Time 0-50km/h(sec.) | 5 | 5 | 5 | - | 6.1 (0-45km/h) | 6.1 (0-45km/h) | 10(0-45km/h) | - | - | - |
| Acc Time 0-100km/h(sec.) | - | - | - | - | - | - | - | - | - | - |
| Price (€) | 19900 | 21400 | 22900 | 15990 | 6990 | 14000 | 6030 | 14999 | 17390 | 17390 |
| version | min | | max | | | | | | min | max |
| Energy density(Wh/kg) | 9.228 | 16.313 | 23.810 | 19.810 | 13.677 | 12.869 | 11.677 | 13.035 | 40.000 | 40.000 |
| Energy efficiency in their cycle | 6.04 | 5.65 | 6.58 | 6.93 | 5.8 | 6.3 | 7.33 | 7.39 | 7.51 | 7.51 |
| Energy efficiency in WLTC | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 8.66 | N/A | N/A |

| Brand | Smart | Fiat | Fiat | Lancia | Honda | Nissan | Toyota | Mitsubishi | Fomm | Eli |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | EQ fortwo | 500e(24) | 500e(42) | Ypsilon | e | Sakura | C+pod | i-MiEV | one | Zero |
| |  |  |  |  |  |  |  |  |  |  |
| Standard Catalogue in Europe | M1 | M1 | M1 | M1 | M1 | M1 | L7E | M1 | L7E | L6E |
| Standard Catalogue in China | M1 | M1 | M1 | M1 | M1 | M1 | - | M1 | - | - |
| Extended Classification in Europe | M0 | M1 | M1 | M1 | M1 | M1 | L7E | M1 | L7E | L6E |
| Industry Classification in China | A00 | A | A | A | A | A | A00 | A | A0 | - |
| Characteristic Tech. | | | | | | | | | Float-Drive | |
| Passenger N. | 2 | 4 | 4 | 5 | 4 | 4 | 2 | 4 | 4 | 2 |
| Top speed(km/h) | 130 | 135 | 135 | 150 | 145 | 130 | 60 | 130 | 80 | 40 |
| Max Rang(km) | 132 | 190 | 320 | 403 | 222 | 180 | 150 | 160 | 166 | 100 |
| TEST TYPE | NEDC | WLTC | WLTC | WLTC | *Maxmium | WLTC | WLTC | NEDC | WLTC | *Maximum |
| Max range convert to WLTC | 112 | 190 | 320 | 403 | N/A | 180 | 150 | 136 | 166 | N/A |
| Maximum power(kW) | 60 | 70 | 87 | 115 | 100 | 47 | 9.2 | 49 | 10 | 6 |
| Kerb weight(kg) | 950 | 1365 | 1365 | 1561 | 1514 | 1070 | 690 | 1080 | 620 | 501 |
| PMR(w/kg) | 63.160 | 51.280 | 63.740 | 73.670 | 66.000 | 43.930 | 13.330 | 45.370 | 16.130 | 12.000 |
| Wheelbase(mm) | 1873 | 2322 | 2322 | 2545 | - | 2495 | 1780 | 2550 | 1760 | 1600 |
| Length(mm) | 2695 | 3631 | 3631 | 4080 | 3895 | 3395 | 2490 | 3475 | 2585 | 2250 |
| Width(mm) | 1633 | 1683 | 1683 | 1955 | 1752 | 1475 | 1290 | 1475 | 1295 | 1380 |
| Height(mm) | 1555 | 1529 | 1529 | 1440 | 1512 | 1655 | 1550 | 1610 | 1550 | 1588 |
| Battery Voltage(V) | - | 400 | 400 | 400 | - | 350 | 177.6 | | | 72 |
| Capacity(KWh) | 17.6 | 24 | 42 | 51 | 35.5 | 20 | 9.06 | 16 | 11.84 | 8 |
| Battery Tech. | Li-ion(NMC) | Li-ion(NMC) | Li-ion(NMC) | Li-ion(NMC) | Li-ion(NMC) | LiFePO4 | Li-ion(NMC) | Li-ion(NMC) | LiFeO4 | LiFePO4 |
| Battery swap | - | - | - | - | - | - | - | - | Yes | - |
| Acc Time 0-50km/h(sec.) | 5 | - | - | - | - | 8 | - | - | - | - |
| Acc Time 0-100km/h(sec.) | 11.6 | 9.5 | 9 | 8.2 | 9 | - | - | 15 | - | - |
| Price (€) | 25000 | 34990 | 34990 | 34900 | 33000 | 16000 | 12000 | 24000 | 17500 | 11590 |
| version | | min | max | | | | | | | |
| Energy density(Wh/kg) | 18.526 | 17.582 | 30.769 | 32.671 | 23.448 | 18.692 | 13.130 | 14.815 | 19.097 | 15.968 |
| Energy efficiency in their cycle | 13.54 | 12.63 | 13.13 | 12.66 | 15.99 | 11.11 | 6.04 | 10 | 7.13 | 8 |
| Energy efficiency in WLTC | 15.71 | 12.63 | 13.13 | 12.66 | N/A | 11.11 | 6.04 | 11.76 | 7.13 | N/A |

## 2.3 Vehicle Classification Criteria

Vehicle classification systems vary across regions and are generally divided into two categories: legally binding regulatory standards and non-binding industrial or recommended standards. Among these, the European Union's type-approval system serves as a foundational framework globally. Established in its modern form in the early 2000s.

Countries such as China have adopted and adapted the EU classification standards, creating official national standards that align with the EU framework but omit certain categories. For instance, China's legal classification system does not formally recognize the L6e/L7e classes, despite their inclusion in the EU system. This reflects differing regulatory priorities and vehicle market dynamics.

Beyond the legal standards, industry-driven or research-based classification systems often introduce refined subcategories. These informal frameworks—such as the M0 class within the broader M1 category—offer greater granularity, particularly in the context of urban mobility, lightweight vehicles, and electric vehicle policy design. Although not legally binding, these extended classifications are increasingly used in academic research, transportation policy, and environmental assessment to better capture the evolving diversity of modern vehicles.

### 2.3.1 Chinese Classification

- **Chinese compulsory national standard**

In China, the legal classification of power-driven vehicles is based on the Chinese compulsory national standard, "GB". This system is partially adapted from the European Union's vehicle type-approval framework, with modifications made to suit

China’s national context, including factors such as traffic conditions, road safety considerations, and regulatory priorities. Within this framework, the target small-sized electric vehicles are legally classified under the M1 category, as M1 is the only applicable class for four-wheeled passenger vehicles with no more than nine seats. The detailed classification criteria are presented in **Table 4**.

**Table 4: Current Chinese definitions for categories L and M1**

| Category | Common classification criteria |
|---|---|
| **L** | Two- or three-wheeled motorcycles and mopeds (including electric versions). |
| **M** | Motor vehicles with at least four wheels, used for passenger transport. |
| **M1**<br><br>**Passenger car** | Vehicles used for passenger transport, the number of seats up to 9, including the driver. |

*Adapted from GB/T 15089-2001 Chapter 3*

One of the key distinctions between the Chinese and EU classification systems is the absence of the L6e and L7e vehicle categories in the Chinese framework. Hence, small-sized electric vehicles must meet the full technical and safety requirements of M1 class vehicles to be approved for public road use. This ensures compliance with crash safety, brake systems, occupant protection, and other critical standards.

- **Chinese recommendatory industry standard**

Additionally, China employs a widely used industry classification system that categorizes small-sized passenger vehicles into A00, A0, and A, based on dimensions like wheelbase and vehicle size. This is a recommendatory industry standard, often used for market segmentations, subsidy policies, and product planning.

**Table 5: Current Chinese definitions for categories A00, A0, and A**

| Category | Common classification criteria | Example |
|---|---|---|
| **A00**<br><br>**Micro-electric passenger cars** | 2 seats including driver<br><br>wheelbase≤2000<br><br>length≤3000, width≤1600, high≤1650<br><br>curb weight≤1200kg | SGMW MiniE，<br><br>GEELY Geometry Panda Mini |
| **A0**<br><br>**Small passenger cars** | 2000<wheelbase≤2300 | CHANGAN Lumin，<br><br>CHERY Little Ant |
| **A**<br><br>**Compact passenger cars** | 2300<wheelbase≤2650 | SGMW Bingo,<br><br>LEAPMOTOR T03，<br><br>Fiat 500e |

*Adapted from T/ZZB 0391—2018, Technical Specification for A00 class Micro Electric Vehicles.*

### 2.3.2 European/Japanese Classification

- **EU type-approval system**

In the European Union, vehicles are classified according to UNECE standards and based on EU regulatory frameworks, so it is legally binding. The target small-size electric vehicles are classified in the following table, including L6e, L7e, and M1 classes.

**Table 6: Current European definitions for categories L6e, L7e, and M1**

| Category | Common classification criteria |
|---|---|
| **L** | Motor vehicles with less than four wheels and some lightweight four-wheelers. |
| **L6e**<br><br>**Light quadricycle** | 4 wheels<br><br>Unladen mass ≤ 350 kg (not including batteries of electric vehicles)<br><br>Vmax ≤ 45 km/h<br><br>Engine Vd ≤ 50 cm3 (PI internal combustion engine)<br><br>Pmax ≤ 4 kW (non-PI internal combustion engine, electric motor) (electric vehicles: maximum continuous rated power; combustion engine vehicles: maximum net power) |

| | |
|---|---|
| **L7e**<br><br>**Heavy Quadricycle** | 4 wheels<br><br>Not L6e<br><br>Unladen mass ≤ 400 kg (not including batteries of electric vehicles), 550 kg (vehicles intended for carrying goods, not including batteries of electric vehicles)<br><br>Pmax ≤ 15 kW (maximum net engine power) |
| **M** | Power-driven vehicles having at least four wheels and used for the carriage of passengers. |
| **M1**<br><br>**Passenger car** | Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat. |

*Adapted from Directive 2002/24/EC, Chapter I, Article 1, Section 3 and ECE/TRANS/WP.29/78/Rev.6, Introduction, Section 2.*

"Current regulations for Quadricycle (L6E, L7E), they are not subject to the same legislation as passenger cars, and do not have to be crash tested before they can be sold for road use"[4]. From Euro NCAP, the European crash test agency declared that the quadricycles have significantly lower safety levels compared to passenger cars because they are not legally required to undergo crash safety testing [4].

- **Extended European Vehicle Classification Scheme**

In this context, the M0 class refers to the lightest category within the M class of passenger vehicles, specifically within M1, based on curb weight. While the M1 category includes a wide range of vehicles with significant variation in size and weight, the M0 classification serves to further refine this range by identifying micro-sized passenger cars, typically distinguished by their notably low curb weight so it becomes increasingly important in discussions of sustainable mobility, light electric vehicle innovation, and future urban transport systems.

This classification is informal and primarily used within the automotive industry, technical research, and urban policy planning. not commonly marketed to consumers.

Typical Weight Range for M0 is the curb weight less than 1,000 kg.

### 2.3.3 Passive safety regulations

Passive safety in vehicles refers to built-in systems and design elements that help reduce injuries during a collision without requiring any active response from the driver or passengers. These systems function automatically and include features such as pre-tensioned seatbelts, airbags, and impact-absorbing structures integrated into the vehicle’s body.

In Battery electric vehicles, they are subject to the same safety requirements as conventional cars, and they must also meet additional requirements that are specific to their electrical systems. For instance, their batteries are extensively tested and must meet standards to prevent potential risks, such as fire or leakage.

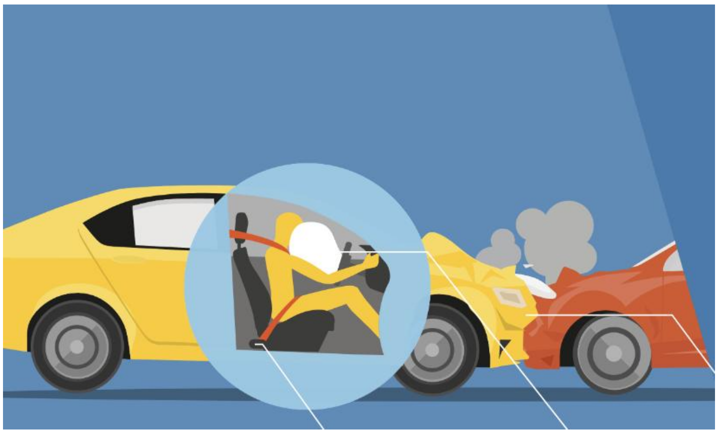


**Figure 2. 8 Passive safety system illustration**

*Adapted from Road Safety Facts Europe. "Passive Safety Systems – What Are They and How Do They Work?"*

Below, we present a detailed comparison of the varying passive safety requirements across different regions and vehicle categories.

**Table 7: Passive Safety regulations through Europe (L and M class) and China (M class)**

| **Region** | **Europe** | | **China** |
|---|---|---|---|
| **Class** | **L(L6e/L7e)** | **M(M1)** | **M(M1)** |
| **Regulations** | **Regulation(EU) No 168/2013** | **Regulation (EC) No 661/2009** | **GB 7258-2017** |
| Safety belt anchorages and | Fitted with body work: | **Mandatory** for all seats; At least two | **Mandatory** for all seats; At least two |

| | | | |
|---|---|---|---|
| safety belts | **Mandatory**<br><br>Others:<br><br>If required | ISOFIX child seat anchorage points in the rear seats (UN ECE R16 &R129) | ISOFIX child seat anchorage points in the rear seats (GB 14166-2024 &GB 27887-2024) |
| Airbags | Not Mandatory | Front and side airbags are **Required** for Front-seat occupants to meet the frontal and side impact crash test requirements under Regulation R94 and R95 | Front and side airbags are **Required** for Front-seat occupants to meet the frontal and side impact crash test requirements under GB 11551-2014 and GB 20071-2006 |
| Deformation zones | The design of energy-absorbing zones is **simplified**, body strength requirements can be relaxed (the use of plastic body panels is permitted), and they are typically | Vehicle's front end **must** incorporate an energy-absorbing crush zone; side elements like B-pillar **must** provide adequate bending strength for front and side | Vehicle's front end **must** incorporate an energy-absorbing crush zone; side elements like B-pillar **must** provide adequate bending strength for front and side |

| | | | |
|---|---|---|---|
| | **exempt** from crash testing | collision tests | collision tests |
| Vehicle occupant protection, including interior fittings, head restraint and vehicle doors | If required | **Mandatory** | **Mandatory** |
| Battery safety | **Relaxed** requirements for electric vehicle battery crash safety, generally **exempt** from ECE R100 | **Comply with ECE R100** requirements for electric vehicle battery crash safety | **Comply with GB 18384-2020** requirements for electric vehicle battery crash safety |

Based on the passive safety regulations presented in the table above, it is evident that L-category EVs have significantly lower safety standards compared to M1-class vehicles in both China and Europe. Many safety requirements for L-class vehicles are either absent or minimal, which constitutes a fundamental difference between L- and M-class vehicles. While L-class EVs are generally more affordable, their low level of safety severely limits their suitability for everyday use.

Consequently, European L-class vehicles are essentially ineligible for entry into the Chinese market. The Renault Twizy, for example, was brought into China on a limited basis around 2013 for exhibitions. However, its open or plastic doors and lack of traditional glass windows make it impractical for everyday use, and it fails to satisfy

China’s compulsory motor-vehicle safety regulations (including crash-test standards), preventing it from being legally registered for road use.

On the other hand, M1-class vehicles in China and Europe are subject to broadly similar safety standards, each aligned with their respective regional regulations. These are largely comparable to European directives such as ECE R94 and R95. However, it is worth noting that Europe imposes stricter requirements in both frontal and side impact tests. For instance, the frontal crash test speed in China is set at 50 km/h, while in Europe it is 56 km/h. In side-impact tests, the European standard also employs a heavier moving barrier, increasing the severity of the evaluation. Additionally, China's C-NCAP system, though modeled after Euro NCAP, applies slightly less rigorous criteria, whereas Euro NCAP remains one of the most demanding safety assessment programs globally.

Therefore, it can be concluded that L-class vehicles offer very low safety performance and are not legally permitted for road use in China. In contrast, M1-class vehicles in Europe and China follow broadly similar safety standards, with European regulations being slightly more stringent.

### 2.3.4 Cross-Market Alignment

China’s vehicle classification system partially overlaps with that of the European Union, particularly in the M1 category, which is consistently defined in both systems as passenger vehicles with four wheels and no more than nine seats. However, each system introduces its own refined subcategories within M1 to accommodate regional needs and regulatory contexts.

In the EU, the M0 subcategory is an informal refinement of M1, used to designate very small passenger cars based on curb weight—typically vehicles under 1,000 kg. In contrast, China employs the A00, A0, and A classes, which classify small vehicles based primarily on dimensional attributes such as wheelbase and body size. Despite differing classification criteria, EU's M0 category roughly corresponds to China's A00 and A0 segments, reflecting a similar effort to distinguish micro-sized urban vehicles.

Notably, China's national compulsory standard (GB) does not include the L6e and L7e categories, which are recognized in the EU for regulating light and heavy quadricycles. Unless an L7e-class vehicle meets China's safety and technical standards for motor vehicles and can be classified as A00 or A0 class for micro passenger cars. In this case, the vehicle would need to comply with the relevant GB standards for M1, including crash safety, lighting, braking systems, and electric drivetrain specifications.

Instead, a loosely corresponding category in China is the Low-Speed Electric Vehicle (LSEV) with respect to the L6e and L7E, a type of electric passenger vehicle characterized by low maximum speed, limited driving range, and relatively basic electric components such as batteries and motors. However, LSEVs lack formal legal recognition in most Chinese jurisdictions due to road safety standards, infrastructure limitations, and enforcement challenges. Consequently, they are typically restricted to special-use environments such as rural areas, private properties, or golf courses.

According to data released by China's traffic management authorities in 2017, LSEVs—often referred to as "elderly mobility vehicles" —were involved in 830,000 traffic accidents over the previous five years, resulting in 18,000 deaths and 186,000 injuries. The number of accidents and fatalities increased by 23.3% and 30.9%, respectively, over that period[5]. In addition to safety concerns, public dissatisfaction has grown due to problems such as illegal parking, occupation of charging infrastructure, and frequent violations of traffic rules. As a result, many local governments have imposed restrictions or outright bans on the use of such vehicles since 2019.

In response to these issues and in an effort to enhance road safety, regulate industry standards, and guide the formal production of LSEVs, China's Standardization Administration (SAC) approved a national standard project titled Technical Requirements for Low-Speed Electric Vehicles in 2016. However, as of now, this standard has not yet been officially issued. Apart from safety reasons, this may be related to traffic order and the development of automobile-related industries.

In July 2020, the launch of the SGMW "MINI EV" marked the emergence of a legitimate micro electric vehicle in the Chinese market. With its similarly affordable price, combined with increasingly stringent regulations and legal restrictions, LSEVs gradually began to phase out. Since then, small EVs such as the Baojun "Kiwi EV" and the Chery "Little Ant" have entered the market with precise targeting strategies, opening up a new direction for urban mobility solutions in China.

Therefore, China's small EVs can be seen as the upgraded successors of LSEVs, with LSEVs roughly corresponding to Europe's L class EVs. These new small EVs offer better performance and higher safety compared to Europe's L class EVs, yet their performance still falls short of that of traditional M1-class passenger cars. As such, they should be considered as positioned between the L and M1class electrical vehicles.

## 2.4 Basic Indicators and Parameters

Based on the database we have compiled, an analysis of several fundamental indicators allows for a preliminary assessment of market segmentation and regional targeting within the EV sector. Some basic but important parameters such as battery capacity and maximum power output provide valuable insights into the positioning of various vehicle models. Additionally, a number of derived metrics, such as power density and energy efficiency, that require further calculation, play an important role in characterizing vehicle performance and market fit. These indicators will be discussed in greater detail in Chapter 3.

### 2.4.1 Battery type and Battery capacity

**1. Battery type**

At present, the EVs on the market basically use lithium-ion batteries (hereinafter referred to as Li-ion batteries). And in the collected database, all models use Li-ion batteries. This is due to the high energy density of Li-ion batteries. They can store a large amount of energy in a relatively small and lightweight package, making them ideal for electric vehicles, where space and weight are important. The energy density of different types of batteries is shown in the Figure 2. 9.

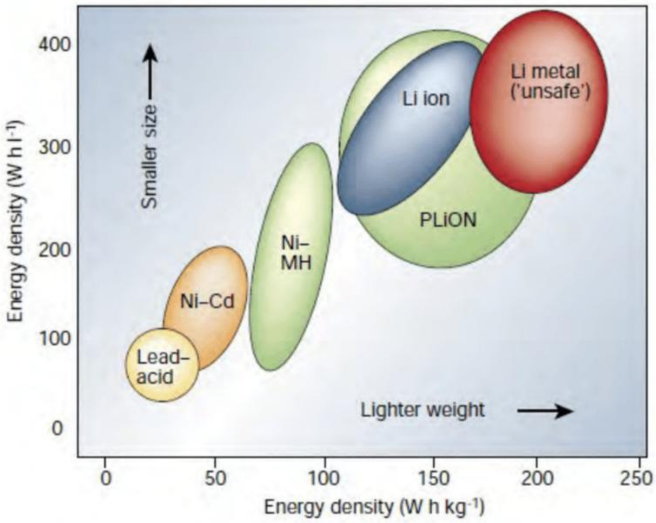



**Figure 2. 9 Comparison of battery technologies (volumetric and mass energy density)**

*Source: Development of Cathode Materials for Li-ion Battery and Megalo-Capacitance Capacitor (Doctoral dissertation), by A. K. Thapa, 2007, University of Louisville. © 2007 by A. K. Thapa.*

From the above figure, we can see that Li-ion batteries have great advantages in both volume energy density and mass energy density and are safer than lithium metal batteries. This is also an important reason why Li-ion batteries stand out. In addition, compared with other secondary batteries, Li-ion batteries also have better lifespan and environmental performance.

The most common chemistries are: lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA) and lithium iron phosphate (LFP).

LFP is a lower cost battery chemistry, over 20% cheaper today than NMC. It does not contain nickel or cobalt, and it offers a more stable chemistry than nickel-rich chemistries, with reduced flammability and a longer cycle life. However, it has a significantly lower energy density, conventionally 20-30% lower than high nickel chemistries at battery cell level[6]. As of 2023, LFP has become the leading technology in China, but market share in Europe and North America is still less than 10%[7].

NMC offers high performance and has become the global standard in BEV production since the 2010s[8]. On the other hand, the exploitation of the required minerals causes environmental problems. The downside of traditional NMC batteries includes sensitivity to temperature, low temperature power performance, and performance degradation with age[9].

NCA delivers high energy density and long cycle life, making it ideal for premium EVs. It uses nickel, cobalt, and aluminum, and typically offers slightly better performance than NMC. However, it is more expensive and poses higher thermal risk, requiring strict safety management. While adopted by companies like Tesla, its market share remains limited outside such partnerships due to cost and material constraints[10].

From Figure 2. 10, we can see that NMC remains the dominant cathode chemistry for electric cars, while the share of LFP batteries is increasing and reached its highest ever level in 2023.

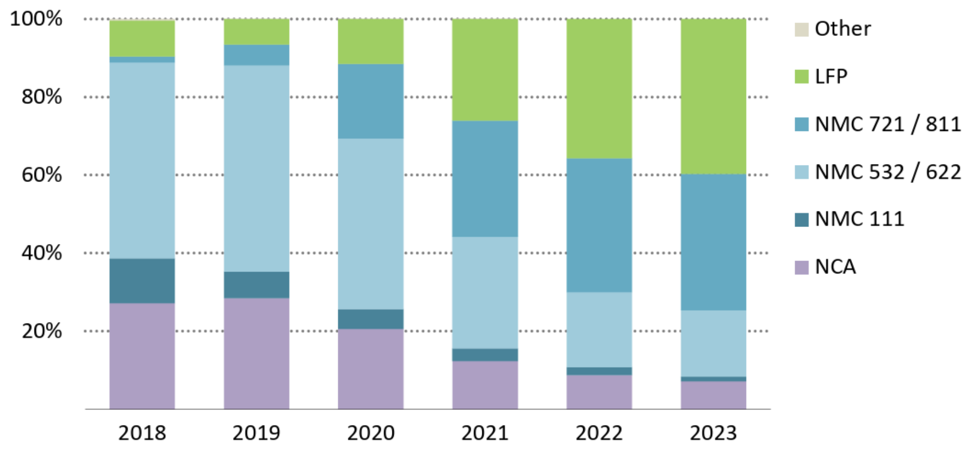



**Figure 2. 10 Battery cathode chemistry in electric car sales, 2018-2023**

*Source: International Energy Agency, 2024[8]*

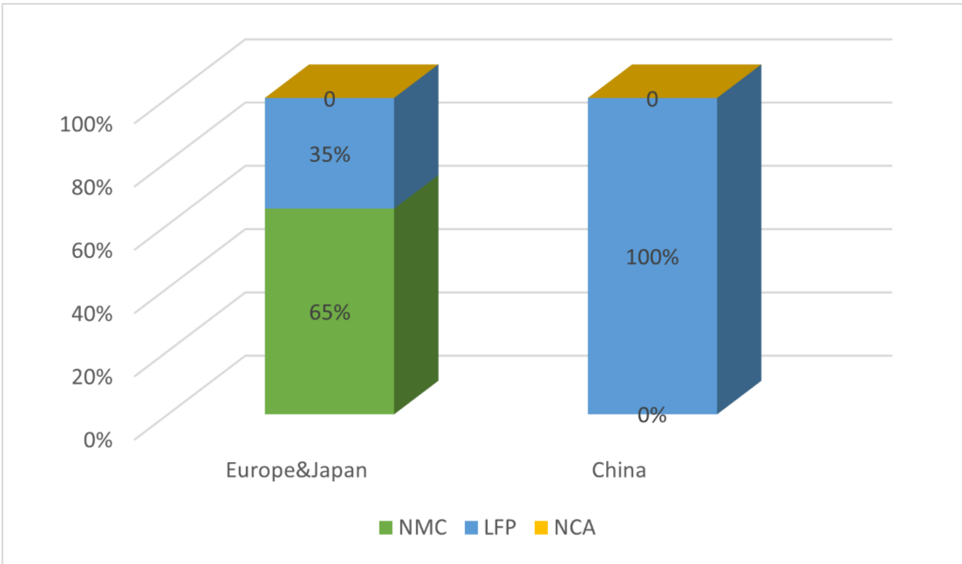



**Figure 2. 11 Proportion of Battery Types in China and Europe& Japan based on the collected database**

Based on the collected dataset, we statistically analyzed the proportion of Battery

Types in China and Europe& Japan. Figure 2. 11 illustrates the distribution of battery types across China, Europe& Japan based on the collected dataset. In China, all vehicles adopt LFP, dominating the market. In contrast, in Europe& Japan shows a higher preference for NMC accounted for 65%, while LFP accounted for 35%.

This divergence stems from differences in energy density requirements, cost structures, and manufacturing dynamics:

LFP batteries, though offering lower energy density than NMC, provide sufficient range for urban-centric EVs common in China, where cost-sensitive consumers and dense charging infrastructure reduce the need for longer-range vehicles. LFP's lower material costs and superior thermal stability make it a pragmatic choice for mass-market models. China’s battery industry, led by firms like CATL, has optimized LFP production at scale, benefiting from lower labor costs, domestic supply chains, and government support. These factors enhance LFP’s cost competitiveness.

In contrast, European small EVs face stricter performance expectations, including longer range and higher energy density, favoring NMC technology. Additionally, European import duties on Chinese-made LFP batteries and the limited domestic LFP capacity further tip the balance toward NMC, often produced in or closer to Europe to avoid tariffs and reduce logistical costs.

Currently, LFP is experiencing a significant increase in market share in Europe. Prior to 2020, the European market was dominated by NCM batteries, with LFP accounting for less than 5%. However, between 2021 and 2023, the share of LFP grew rapidly and now stands at approximately 20–30%[11]. Due to its advantages in cost, safety, and environmental impact, LFP continues to gain traction in Europe. Many automakers are shifting their models to use LFP batteries, and battery manufacturers, such as BYD and Northvolt, are establishing LFP production facilities in Europe to reduce dependence on the Asian supply chain. As a result, LFP is emerging as a potential mainstream technology in both the European and global EV markets.

## 2. Battery capacity

Battery capacity is a fundamental parameter that directly influences several key aspects of electric vehicles, including driving range, charging time, cost, and overall performance. Capacity is positively correlated with range, as illustrated in Figure 2. 12. Notably, the slope in Europe is steeper, which may be attributed to differences in testing cycles. For example, China's CLTC cycle tends to yield higher range estimates compared to the WLTC used in Europe—this issue will be discussed in detail in Chapter 3. In terms of cost, the battery accounts for approximately 30–50% of the total vehicle cost, and this cost increases with capacity. Price per kWh for LFP in China is under 70 us dollars. NMC is around \$130/kWh, and NCA is around \$120/kWh[12].

As shown in Figure 2. 13, the battery capacity of small EVs in China is generally concentrated below 30 kWh, whereas in Europe and Japan, it is primarily below 20 kWh. This difference corresponds to the typical driving range of vehicles in these regions: in China, most models fall into the low-to-medium range segment (<350 km), while in Europe and Japan, they are predominantly short-range vehicles (<200 km), shows in Figure 2. 17. This variation is also influenced by urban geography—Chinese cities are generally larger, resulting in different range expectations. Furthermore, the types of batteries used in different regions also have an impact on this difference. In China, small EVs almost exclusively use LFP batteries, while in Europe and Japan, NMC batteries are more commonly used. For the same approximate battery cost of \$2,000, an LFP battery in China can provide around 30 kWh of capacity, whereas in Europe or Japan, the same investment in an NMC battery typically yields only about 15 kWh, due to higher material and production costs. Therefore, the price factor also directly leads to a lower battery capacity in Europe& Japan than in China.

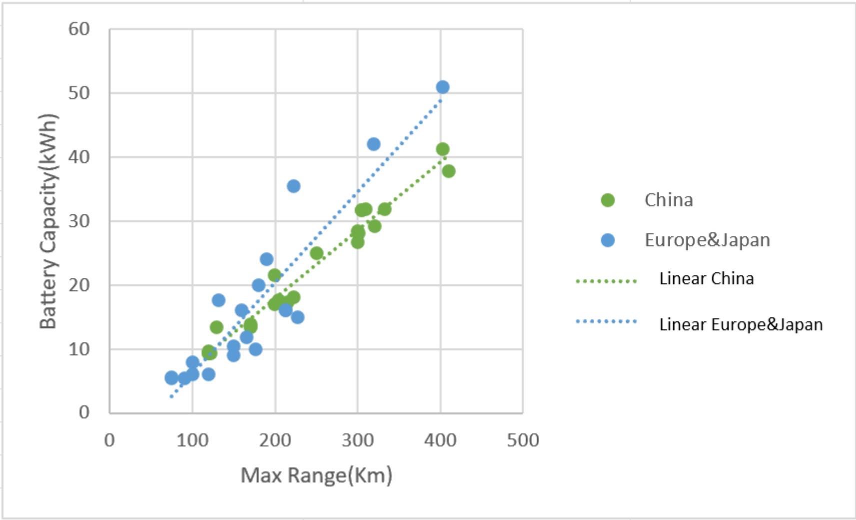



**Figure 2. 12 Battery capacity vs Max range through China and EU&JP**

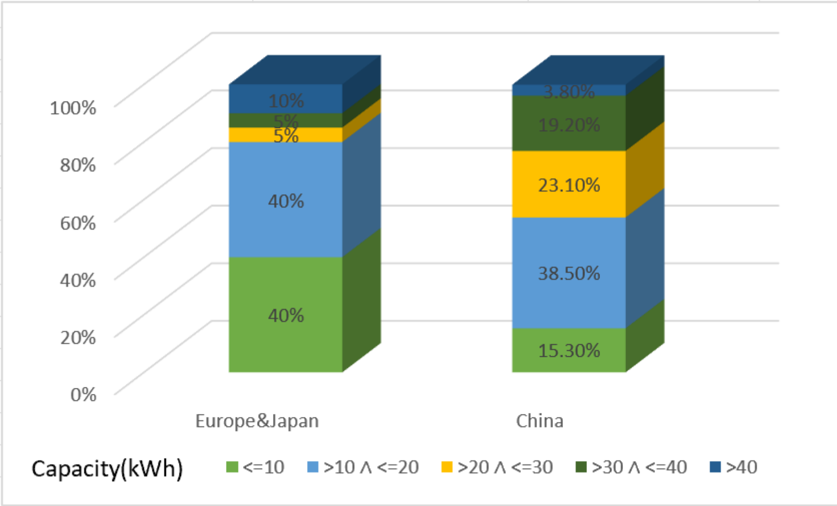



**Figure 2. 13 Proportion of Battery capacity in China and EU&JP**

## 2.4.2 Maximum Power

The maximum power (kW) of an electric vehicle refers to the peak power output that the motor can deliver for a short duration. This parameter reflects the instantaneous dynamic performance of an EV and directly influences its acceleration capability, top speed, and performance under high-load conditions such as hill climbing and overtaking.

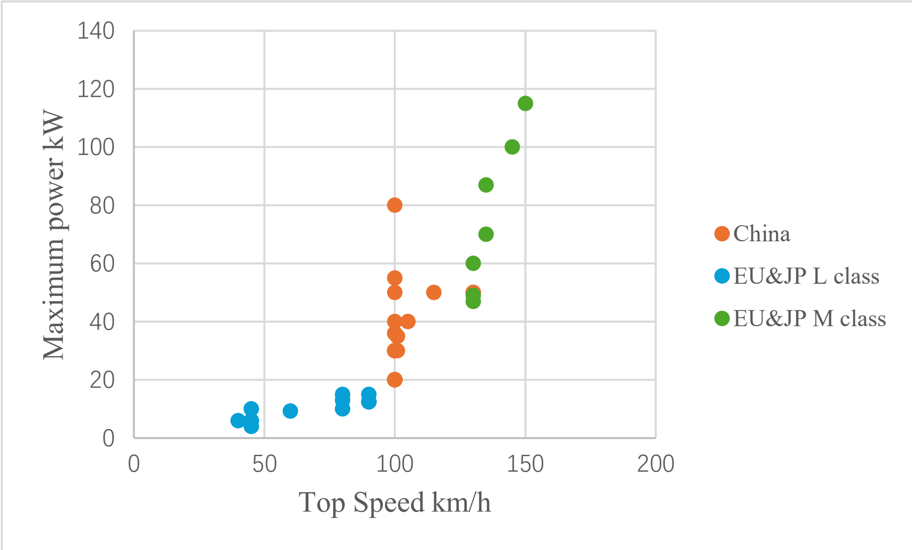



**Figure 2. 14 Maximum power vs Top speed through China and EU&JP**

Figure 2. 14 illustrates the relationship between maximum power and top speed based on our database, covering small EVs in China and in Europe and Japan's L-class and M-class segments.

In Europe and Japan, L-class vehicles exhibit both low maximum power and low top speed, with ultra-low power levels generally not exceeding 20 kW and top speeds limited to 90 km/h, and most of them are concentrated at 45km/h(L6e) and 90km/h(L7e).

Chinese compact, economy-oriented small EVs mostly fall within the 20–60 kW range, categorizing them as low-power vehicles. Their top speeds are generally around 100 km/h, which aligns well with the demands of short-distance urban commuting and low-speed mobility. Their low energy consumption also contributes to favorable range performance.

In contrast, the M class small EVs in Europe and Japan tend to have maximum power outputs between 50–100 kW, which places them in the low-to-medium power category. These vehicles generally feature higher top speeds of 130–150 km/h, offering better overall performance and a more balanced trade-off between range and driving capability. However, this typically comes at a higher cost compared to their Chinese counterparts.

### 2.4.3 Vehicle Weigh

Curb weight refers to the total weight of a vehicle with all standard equipment, necessary operating consumables (such as oil and coolant), fully charged battery, but without passengers or cargo. It is influenced by various factors, including vehicle size, battery capacity, body materials, powertrain type, and equipment level. Curb weight, in turn, affects vehicle performance, energy consumption, and safety. Apart from material considerations, heavier vehicles typically carry a higher capacity battery and offer better performance. Moderate weight can also enhance tire grip and improve high-speed stability.

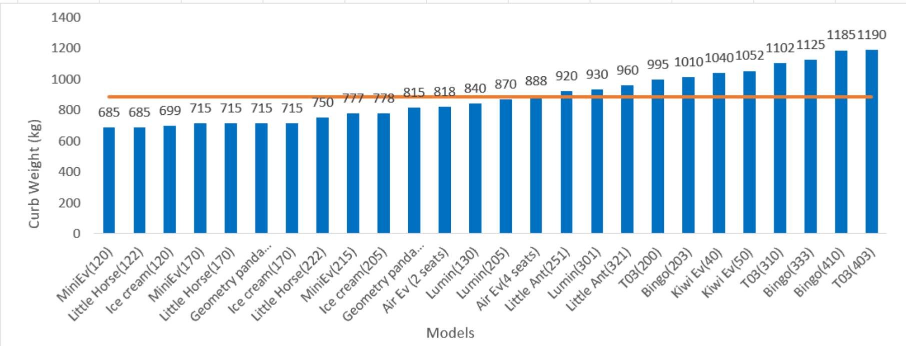



**Figure 2. 15 Curb weight of small EVs models in China**

*The orange line indicates the average weight across all listed vehicles.*

As illustrated in Figure 2. 15 and Figure 2. 16, the average curb weight of small EVs in China is approximately 884 kg, positioned between the averages of L class (522 kg) and M class (1,272 kg) vehicles in Europe and Japan. Compared to L-class vehicles, Chinese small EVs tend to be larger in size and offer higher performance. In contrast, when compared with M-class vehicles in Europe and Japan, Chinese small EVs are generally smaller in size, with lower battery capacity and power output, making them more cost-effective and better suited for the entry-level segment of the market.

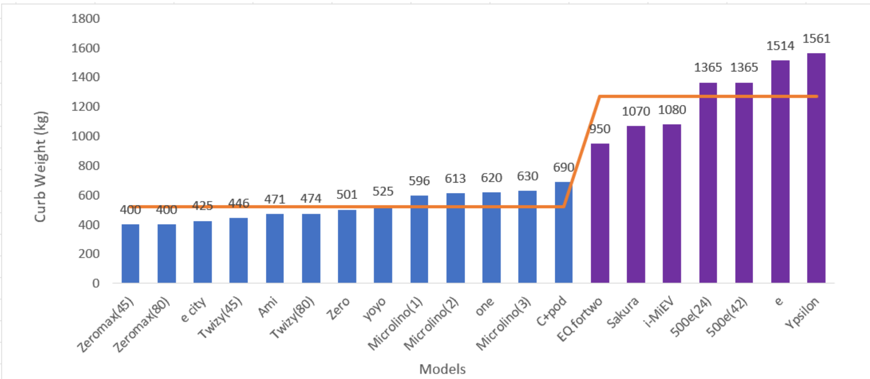



**Figure 2. 16 Curb weight of small EVs models in EU&JP**

*The orange line indicates the average weight across 2 classes vehicles. The blue bar indicate L class and the purple bar indicate M class.*

## 2.4.4 Range and price

Based on the collected dataset, we statistically analyzed the distribution of driving range for small-sized electric vehicles in China and Europe& Japan. The result shows that in China, the range is more distributed between 200-350km, and the average range is approximately 235 km. In contrast, 70% of small-sized electric vehicles in Europe and Japan have a driving range below 200 km, resulting in a lower average range of 178 km. The distribution charts Figure 2. 17 are shown below.

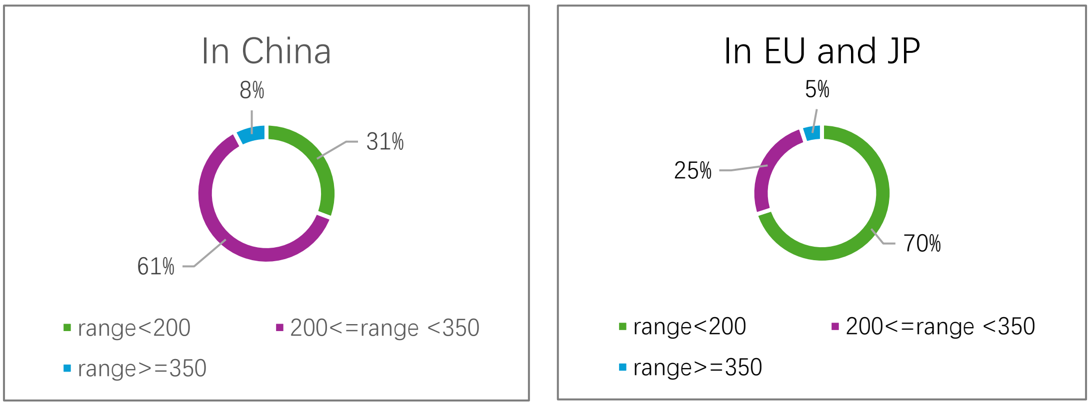



**Figure 2. 17 Proportion of driving Range in China and EU&JP**

The difference in driving range can largely be attributed to the generally larger urban areas in China compared to Europe and Japan, which leads to longer average commuting distances. Additionally, the type of test cycle used also plays a role—China's EVs are typically tested under the CLTC cycle, which tends to yield higher range than the WLTC cycle, which we will discuss in more detail in Chapter 3.

In general, within the same region, EVs with longer driving ranges tend to be more expensive. However, vehicle costs exhibit significant regional variations, leading to divergent pricing across different markets. The Chinese market offers a significant price advantage compared to Europe and Japan, as illustrated in Figure 2. 18.


**Figure 2. 18 Small EVs average price in China and EU&JP**

Small-sized EVs in China are priced significantly lower, the average price is lower than 7,000 euros, often less than half the price of L-segment vehicles in Europe and Japan, while offering better performance and safety, and their prices are approximately one-quarter of those of M-segment vehicles in Europe and Japan. The primary reasons for this include lower material and labor costs in China, as well as the cost advantage of domestically produced LFP batteries compared to the NMC batteries predominantly used in Europe. This is further discussed in Section 2.4.1 on batteries. Additionally, as China is still in the early stages of the development of electric vehicles, intense competition among manufacturers and suppliers, combined with government subsidies, further contributes to China's pricing advantage.

# Chapter 3

# Research Conclusion

## 3.1Power density and Energy density

### 3.1.1 Power Density

Power density (W/kg), also called PMR, or power-to-mass ratio, refers to the ratio of vehicle's maximum power to its weight[13]. It indicates the acceleration capability and performance independent of their weights.

$$PMR = \frac{Maximum\ power(W)}{Curb\ weight(kg)} \tag{1}$$

The results of the calculated average PMR for small electric vehicles from different regions based on the dataset are as follows:

- China: Average PMR=38.29 W/kg
- Europe& Japan: Average PMR=32.16 W/kg
  - L class Average PMR=18.77 W/kg
  - M class Average PMR=58.16 W/kg

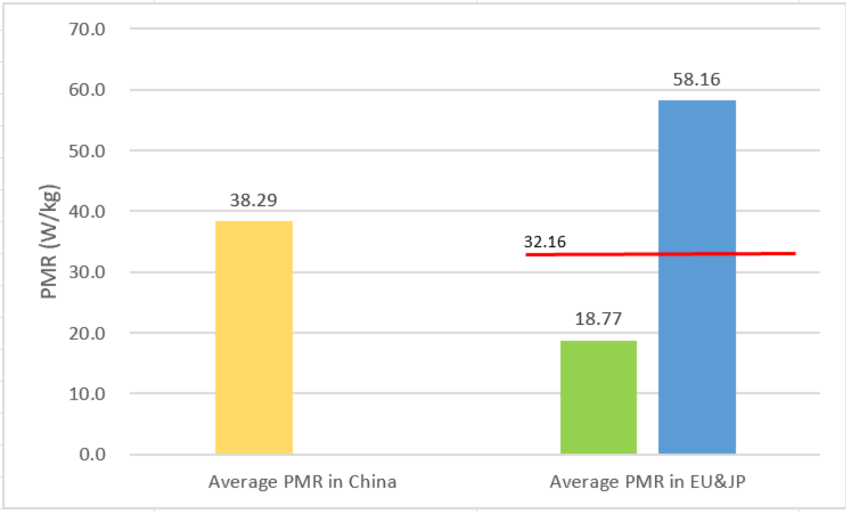



**Figure 3. 1 The average PMR of small EV models in China and EU&JP**

*The green bar indicates the L class and the blue bar indicates the M class, the red line is the average PMR value in Europe and Japan.*

On average, Chinese small EVs have a PMR approximately 19% higher than their European and Japanese counterparts. The percentage difference can be calculated as:

$$\frac{38.29 - 32.16}{32.16} * 100\% \approx 19.06\%$$

The higher PMR indicates that Chinese small EVs generally offer better acceleration potential and higher performance per unit mass. A higher PMR often translates into quicker response and greater power availability, particularly important for urban driving dynamics.

The primary reason for this discrepancy lies in vehicle classification differences:

Chinese small EVs predominantly fall under the “M class” (M1 category), which includes standard passenger vehicles that must meet certain safety and performance requirements, including minimum power and top speed standards. For example, the battery electric passenger car shall be tested in accordance with the test methods specified in GB/T 18385, and the maximum speed attainable within 30 minutes shall not be less than 80 km/h for the battery electric passenger cars with seating capacity less than five[14].

In contrast, many European and Japanese small EVs belong to the L6e and L7e categories, which are classified as quadricycles. These vehicles are designed for low-speed, short-distance urban use. Their average PMR are only 18.77 W/kg. Subject to less stringent performance and safety regulations. Not required to meet the same standards for top speed and power as M-class vehicles. Thus, the PMR on average will be lower than that of China.

However, this does not mean that the dynamic performance of Europe and Japan's small-sized EVs is inferior to that of China, on the contrary, European M-class vehicles show greater PMR, stronger power and maximum speed. Their average PMR can reach 58.16 W/kg, approximately 52% higher than the Chinese same class average PMR. The percentage difference can be calculated as:

$$\frac{58.16 - 38.29}{38.29} * 100\% \approx 51.89\%$$

Their power requirements are higher than those in China, and because most of them use NMC batteries, which have higher energy density, and can reduce the weight of the battery pack, further increasing the PMR.

If compare the L class and M class in Europe and Japan, use the same calculation method:

$$\frac{58.16 - 18.77}{18.77} * 100\% \approx 209.86\%$$

The average difference is over 200%, which creates a considerable gap in the market. And since the Chinese average PMR value is in the middle, referring to the data of Chinese vehicles, may help the European and Japanese markets to fix the gap.

### 3.1.2 Energy Density

Energy density(kWh/kg) refers to the ratio of the amount of energy stored in the vehicle's battery system to the vehicle's weight. It reflects how efficiently a vehicle carries its battery energy, the higher energy density means better range potential.

$$Energy\ Density = \frac{Battery\ capacity(Wh)}{Curb\ weight(kg)} \tag{2}$$

The results of the calculated average energy density for small-sized electric vehicles from different regions based on the dataset are as follows:

- China: Average Energy Density =23.59 Wh/kg
- Europe& Japan: Average Energy Density =20.14 Wh/kg

  L class Average Energy Density =19.12 Wh/kg

  M class Average Energy Density =22.36 Wh/kg

On average, Chinese small-sized EVs have an energy density approximately 17% higher than their European and Japanese counterparts. The percentage difference can be calculated as:

$$\frac{23.59 - 20.14}{20.14} * 100\% \approx 17.13\%$$

Also in chapter 2, we discussed the range distributions among regions. The disparity in driving range distribution is believed to be one of the primary factors contributing to differences in energy density across regions. Vehicles with shorter range generally employ batteries with smaller capacity, which limits overall vehicle performance and energy efficiency.

### 3.1.3 Cross-comparison

To further investigate the current small-size electric vehicles (EVs) in China, Europe& Japan, we generated two scatter plots based on data extracted from the database are shown as Figure 3. 2 below.

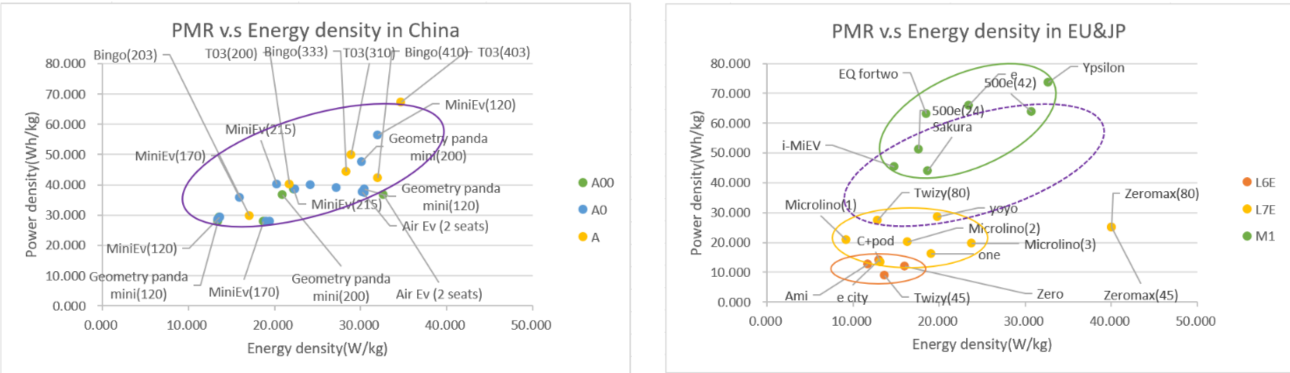



**Figure 3. 2 PMR vs Energy density in China and Europe & Japan**

From these plots, it can be observed that the distribution pattern of Chinese vehicles is generally similar to that of Europe& Japan's M1 vehicles, with a significant overlap, since all Chinese vehicles, whatever A00, A0, or A fall under the M1 category. However, China's distribution appears to be slightly shifted downward with respect to the M1 area in EU& JP, shown as the purple dashed circle in Figure 3. 2. And in China, there is barely any presence of vehicles overlapping with L categories.

In contrast, Europe and Japan show a gradual transition across three classification zones, progressing downward from M1 to L categories. Interestingly, there appears to be a gap between the smaller M1 vehicles and the L category vehicles. This gap is notably filled by the A00 and A0 vehicles from China, suggesting that Chinese models may provide an effective bridge between these two classes in the global small-size EV market. And the overlapping part of the circle with China, such as the FIAT 500e and Nissan Sakura, may be more popular in the global market.

## 3.2 Efficiency

The Energy Efficiency that introduced here is not the same as the usual energy efficiency that defined by the ratio of energy input and energy output. Here the Energy efficiency is similar as how much liter of gasoline to be consumed for an ICE vehicle after travelling hundred kilometers but defined in the range of electric vehicle conception is the standard metric for measuring the energy consumption of battery electric vehicles (BEVs). It indicates how much electricity (in kWh) a vehicle uses to travel 100 km. From the mathematical point of view, lower energy efficiency quantity illustrates for travelling the same distance, the vehicle with less efficiency will consume less energy, so as saving cost from economic aspect, and vice versa[15].

$$Energy\ efficiency\ \left(\frac{kWh}{100km}\right) = \frac{Battery\ capacity(kWh)}{Traveled\ distance(100km)} \tag{3}$$

As shown in the vehicle dataset form above in Table 2 and Table 3, due to the diversity requirement of the commercial vehicle market, the manufacturer needs to come over the same vehicle but with different configuration for the customers to select. Therefore, identical vehicles with multiple battery capacity and different corresponding travelling range (in WLTC) are introduced.

By using the definition of this energy efficiency, we calculated the **MAX** and **MIN** efficiency for each vehicle. *(Pay attention to that, the result of max is not corresponding to the example with max battery capacity, so as for the min, since after mathematical computing, the example with minimum capacity can be the one contributes to the maximum energy efficiency result.)

Since our research is based on different countries and vehicle levels, the comparison graphs are built to give an obvious and intuitive explanation of how vehicles with different energy efficiency are distributed. To fill the X axis, the Curb Weight (The weight of a vehicle with all standard equipment, necessary operating fluids like oil and coolant, and a full tank of fuel — but without any passengers or cargo.) is a good choice.

To ensure comprehensive analysis, it is important to acknowledge that the classification standards for vehicle levels differ between regions. Specifically, the categories A00, A0, and A are classification levels that are defined according to Chinese regulatory standards, whereas L6E, L7E, M0, and M1 are vehicle levels typically used under European and Japanese regulations. These systems are not directly interchangeable, and each follows its own set of technical and dimensional criteria.

However, because the aim of this study is to conduct an overlapping investigation, we have assigned both classification levels to the vehicles listed in the dataset or visual form. This was done by evaluating whether each vehicle meets the specific measurement criteria defined for both the Chinese and the European/Japanese levels. If a vehicle conforms to both standards, it is labeled accordingly under both systems.

By adopting this dual classification approach, the resulting graphs and visualizations can include all vehicles under consideration, regardless of their origin or regulatory system. This allows for a more accurate, and visually clear comparison across different types of vehicles. The following conclusions have been drawn by energy efficiency based on evaluations conducted under various standards and criteria.

Each data point in the figure corresponds to a specific vehicle model, with its commonly recognized or “special” designation labeled accordingly. These vehicles and their technical specifications names can be found on the Excel table at the beginning of this chapter. The precise energy efficiency value for each vehicle that is measured in kWh/100km is displayed adjacent to its name for ease of reference.

### 3.2.1 Energy efficiency VS Curb weight (By Region)

The first figure derived from our research data illustrates the distribution of energy efficiency across various micro-EV plotted against their curb weight. As shown in the Figure 3.3, the estimated distribution of Chinese vehicles is highlighted within the green translucent elliptical area, while the European vehicles are represented by the blue elliptical area. Since Japanese cars are relatively scattered in the graph, therefore they are not marked by ellipse with specific color. These visual groupings suggest a regional trend in both curb weight and energy consumption characteristics.

As it can be observed in the graph, the Chinese vehicles that act as our research targets are mainly concentrated, which represents medium to relatively high levels of both curb weight and energy efficiency. These data points form a roughly linear trend, suggesting that as the weight of vehicles increases, their energy efficiency tends to rise as well. This indicates a consistent design strategy with weight optimization and energy conservation among Chinese manufacturers.

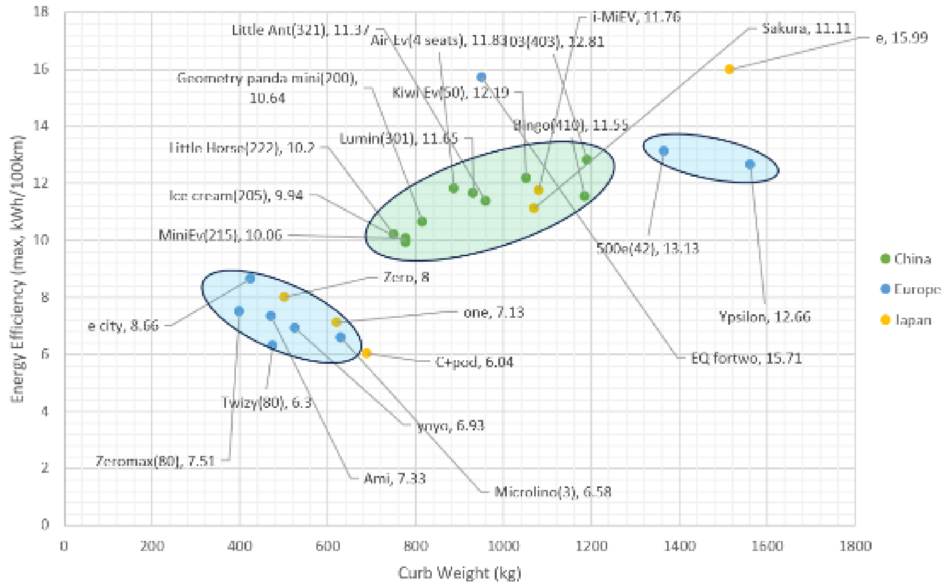



**Figure 3. 3 Energy efficiency VS Curb weight (By Region)**

In contrast, European vehicles exhibit more dispersed in 2 areas. While the majority are positioned in the lower weight and lower efficiency range, a few heavier models demonstrate similar energy efficiency levels compared with the Chinese area, suggesting more advanced energy management and optimization in certain cases.

The distribution of Japanese models overlaps with both Chinese and European vehicles but shows significant individual variation. From the perspective of energy efficiency, there is no clear regional consistency based on country of origin. This may indicate that Japanese models are designed with focus on comfort, safety or other reason, but compromising energy efficiency in return.

From a quantitative perspective, the Figure 3. 4 below highlights the boundary values for China by using an orange rectangular region. This region defines the distribution of Chinese models in terms of both curb weight and energy efficiency. The lower limit of the curb weight for Chinese vehicles is approximately **680 kg**, while the upper limit reaches around **1250 kg**. Correspondingly, their energy efficiency ranges from a lower limit of **9.2 kWh/100km** to an upper limit of **13.5 kWh/100km**. This orange area serves as a reference frame for comparing vehicles from Europe and Japan, which tend to fall outside or at the margins of this defined range.

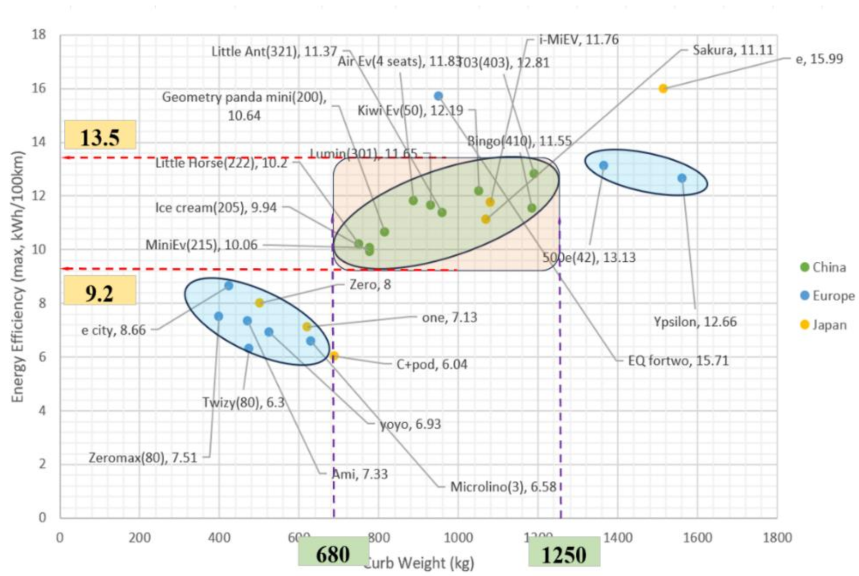



**Figure 3. 4**

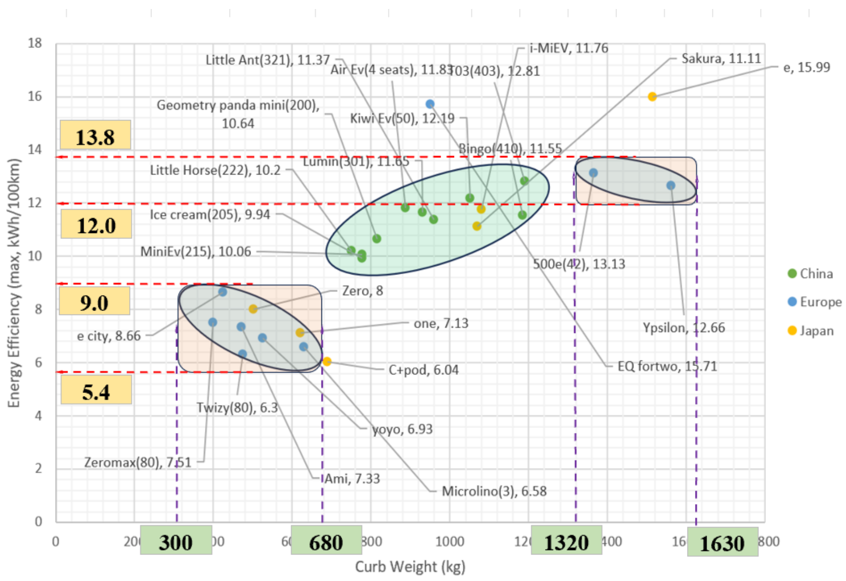



**Figure 3. 5**

Figure 3. 5, for European vehicles, the first area consisting of lightweight models, falls within a curb weight range of approximately **300** to **680** kg, and an energy efficiency range of around **5.4** to **9.0** kWh/100km. Representative models in this group include the Twizy, Ami, Microlino, these vehicles reflect a European design emphasis on compact urban mobility with optimized energy usage. Second area of European models consists of heavier vehicles, positioned in the curb weight range of approximately 1320 to 1630 kg, and energy efficiency ranging from **12.0** up to **13.8** kWh/100km. This group includes models such as the 500e and Ypsilon. These vehicles prioritize interior space, comfort, and performance, but also with high energy efficiency.

### 3.2.2 Energy efficiency VS Curb weight (By European Standard)

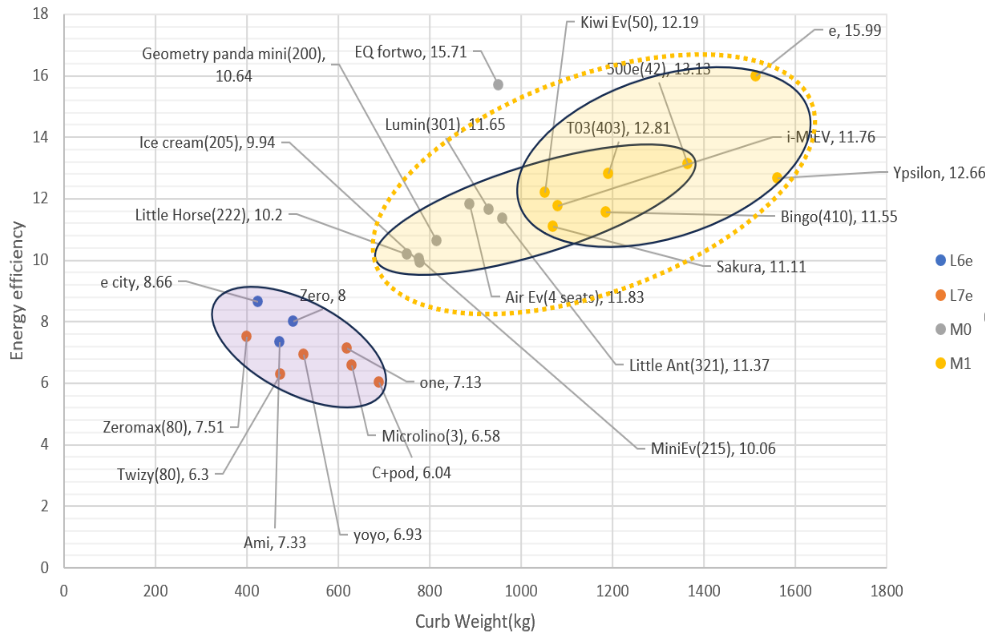



**Figure 3. 6 Energy efficiency VS Curb weight (By European Standard)**

After segmenting the chart based on the European classification system, all vehicles (including Chinese models) have been reclassified into the corresponding categories defined by European standards (L6e, L7e, M0, and M1). As a result, 3 main elliptical areas have been identified within the figure. The grey data points, representing vehicles in the M0 class, and the yellow data points, corresponding to M1class, occupied one elliptical area per each. Based on this and for the next step, we organized these two ellipses into a larger combined ellipse. Meanwhile, the L6e and L7e vehicles, mostly represented in blue and orange and grouped in a separate elliptical area at the lower left of the figure, remain distinct due to their ultra-light design.

Through this hierarchical grouping, the entire figure can now be clearly divided into two areas:

1. One covering light electric quadricycles (L6e and L7e) with low curb weight.
2. The other encompassing standard micro and small passenger vehicles (M0 and M1) that span a wider range of curb weight and energy efficiency.

This division highlights the structural and regulatory basis for vehicle categorization, while also visually emphasizing the different design philosophies and usage scenarios associated with each group.

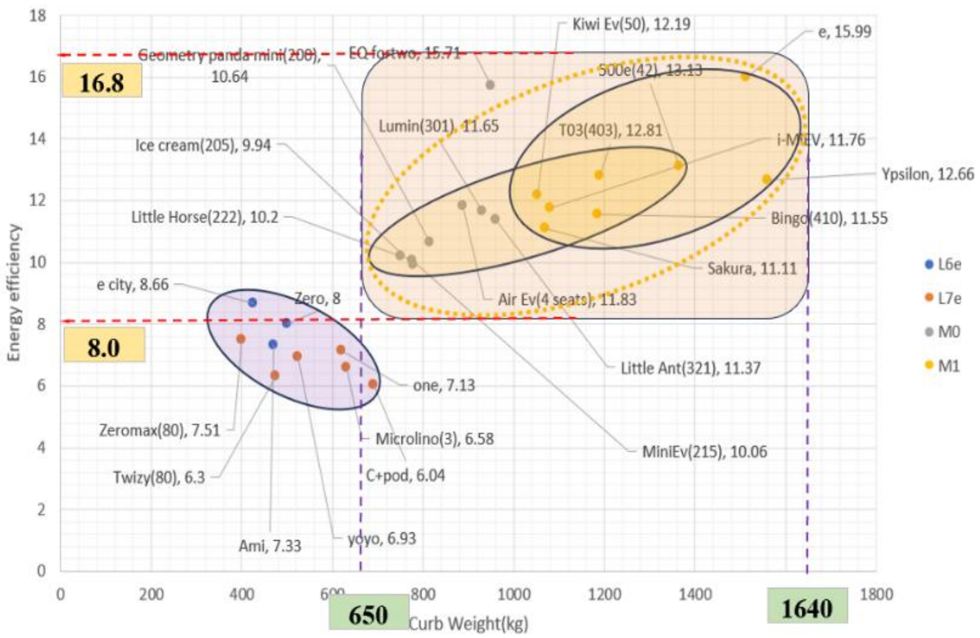



**Figure 3. 7**

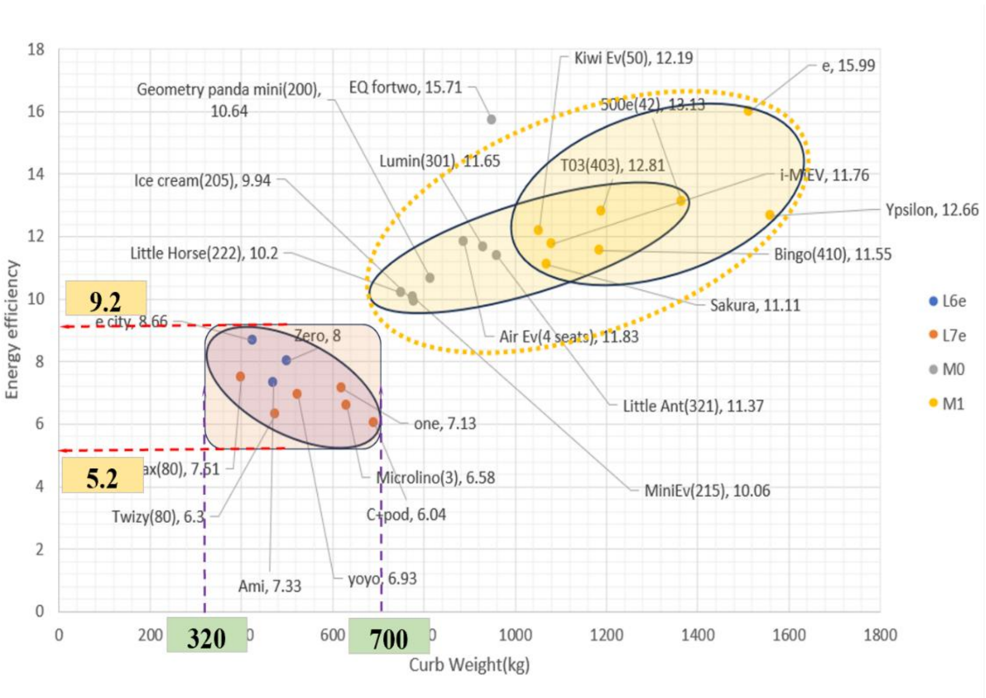



**Figure 3. 8**

The primary purpose of this diagram is to visually illustrate how the selected Chinese vehicles are positioned when evaluated under the framework of European vehicle classification standards. By mapping Chinese vehicles into the corresponding European regulatory categories, the figure offers a clear, comparative perspective on how these vehicles align with each other.

By applying the same analytical approach described in the previous section, and examining the distribution from a quantitative perspective, we observed that the entire large ellipse which covered both the M0 and M1 categories with a curb weight range of approximately **650 kg** to **1640 kg** and covered an energy efficiency range from **8.0 kWh/100km** up to **16.8 kWh/100km**, shown as Figure 3. 7

In comparison, the smaller ellipse shows almost no significant deviation in their respective limit values from those defined on the previous page. The specific data comparison will be reflected in the following article.

### 3.2.3 Energy efficiency VS Curb weight (By Chinese Standard)

When we switch the classification framework from the European standard to the Chinese classification, the distribution of data points changes notably. In this new scheme we can observe that the A00 and A0 categories show a high degree of overlapping, particularly in the mid-range of curb weight and energy efficiency. This suggests that, under the Chinese classification system, the boundaries between A00 and A0 levels are not sharply distinguished, and many models can be considered borderline or transitional between the two levels.

In contrast, the A categories vehicles stand out with a much clearer concentration in the upper-right quadrant of the plot, typically characterized by higher curb weights and energy consumption. This shows that under Chinese standards, A represents vehicles with large curb mass and energy efficiency.

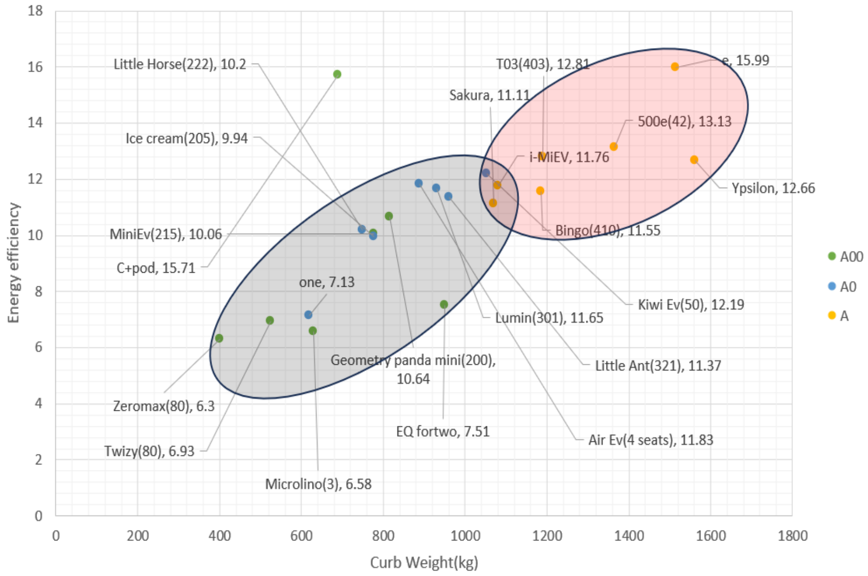



**Figure 3. 9 Energy efficiency VS Curb weight (By Chinese Standard)**

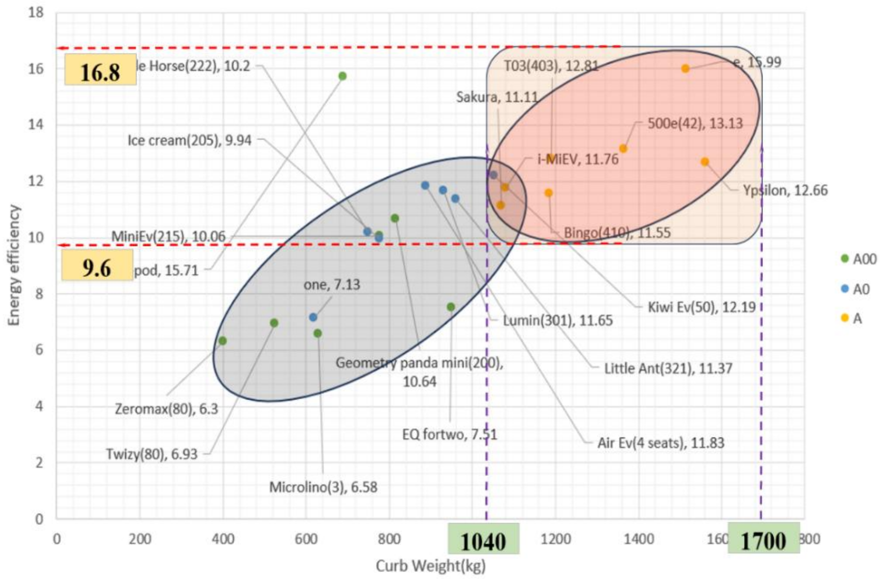



**Figure 3. 10**

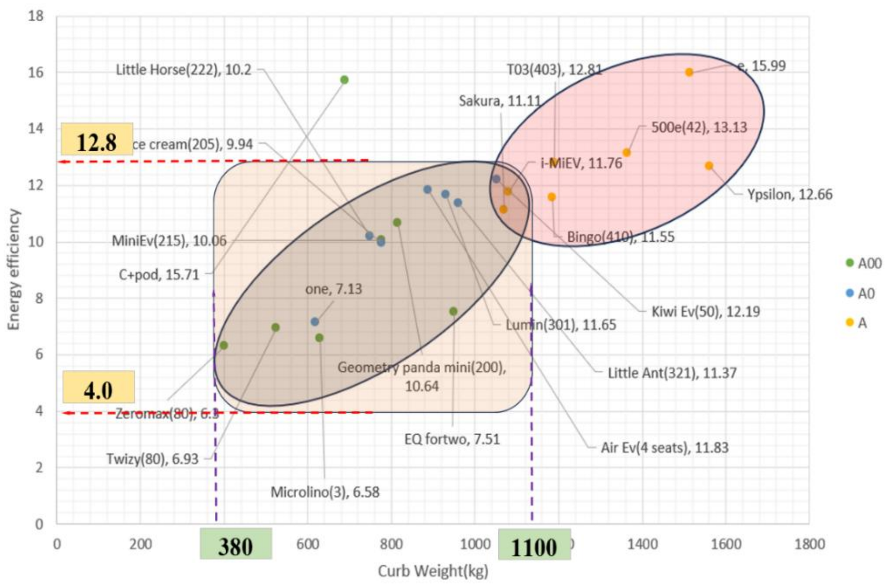



**Figure 3. 11**

Quantitative summarize:

A class:

Curb Weight Range: **1040 kg** to **1700 kg**

Energy Efficiency Range: **9.6 kWh/100km** to **16.8 kWh/100km**

A00&A0 class:

Curb Weight Range: **380 kg** to **1100 kg**

Energy Efficiency Range: **4.0 kWh/100km** to **12.8 kWh/100km**

### 3.2.4 Energy efficiency VS Curb weight (MAX & MIN compare)

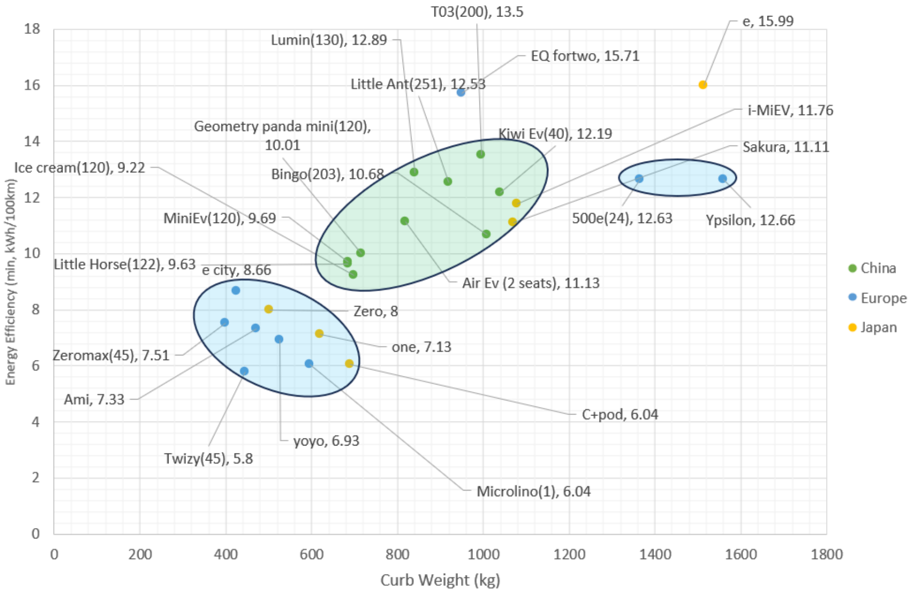



**Figure 3. 12 Energy efficiency VS Curb weight (MAX & MIN compare)**

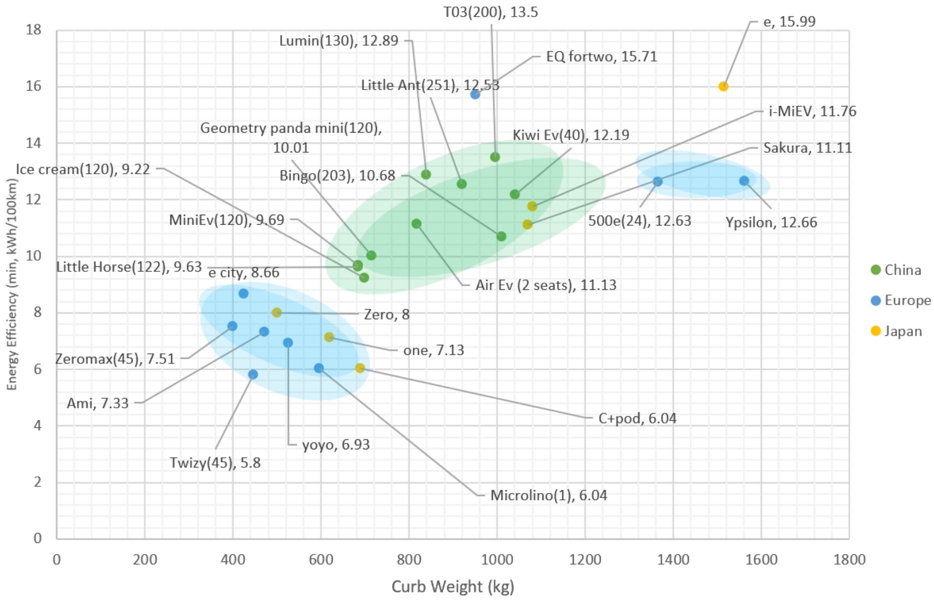



**Figure 3. 13**

As shown in Figure 3. 12 above, we have re-plotted the distribution of vehicle models based on the smaller battery capacity (**MIN version**) for each car, corresponding to the models previously analyzed in 2.4.1, which were based on the maximum battery configuration (**MAX version**). This updated figure allows for a direct visual comparison of downsizing the battery capacity. By simplifying the boundaries of the elliptical regions, as shown in Figure 3. 13 it becomes clear that the **MIN version** color regions remain closely aligned with their corresponding **MAX version** areas. This spatial consistency suggests that when manufacturers developed the lower battery capacity variants, they did not make substantial changes to the fundamental vehicle class or configuration. The vehicles still maintain similar curb weights and energy efficiency levels, preserving the original design intent and market positioning.

### 3.2.5 Conclusion

**Table 8 Boundary limit by country**

| | CHINA | EUROPE |
|---|---|---|
| **Curb weight lower limit** | 680 | 300/1320 |
| **Curb weight upper limit** | 1250 | 680/1630 |
| **Energy efficiency lower limit** | 9.2 | 5.4/12 |

| | | |
|---|---|---|
| **Energy efficiency upper limit** | 13.5 | 9/13.8 |

**Table 9 Boundary limit by standard**

| | **M0/M1** | **L6E/L7E** |
|---|---|---|
| **Curb weight lower limit** | 650 | 320 |
| **Curb weight upper limit** | 1640 | 700 |
| **Energy efficiency lower limit** | 8 | 5.2 |
| **Energy efficiency upper limit** | 16.8 | 9.2 |

**Table 10 Boundary limit by standard**

| | **A** | **A0/A00** |
|---|---|---|
| **Curb weight lower limit** | 1040 | 380 |

| | | |
|---|---|---|
| **Curb weight upper limit** | 1700 | 1100 |
| **Energy efficiency lower limit** | 9.6 | 4.0 |
| **Energy efficiency upper limit** | 16.8 | 12.8 |

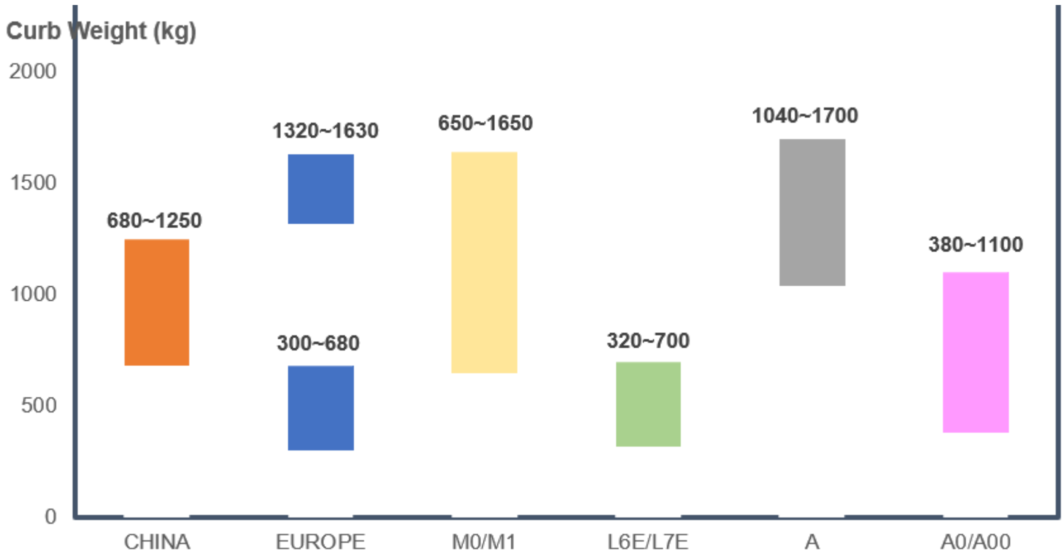



**Figure 3. 14 Bar chart of curb weight distribution by standard**

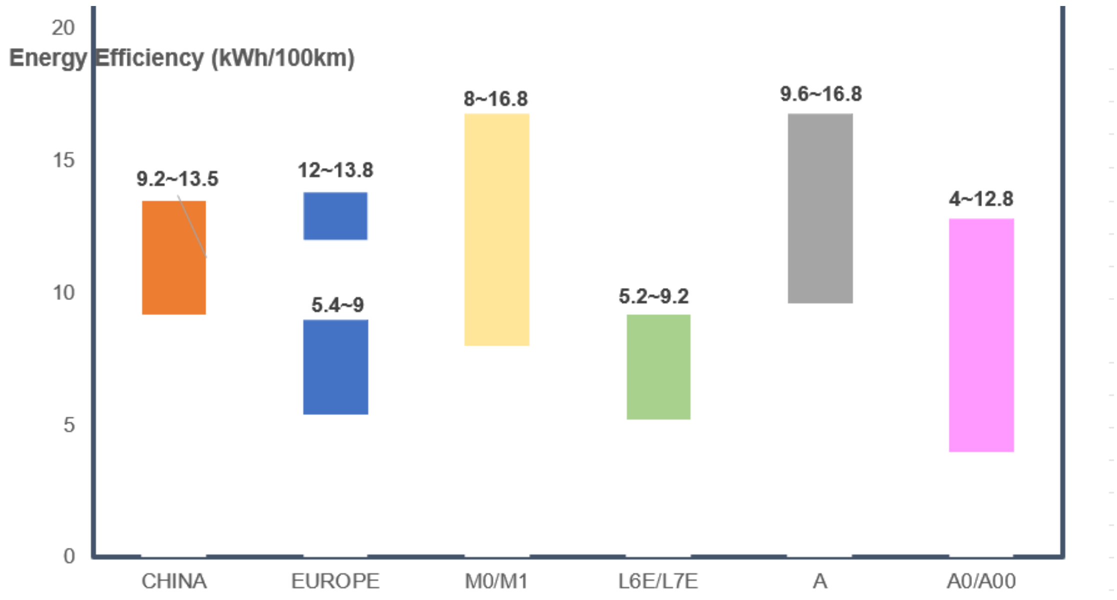



**Figure 3. 15 Bar chart of Energy efficiency distribution by standard**

As shown in the Figure 3. 15 Bar chart of Energy efficiency distribution by standard, it can be observed that the subjects of our study are situated within the overlapping areas of orange, blue, and light yellow. Based on the bar chart shown above, we can roughly outline the range of curb weight that we are studying. Additionally, we can compare the energy efficiency intervals defined in the triangular chart below with the approximate range in the bar chart above.

## 3.3 Estimation Cubic

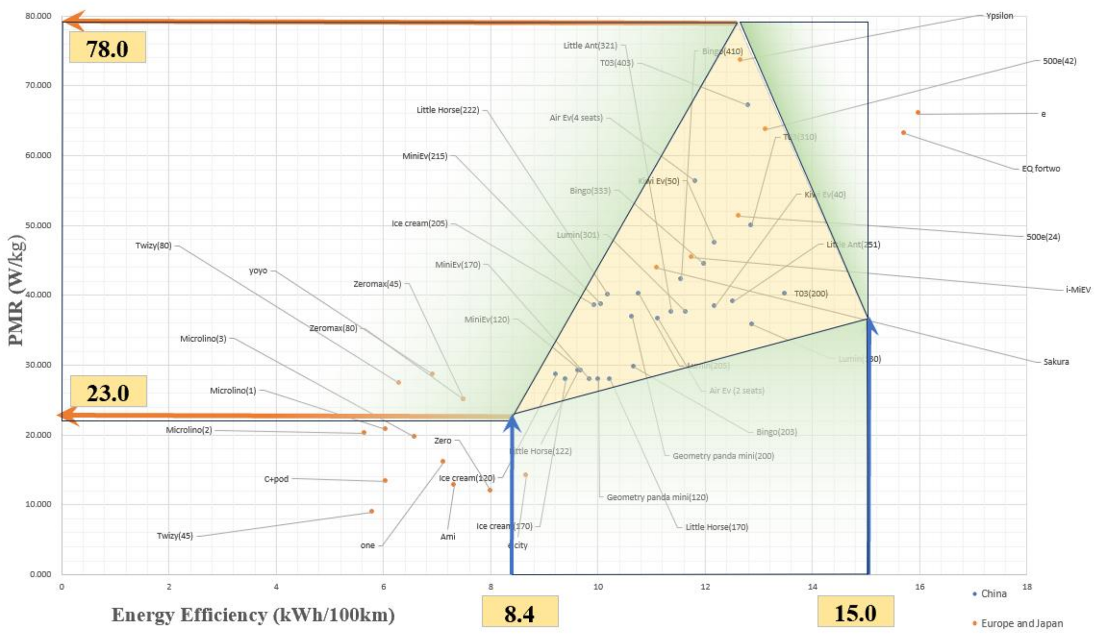



**Figure 3. 16 Estimation of target vehicle distribution by triangle**

This chart illustrates the relationship between energy efficiency (kWh/100km) and power-to-mass ratio (PMR in W/kg) for electric vehicles (EVs) from China, Europe, and Japan. Chinese EVs (represented by blue dots) are primarily concentrated in the upper-left corner of the chart, exhibiting relatively middle level energy efficiency and PMR, while European and Japanese EVs (represented by orange dots) are mostly found in the lower PMR regions, indicating that these vehicles have lower power outputs and lower energy efficiency.

The yellow triangular area in the middle of the chart represents a key region where Chinese, European, and Japanese electric vehicles (EVs) overlap in terms of both energy efficiency and power-to-mass ratio (PMR). This area reflects a balance point in vehicle design, where manufacturers aim to optimize both performance and energy efficiency. (And this area is the best area that we should concentrate our research target for the next process.) Notably, this triangular region is bounded by several key values: **8.4 kWh/100km** on the x-axis (representing the lower end of energy efficiency), and **15.0 kWh/100km** (the upper end of energy efficiency), with the PMR values ranging between **23,000 W/kg** and **78,000 W/kg** on the y-axis. Within this triangular area, the vehicles are positioned in a way that suggests they achieve a compromise between lower energy consumption (high energy efficiency) and higher power output (higher PMR). The vehicles placed inside this region include models from all three regions (China, Europe, and Japan), indicating that these manufacturers are targeting similar energy and performance metrics despite differing design philosophies. In summary, the triangular area represents an idealized region of balance between energy efficiency and power capabilities, showcasing the global convergence in EV design as manufacturers seek to meet both performance and energy consumption goals.

Based on the regional values obtained above, we can calculate other necessary design parameters. To visualize this, we can represent the calculations using a cube, where each axis corresponds to a different parameter essential for the design. By adjusting these parameters within the defined region, we can achieve the optimal balance between performance and energy efficiency for the design, providing a clear and structured way to analyze and fine-tune the vehicle specifications.

Based on the bar chart, we have established the mass range, and from the triangular chart, we have derived the corresponding energy efficiency intervals. By assuming the required driving range for the vehicle, we can calculate the following parameters:

- **Mass: 650-1250 kg**
- **Energy efficiency**: **8.40-15.0 kWh/100 km**

**Assumptions:**

1. The desired driving range is between **100 and 250 km**

This implies that the required battery capacity will range from **8.4 to 37.5 kWh,** depending on the exact range chosen.

2. The desired Power-to-Mass Ratio (PMR) is expected to be between **23 and 78 W/kg**

Consequently, the required power output will range from **14.95 kW to 97.5 kW**, depending on the mass and energy efficiency parameters.

By considering these values and their corresponding calculations, we can assess the overall design requirements for the vehicle in terms of mass, energy efficiency, battery capacity, and power output, thus ensuring the feasibility of meeting the desired performance specifications.

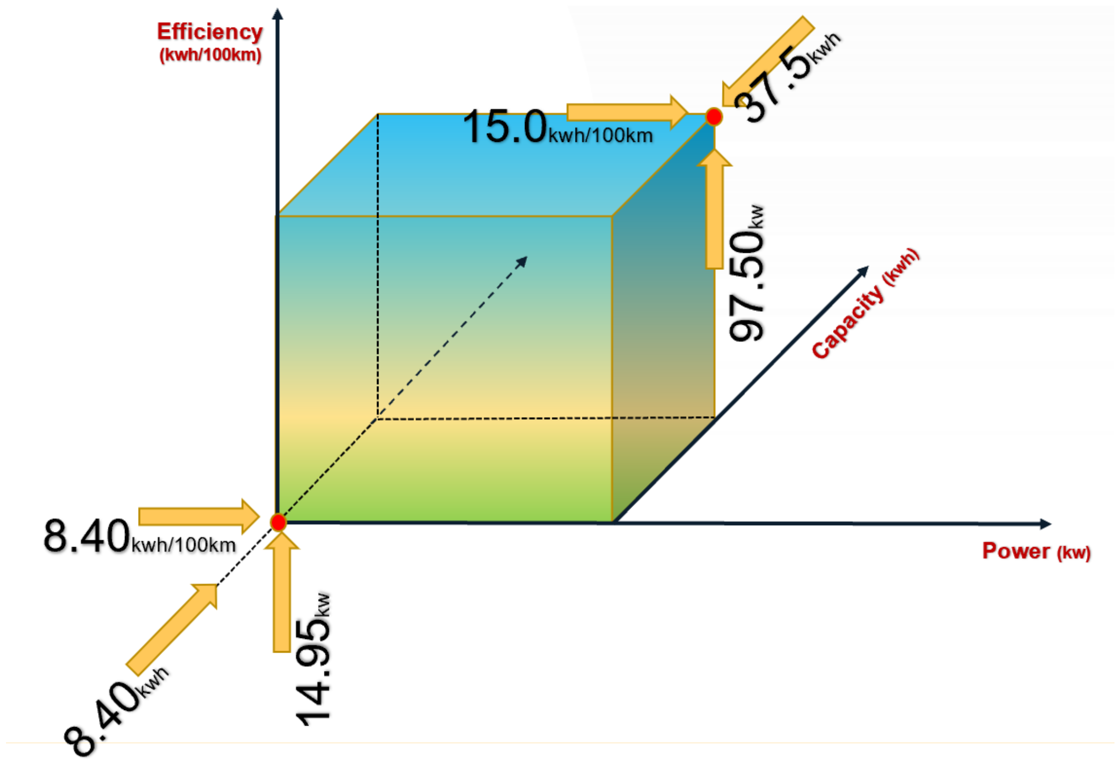



**Figure 3. 17 Estimation Cubic**

This 3D representation provides a clear visualization of how energy efficiency, battery capacity, and power are interrelated, allowing we to better understand how the design and performance of a vehicle with specific energy and power requirements fit into the overall system. The data can help manufacturers design vehicles with optimal parameters to meet the desired performance and efficiency goals. The red dot on the graph represents a specific point within this 3D space, which corresponds to a specific combination of 8.40 kWh/100 km, 14.95 kW, and 8.40 kWh (representing the minimum values for energy efficiency, power, and capacity, respectively). By adjusting each parameter (efficiency, power, and capacity), we can explore how changes in one factor affect the other two.

# Chapter 4

# Sensitive Analysis

The primary objective of this section is to investigate the impact of vehicle mass and driving cycles on the electrical efficiency of electric vehicles. We first introduce the three major driving cycles commonly used in vehicle testing and simulation: NEDC, WLTC, and CLTC. Then, we establish a longitudinal vehicle model that allows for the adjustment of vehicle weight and the input of different driving cycles into the driver maneuver module. By simulating the model under various vehicle weight conditions, we obtained the corresponding energy consumption values. Using this data, we evaluated the potential benefits of vehicle lightweighting by calculating the achievable driving range and the resulting reduction in required battery capacity. Subsequently, we analyzed how vehicle mass can be reduced through dimensional downsizing and provided a reasonable range for dimension and weight optimization. Finally, through simulation results and numerical analysis, we demonstrate that the CLTC cycle is particularly well-suited for compact urban electric vehicles, offering more practical and economically favorable outcomes.

## 4.1 Driving Cycles

A driving cycle is a series of data points representing the speed of a vehicle versus time[16]. For example, Figure 4. 1 is a WLTC cycle.

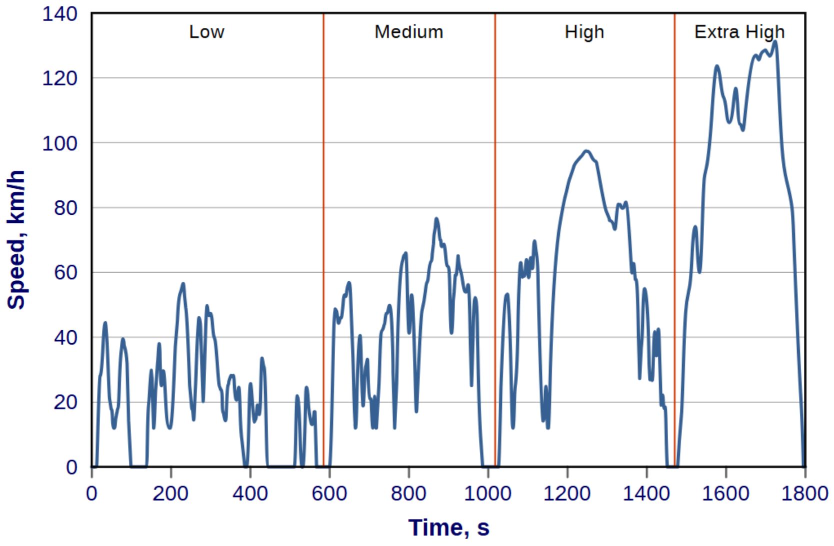



**Figure 4. 1 WLTC cycle for class 3b vehicles**

*Source: DieselNet. (n.d.). Worldwide harmonized Light vehicles Test Cycle (WLTC)[17].*

Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, for example, fuel consumption, electric vehicle autonomy and polluting emissions. In our section, we intend to get the energy consumption by simulating the vehicles associated with different driving cycles.

### 4.1.1 NEDC

NEDC is the short term of New European Driving Cycle, which last updated in 1997, designed to assess the emission levels of car engines and fuel economy in passenger cars. It consists of four repeated ECE-15 urban driving cycles, which simulates city traffic with many stop/start phases, and one Extra-Urban driving cycle corresponds to an extra-urban journey at a maximum speed of 120 km/h[18], shown as Figure 4. 2.

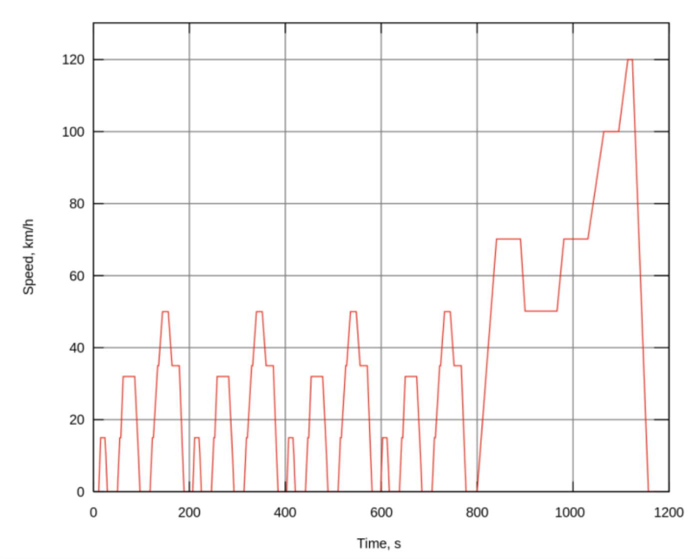



**Figure 4. 2 NEDC cycle**

*Source: Fernández Rey, E. J. (2020, May 16). Los ciclos de medición de autonomías: NEDC, WLTP y EPA.*

The NEDC was replaced by the WLTC due to its inability to accurately reflect contemporary driving conditions, including inadequate acceleration patterns, an excessive number of stop phases, and the omission of higher-speed scenarios[19]. And Figure 4. 3 presents a comparison between the WLTC and NEDC driving cycles. As shown in the figure, the WLTC cycle significantly improves upon the limitations of the NEDC, providing a representation that more closely reflects real driving conditions.

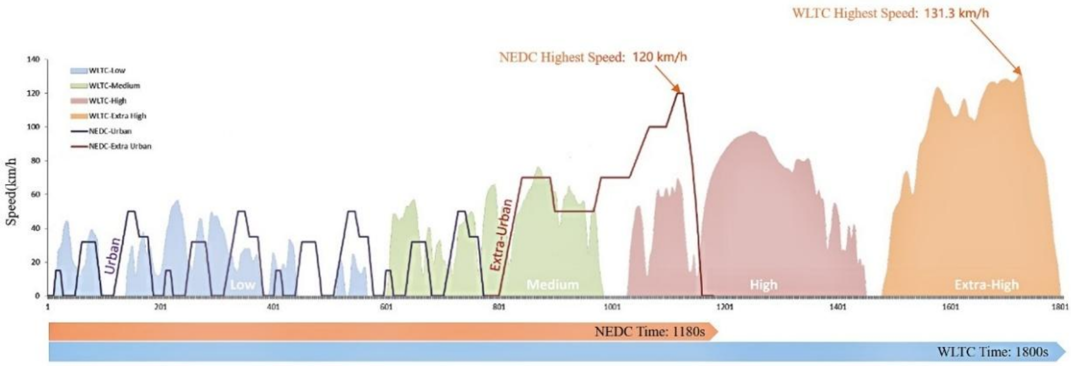



**Figure 4. 3 comparison between the WLTC and NEDC**

*Adapted from Industrial Technology Research Institute. (2018). Explanation of differences between WLTC and NEDC driving cycles for vehicle energy efficiency testing. Auto Energy Efficiency Research.*

### 4.1.2 WLTC

WLTC is the short term for Worldwide Harmonized Light Vehicles Test Cycle. The tests have been developed by the UN ECE GRPE group. The WLTC cycles are part of the Worldwide harmonized Light vehicles Test Procedures (WLTP), published as UNECE Global technical regulation No 15 (GTR 15).

The WLTP replaces the European NEDC based procedure for type approval testing of light-duty vehicle, with the transition from NEDC to WLTP occurring over 2017-2019. The WLTP is also introduced for vehicle certification in Japan.

The WLTP procedures includes several WLTC test cycles applicable to vehicle categories of different PMR, as in Table 11.

**Table 11: WLTC Test Cycles**

| Category | PMR, W/kg | v_max, km/h | Speed Phase Sequence |
|---|---|---|---|
| Class 3b | PMR > 34 | v_max ≥ 120 | Low 3 + Medium 3-2 + High 3-2 + Extra High 3 |
| Class 3a | | v_max < 120 | Low 3 + Medium 3-1 + High 3-1 + Extra High 3 |
| Class 2 | 34 ≥ PMR > 22 | - | Low 2 + Medium 2 + High 2 + Extra High 2 |
| Class 1 | PMR ≤ 22 | - | Low 1 + Medium 1 + Low 1 |

*Source: DieselNet. (n.d.). Worldwide harmonized Light vehicles Test Cycle (WLTC)[17].*

For example, Class 3 is representative of vehicles driven in Europe and Japan With the highest power-to-mass ratio[17].

In Class 3, vehicles are divided into 2 subclasses according to their maximum speed: Class 3a with $v\_max < 120$ km/h and Class 3b with $v\_max \geq 120$ km/h[17]. as in Table 11, and the vehicle speed for Class 3b is shown in Figure 4. 1 (Class 3a trace would look very similar).

Class 2 is representative of vehicles driven in India and of low power vehicles driven in Japan and Europe. And Class 1 with the lowest power-to-mass ratio, representative of vehicles driven in India[17].

**Table 12: WLTP Class 3 cycle: selected parameters**

| Phase | Duration | Stop Duration | Distance | p_stop | v_max | v_ave w/o stops | v_ave w/ stops | a_min | a_max |
|---|---|---|---|---|---|---|---|---|---|
| | *s* | *s* | *m* | | *km/h* | *km/h* | *km/h* | *m/s²* | *m/s²* |
| **Class 3b** (v_max ≥ 120 km/h) | | | | | | | | | |
| Low 3 | 589 | 156 | 3095 | 26.5% | 56.5 | 25.7 | 18.9 | -1.47 | 1.47 |
| Medium 3-2 | 433 | 48 | 4756 | 11.1% | 76.6 | 44.5 | 39.5 | -1.49 | 1.57 |
| High 3-2 | 455 | 31 | 7162 | 6.8% | 97.4 | 60.8 | 56.7 | -1.49 | 1.58 |
| Extra-High 3 | 323 | 7 | 8254 | 2.2% | 131.3 | 94.0 | 92.0 | -1.21 | 1.03 |
| Total | **1800** | **242** | **23266** | | | | | | |
| **Class 3a** (v_max < 120 km/h) | | | | | | | | | |
| Low 3 | 589 | 156 | 3095 | 26.5% | 56.5 | 25.7 | 18.9 | -1.47 | 1.47 |
| Medium 3-1 | 433 | 48 | 4721 | 11.1% | 76.6 | 44.1 | 39.3 | -1.47 | 1.28 |
| High 3-1 | 455 | 31 | 7124 | 6.8% | 97.4 | 60.5 | 56.4 | -1.49 | 1.58 |
| Extra-High 3 | 323 | 7 | 8254 | 2.2% | 131.3 | 94.0 | 92.0 | -1.21 | 1.03 |
| Total | **1800** | **242** | **23194** | | | | | | |

*Source: DieselNet. (n.d.). Worldwide harmonized Light vehicles Test Cycle (WLTC)[17].*

### 4.1.3 CLTC

CLTC is the short term of China Light-Duty Vehicle Test Cycle, it is a driving cycle developed by the China Automotive Technology & Research Center to replace European testing procedures and is standardized by the national standard GB/T38146.1-2019.

The CLTC is designed to simulate typical urban and rural driving conditions in China. Chinese cities generally experience higher congestion levels, leading to a greater proportion of low-speed driving, frequent stops and longer idling times. The expressways maximum speed limit in China is set at 120 km/h[20]. This standard benefits electric vehicles, which under this cycle are able to produce higher driving range numbers compared to the NEDC and WLTP.

The CLTC-P (passenger cars) test cycle are shown in the Figure 4. 4, which includes three phases of (1) slow (2) medium (3) fast driving

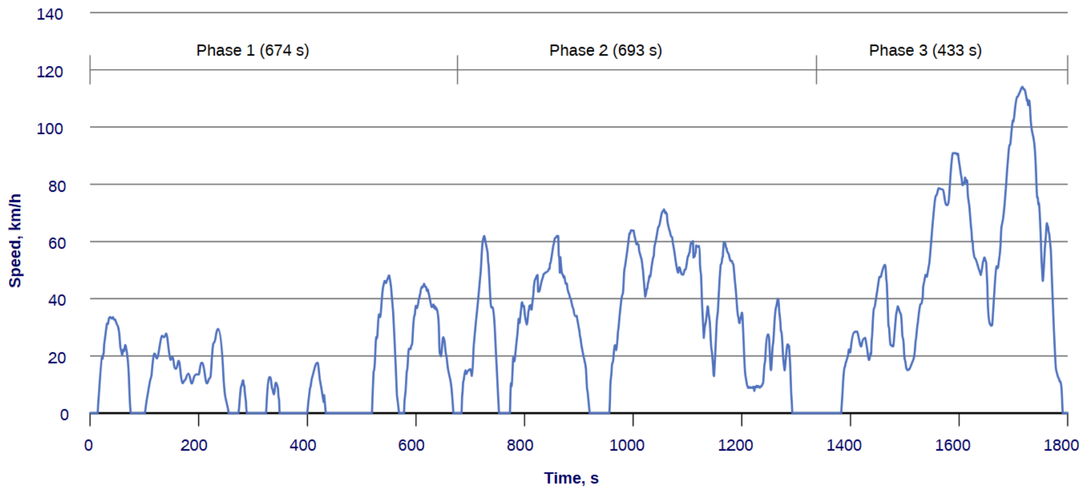



**Figure 4. 4 CLTC-P Cycle**

*Source: DieselNet. (n.d.). China Light-Duty Vehicle Test Cycle (CLTC).*

### 4.1.4 Conversion Factor

The range is calculated by running the test cycle and measuring energy consumption from the battery’s available capacity.

The driving range of an electric vehicle can be calculated by dividing the usable battery energy by the vehicle’s energy consumption.

Due to the different test conditions( temperature, vehicle speed, test time, etc.) , the energy consumption from the battery of the same vehicle is different, which will lead to different ranges.

Here we introduce the conversion factor relative to WLTC(this conversion factor is an empirical value, not a complete exact equivalent), as shown in our database, we convert the range to WLTC range for analysis and comparison and we will also verify the conversion factor of CLTC to WLTC in the Modelling part.

- NEDC to WLTC

The NEDC, originally developed in the 1970s, has since been replaced by the WLTC. The NEDC features a relatively simple 20-minute driving cycle, with most of the test conducted at speeds below 50 km/h. As a result, it tends to overestimate EV range compared to the more rigorous WLTC[21].

NEDC to WLTP conversion factor: 0.85

Example: 500 km (NEDC) × 0.85 = 425 km (WLTC)

- CLTC to WLTC

The CLTC is tailored specifically for Chinese traffic conditions and driving behaviors, it has only 3 phases, and tends to more EV range compared to WLTC[21].

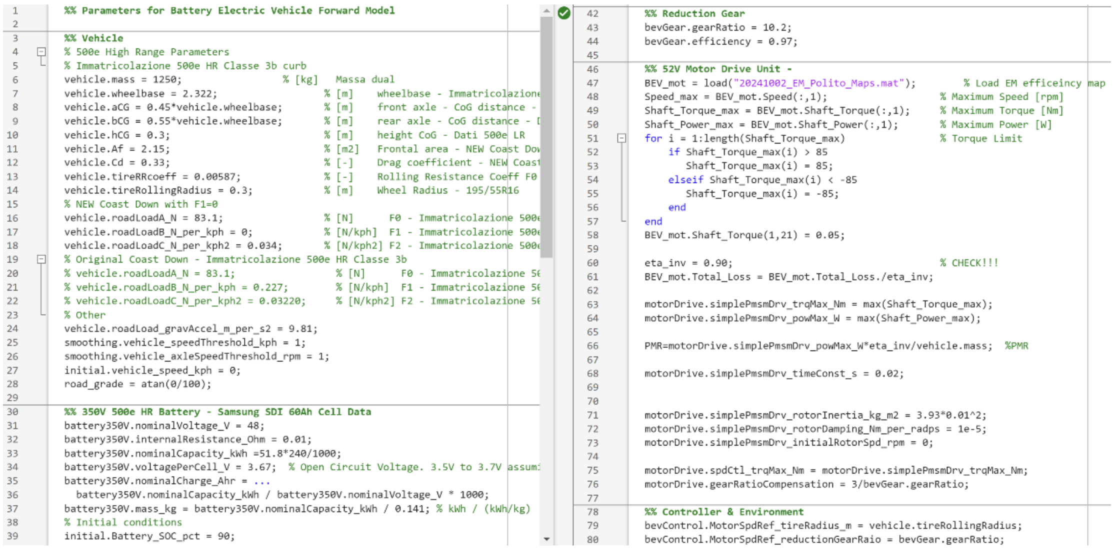
CLTC to WLTP Conversion Factor: 0.8

Example: 500 km (CLTC) × 0.8 = 400 km (WLTC)

## 4.2 Vehicle model

### 4.2.1 Preparatory work

Before building the model, it is essential to gather and define the parameters related to the Battery electric vehicle model, such as vehicle mass, battery capacity, and other relevant specifications. In addition, the velocity and time vectors for various driving cycles must be obtained and prepared. These vectors should be stored in MATLAB data format to facilitate loading into the model as reference inputs for vehicle control.



```matlab
%% Parameters for Battery Electric Vehicle Forward Model

%% Vehicle
% 500e High Range Parameters
% Immatricolazione 500e HR Classe 3b curb
vehicle.mass = 1250;                  % [kg]   Massa dual
vehicle.wheelbase = 2.322;                   % [m]    wheelbase - Immatricolazione
vehicle.aCG = 0.45*vehicle.wheelbase;        % [m]    front axle - CoG distance -
vehicle.bCG = 0.55*vehicle.wheelbase;        % [m]    rear axle - CoG distance - D
vehicle.hCG = 0.3;                           % [m]    height CoG - Dati 500e LR
vehicle.Af = 2.15;                           % [m2]   Frontal area - NEW Coast Dow
vehicle.Cd = 0.33;                           % [-]    Drag coefficient - NEW Coast
vehicle.tireRRcoeff = 0.00587;               % [-]    Rolling Resistance Coeff F0
vehicle.tireRollingRadius = 0.3;             % [m]    Wheel Radius - 195/55R16
% NEW Coast Down with F1=0
vehicle.roadLoadA_N = 83.1;                  % [N]      F0 - Immatricolazione 500e
vehicle.roadLoadB_N_per_kph = 0;             % [N/kph]  F1 - Immatricolazione 500e
vehicle.roadLoadC_N_per_kph2 = 0.034;        % [N/kph2] F2 - Immatricolazione 500e
% Original Coast Down - Immatricolazione 500e HR Classe 3b
% vehicle.roadLoadA_N = 83.1;                  % [N]      F0 - Immatricolazione 50
% vehicle.roadLoadB_N_per_kph = 0.227;         % [N/kph]  F1 - Immatricolazione 50
% vehicle.roadLoadC_N_per_kph2 = 0.03220;      % [N/kph2] F2 - Immatricolazione 50
% Other
vehicle.roadLoad_gravAccel_m_per_s2 = 9.81;
smoothing.vehicle_speedThreshold_kph = 1;
smoothing.vehicle_axleSpeedThreshold_rpm = 1;
initial.vehicle_speed_kph = 0;
road_grade = atan(0/100);

%% 350V 500e HR Battery - Samsung SDI 60Ah Cell Data
battery350V.nominalVoltage_V = 48;
battery350V.internalResistance_Ohm = 0.01;
battery350V.nominalCapacity_kWh =51.8*240/1000;
battery350V.voltagePerCell_V = 3.67;  % Open Circuit Voltage. 3.5V to 3.7V assumi
battery350V.nominalCharge_Ahr = ...
  battery350V.nominalCapacity_kWh / battery350V.nominalVoltage_V * 1000;
battery350V.mass_kg = battery350V.nominalCapacity_kWh / 0.141; % kWh / (kWh/kg)
% Initial conditions
initial.Battery_SOC_pct = 90;
```

```matlab
%% Reduction Gear
bevGear.gearRatio = 10.2;
bevGear.efficiency = 0.97;

%% 52V Motor Drive Unit -
BEV_mot = load("20241002_EM_Polito_Maps.mat");        % Load EM efficeincy map
Speed_max = BEV_mot.Speed(:,1);                    % Maximum Speed [rpm]
Shaft_Torque_max = BEV_mot.Shaft_Torque(:,1);      % Maximum Torque [Nm]
Shaft_Power_max = BEV_mot.Shaft_Power(:,1);        % Maximum Power [W]
for i = 1:length(Shaft_Torque_max)                 % Torque Limit
    if Shaft_Torque_max(i) > 85
       Shaft_Torque_max(i) = 85;
    elseif Shaft_Torque_max(i) < -85
       Shaft_Torque_max(i) = -85;
    end
end
BEV_mot.Shaft_Torque(1,21) = 0.05;

eta_inv = 0.90;                                    % CHECK!!!
BEV_mot.Total_Loss = BEV_mot.Total_Loss./eta_inv;

motorDrive.simplePmsmDrv_trqMax_Nm = max(Shaft_Torque_max);
motorDrive.simplePmsmDrv_powMax_W = max(Shaft_Power_max);

PMR=motorDrive.simplePmsmDrv_powMax_W*eta_inv/vehicle.mass;  %PMR

motorDrive.simplePmsmDrv_timeConst_s = 0.02;


motorDrive.simplePmsmDrv_rotorInertia_kg_m2 = 3.93*0.01^2;
motorDrive.simplePmsmDrv_rotorDamping_Nm_per_radps = 1e-5;
motorDrive.simplePmsmDrv_initialRotorSpd_rpm = 0;

motorDrive.spdCtl_trqMax_Nm = motorDrive.simplePmsmDrv_trqMax_Nm;
motorDrive.gearRatioCompensation = 3/bevGear.gearRatio;

%% Controller & Environment
bevControl.MotorSpdRef_tireRadius_m = vehicle.tireRollingRadius;
bevControl.MotorSpdRef_reductionGearRaio = bevGear.gearRatio;
```

**Figure 4. 5 Matlab workspace-Parameters for the Model**

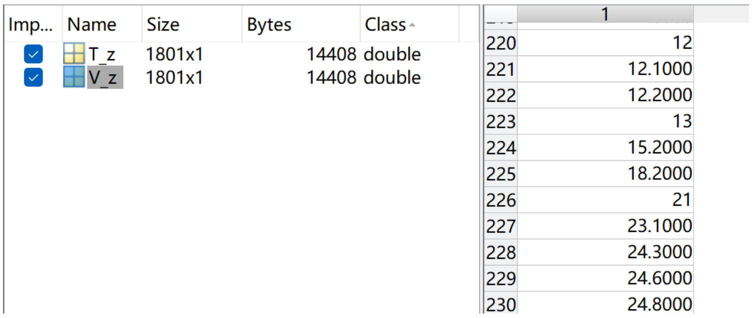



**Figure 4. 6 Matlab data-Parameters for the Cycle**

### 4.2.2 Modelling

Before model construction, the necessary maneuver definitions and parameter configurations are loaded and completed in the MATLAB workspace shown as Figure 4. 7. With these inputs properly initialized, the model can then be developed and executed for simulation.

```
%% Model Parameters for Battery Electric Vehicle System Model
close all
clear all
clc

%% Maneuver
load('WLTC_Class3b_Dual_2Urban_1High_1ExtraHigh');  % Speed and Time vectors for desired Driving Cycle
%load('CLTC_p.mat');
%load('DrivingCycles\RDE_Urban.mat');
%load('DrivingCycles\custom_cycle.mat');
%load('DrivingCycles\T001_EAD.mat');
%load('DrivingCycles\WLTC_Class2.mat');
V_z=V_z;
%V_z = V_z./3.6; % CLTC
T_z = T_z.*1;           % [s]     Time
t_WLTC = max(T_z);         % [s]     WLTC time
t_WLTC_city = 1000;       % [s]     WLTC-city time
t_RDE_Urban = 2326;       % [s]     RDE-Urban time
Time = T_z(end,1);            % [s]     Simulation Time
Vveh=[T_z,V_z];

% Vveh(:,2)=Vveh(:,2)/3.6;
% Pbatt(:,2)=Pbatt(:,2)/1000;
% Pmot(:,2)=Pmot(:,2)/1000;


%% Vehicle
run("Init_FWD_500eHR.m")                    % 500e Frugal

%% Open Simulink Model
open('HIL_500eHR.slx')
```

**Figure 4. 7 Initial of HIL model**

Then we establish the HIL model of Fiat 500e, it has two main blocks shown as Figure 4. 8: the first one is the controller shown as Figure 4. 9, which in charge of the maneuver, here we can load different speed and time vectors for desired driving cycle to the driver and emerge the command torque for the vehicle. The second one is the forward vehicle model shown as Figure 4. 10, the torque command and the brake command from the controller are sent to the vehicle, and operate the vehicle longitudinal dynamics. Motor and driver system received the torque command, and the battery powers the motor, then drives the vehicle. The vehicle speed and acceleration information are feedback to the controller and complete the loop. Through the data extracted from the simulation, we can obtain the energy consumption of the vehicle in order to analyze and optimize the energy consumption of the battery.

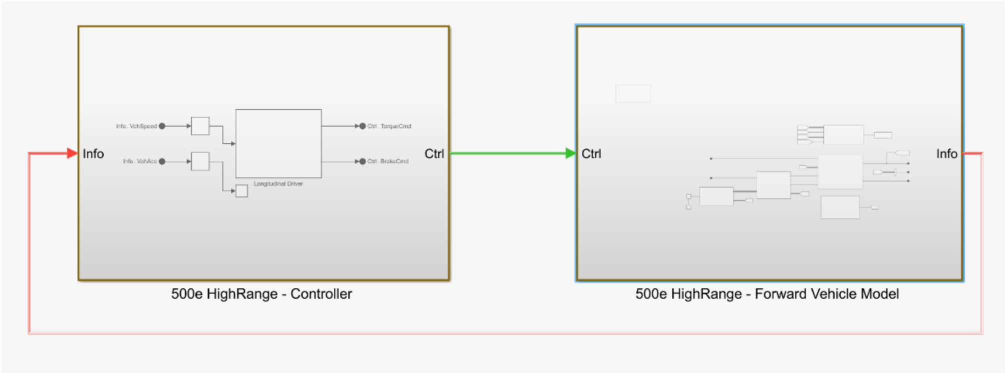



**Figure 4. 8 HIL model of Fiat 500e**

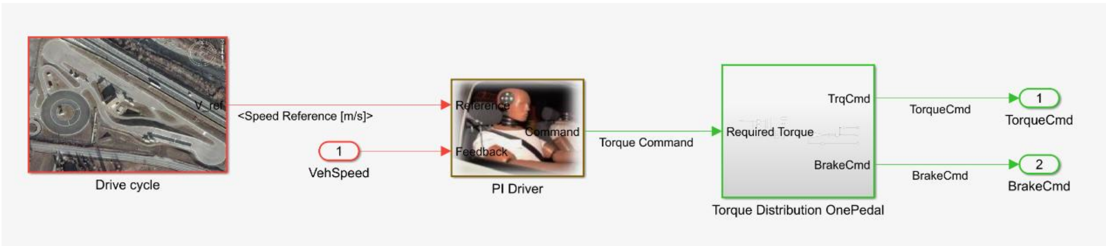



**Figure 4. 9 Fiat 500e Controller**

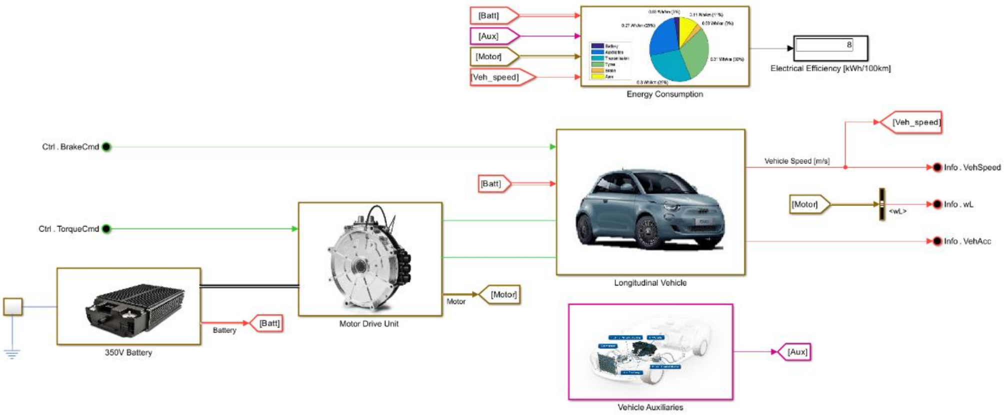



**Figure 4. 10 Fiat 500e Forward vehicle model**

The energy consumption block is described in detail below. In order to establish the longitudinal drive of the vehicle, about 58% of the battery capacity is used for driving and the rest is for other use such as air conditioning, we refer them collectively as vehicle auxiliaries. When referring the energy consumption, we need to use the battery's total usable capacity.

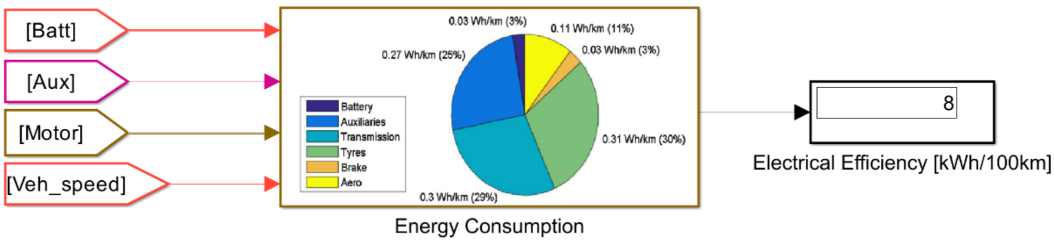



**Figure 4. 11 Energy Consumption Block**

The calculation method of vehicle electrical efficiency through the cycle is shown below and the block are demonstrated as Figure 4. 12.

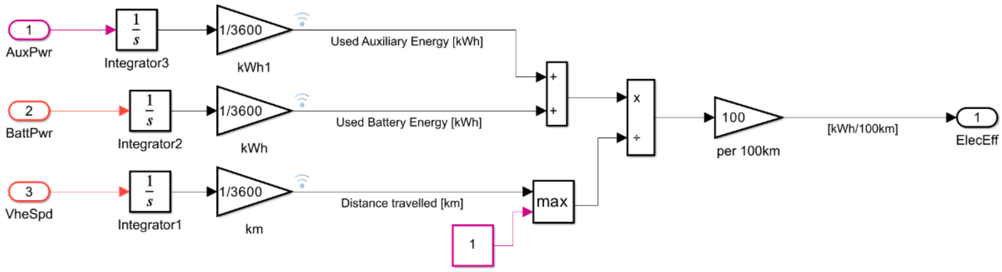



**Figure 4. 12 Electrical Efficiency Calculation Block**

$$Electrical\ efficiency = \frac{Used\ Energy(kWh)}{Travelled\ distance(km)} * 100 \qquad (4)$$

The used energy includes used battery energy for driving $E_{Bat}$ and used auxiliary energy $E_{Aux}$ .

$$E_{Bat}(kWh) = \frac{1}{3600} \cdot \sum_{i=1}^{n} P_{Bat}(i) \cdot \Delta t \tag{5}$$

$$E_{Aux}(kWh) = \frac{1}{3600} \cdot \sum_{i=1}^{n} P_{Aux}(i) \cdot \Delta t \tag{6}$$

$$Travelled\ distance(km) = \frac{1}{3600} \cdot \sum_{i=1}^{n} v(i)\left({}^{km}/_{h}\right) \cdot \Delta t \tag{7}$$

## 4.3 Analyze

### 4.3.1 Weight vs. Electrical Efficiency Analysis (WLTC Cycle)

From chapter 3 we can know, in the distribution of energy efficiency and curb weight among passenger vehicles, there is a clear positive correlation between curb weight and energy consumption, and also, there exists a noticeable gap between Europe's L-class and M-class vehicles. Interestingly, Chinese vehicles tend to be concentrated within this intermediate range, effectively filling the gap with models compared with the M-class that are generally smaller in size, lighter in weight (with curb weights typically ranging from 700 to 1000 kg), and exhibit lower energy consumption—approximately between 9 and 12 kWh/100 km, and also the performance and security level not as L-class. Therefore, reducing the existing M-class vehicle weight in Europe emerges as a critical strategy for lowering the energy efficiency and filling the gap in the European market.

To explore this approach, we use the iconic European model Fiat 500e as a case study. By reducing the curb weight of the Fiat 500e to approach the weight levels commonly achieved by comparable Chinese models, the vehicle's energy efficiency can be significantly improved. This strategy has the potential to address the existing market gap in Europe by offering a product with: (1) Lower energy consumption, which means that for the same range we can use the battery with lower capacity, not only for companies to reduce manufacturing costs but also for customers reduce charging costs for daily use. (2) Pricing advantages over existing M-class cost reduction. (3) superior performance and security compared to L-class vehicles.

Such a positioning could enable the vehicle to occupy a previously underserved market segment, thereby enhancing competitiveness in the European EV landscape.

Therefore, we test the Fiat 500e in the WLTC cycle for different vehicle masses from 100% original weight 1250 kg, reducing to 70% weight 875 kg, 10% at every interval. By calculating the PMR, we can determine the specific WLTC cycle for testing. The PMR calculation formula as in 3.1.1. According to the calculated PMR, they are all over 34 W/kg, we apply WLTC-3b class for testing (our tested WLTC-3b cycle is not the standard one with low, medium, high, extra high 4 different speed phases; our defined WLTC_3b cycle also has 4 phases, but they are 2 urban phases, a high and a extra high phase in sequence, and the cycle time last for 2811.3 s . The specific curve is shown in the Figure 4. 13 Tested WLTC-3b cycle.

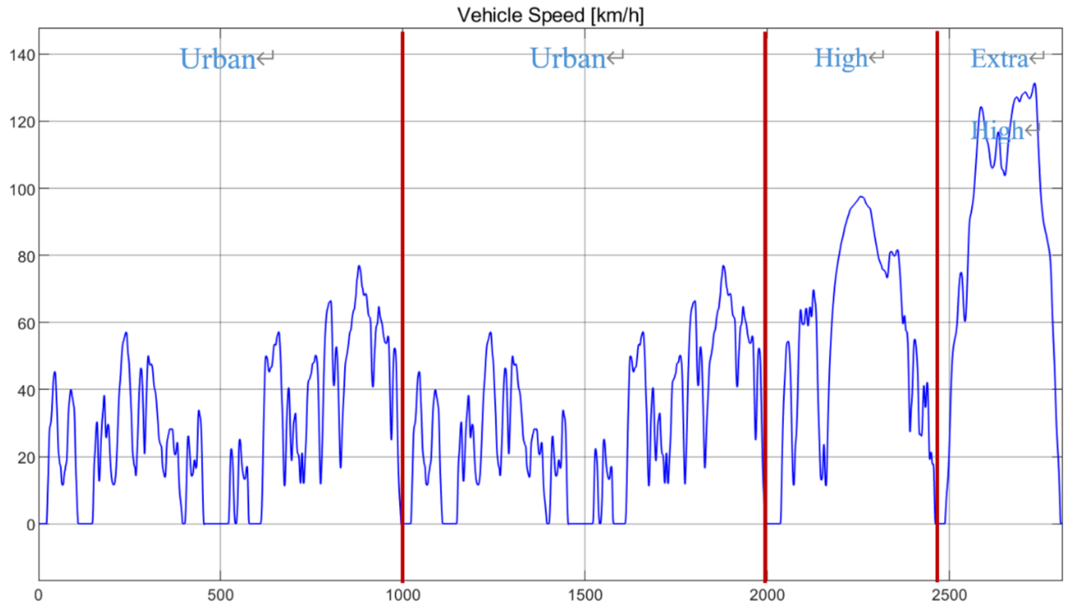



**Figure 4. 13 Tested WLTC-3b cycle**

The Table 13 below shows the data for our simulations, where electrical efficiency is the result we obtained. As the weight of the vehicle decreases, the electrical efficiency of the vehicle decreases significantly, which can meet our purpose.

**Table 13 Simulation and Computation Results (WLTC)**

| Vehicle mass | 100%mass (1250kg) | 90%mass (1125kg) | 80%mass (1000kg) | 70%mass (875kg) |
|---|---|---|---|---|
| Power*eta max(Shaft_Power_max)*0.9 | 42565 | 42565 | 42565 | 42565 |
| PMR | 34.0522 | 37.8358 | 42.5653 | 48.6461 |
| Cycle | WLTC_Class3b | WLTC_Class3b | WLTC_Class3b | WLTC_Class3b |
| Electrical Efficiency (kwh/100km) | 10.09 | 9.64 | 9.213 | 8.804 |
| Range(km) | 211.1 | 220.95 | 231.2 | 241.94 |

+9.85km +10.25km +10.74km

From the resulting efficiency, we can calculate the WLTC range for each vehicle. By calculating the WLTC range, the influence of vehicle mass reduction on electrical efficiency can be more clearly observed and evaluated. The calculation method of the range is shown below.

The WLTC range $R_{WLTC}$ [km] is determined by the usable battery pack capacity $C_{BP,usable}$ [kWh] divided by the tested WLTC electrical efficiency $E_{WLTC}$ [kWh/100km]

$$R_{WLTC}(km) = C_{BP,usable} * \frac{100}{E_{WLTC}} \tag{8}$$

Through the calculated WLTC range, we can more intuitively see the effect of reduce the electrical efficiency. Reducing the Fiat 500e's curb weight by 10% 125 kg can lead to about 10 km increase in driving range. When reducing to 70% weight 875 kg, the range can totally increase 30 km. For electric vehicles with a baseline range of around 200 km, an extension of 30 km represents a significant improvement, which means that the user's daily commute can travel one more time, reduced the charging frequency.

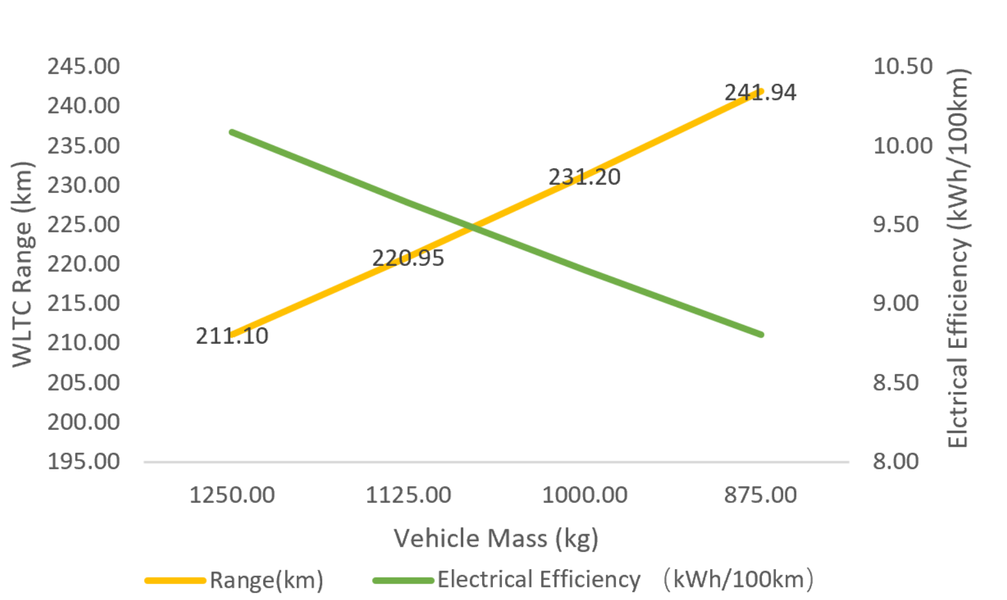



**Figure 4. 14 Tested result figure of WLTC-3b cycle**

However, we believe that the Fiat 500e's existing design, with its 211 km range, is already well-aligned with the needs of daily urban use. Assuming an average daily commute of 30 km, charging the vehicle once every seven days would better suit users' routine-based lifestyles. So we set Fiat 500e's 211.1 km range as reference and reverse the process to calculate the battery capacity and battery pack mass.

The required usable battery pack size $S_{BP,usable}$ [kWh]

$$S_{BP,usable,req} = \frac{R_{WLTC}}{100} \cdot E_{WLTC} \tag{9}$$

The battery data for the Fiat 500e with a nominal capacity of 23.7 kWh is summarized in Table 14. The table includes all necessary parameters related to the battery for the calculations.

**Table 14 Fiat 500e Battery**

| LR Battery - 23.7kWh Nominal - 21.3kWh Useable | | |
|---|---|---|
| Nominal Capacity | 23.7 | kWh |
| Useable Capacity | 21.3 | kWh |
| Is Useable Capacity > WLTC Requirement? | YES | |
| Electrical Characteristics | | |
| Number of Series | 108 | - |
| Number of Parallels | 1 | - |
| Number of Cells | 108 | - |
| Cathode Material | NMC-622 | - |
| Nominal Voltage | 394 | V |
| Nominal Ampere-Hours | 60 | Ah |
| Mechanical Characteristics | | |
| Cell Specific Energy Density | 223.47 | Wh/kg |
| Battery Pack Specific Energy Density 58% | 129.61 | Wh/kg |
| Battery Mass (calculated) | 182.48 | kg |
| Battery Height | 97.67 | mm |
| Battery Length | 738.70 | mm |
| Battery Width | 707.68 | mm |
| Cell Only Mass | 105.84 | kg |

| Available Cell from 500e LR | | |
|---|---|---|
| Baseline 500e Cell - Samsung SDI 60 Ah NMC | | |
| Cell Chemistry | NMC-NCA | - |
| Cell Nominal Voltage | 3.65 | V |
| Cell Nominal Capacity | 60.00 | Ah |
| Cell Specific Energy Density | 223.47 | Wh/kg |
| Cell Height | 97.67 | mm |
| Cell Length | 147.74 | mm |
| Cell Width | 28.32 | mm |
| Cell Weight | 0.98 | kg |
| Cell Volumetric Energy Density | 535.91 | Wh/L |

Usually, to increase the life-time of the battery pack, the size is reduced so that the state of charge (SoC) is confined from 90% to 10%. And based on the data in Table 14, we define the conversion factor between nominal capacity and usable capacity as 0.9. Thus, the required nominal battery pack size is

$$S_{BP,nom,req} = \frac{S_{BP,usable,req}}{0.9} \quad (10)$$

Then, we can calculate the number of cells N of the battery to achieve a WLTC range of 211.1 km for each vehicle. Based on the electrical characteristics of the battery, the cells are connected in series. Therefore, the number of series connections $N_s$ is equal to the total number of cells N and the number of parallel connections is set as $N_p$=1.

$$S_{BP,nom} = V_{BP,nom}C_{BP,nom} \geq S_{BP,nom,req} \quad (11)$$

$$V_{BP,nom} = V_{cell,nom} \cdot N_s = 3.65V \cdot N_s \tag{12}$$

$$C_{BP,nom} = C_{cell,nom} \cdot N_p = 60\ Ah \tag{13}$$

Consequently, we obtain the total number of cells N is calculated using the following equation:

$$N = \frac{S_{BP,nom,req}}{3.65V * 60Ah} \cdot 1000 \tag{14}$$

Where $S_{BP,nom,req}$ is the required nominal battery pack energy (in kWh), and the denominator represents the energy content of a single cell. The result is rounded up to the nearest integer.

Based on the battery pack specific energy density $D_{BP}$ of 129.61 Wh/kg, the total mass of the battery pack can be estimated accordingly.

$$M_{BP}(kg) = S_{BP,nom} \cdot \frac{1000}{D_{BP}} \tag{15}$$

The complete calculation results are summarized in the Table 15. It can be observed that for every 10% reduction in vehicle weight (125 kg), the number of battery cells required can be reduced by 4–5 cells, assuming the WLTC range remains unchanged. When the vehicle weight is reduced to 70% of its original value, a total reduction of 13 cells can be achieved. This corresponds to a decrease in nominal capacity of approximately 3 kWh and a battery pack weight reduction of around 20 kg.

**Table 15 Computation Results of the Battery (WLTC)**

| Vehicle mass | 100%mass (1250kg) | 90%mass (1125kg) | 80%mass (1000kg) | 70%mass (875kg) |
|---|---|---|---|---|
| PMR | 34.0522 | 37.8358 | 42.5653 | 48.6461 |
| Electrical Efficiency $E_{WLTC}$ (kWh/100km) | 10.09 | 9.64 | 9.213 | 8.804 |
| Required usable battery capacity $S_{BP,usable,req}$ (kWh) | 21.3 | 20.35 | 19.45 | 18.59 |
| Required nominal battery capacity $S_{BP,nom,req}$ (kWh) | 23.7 | 22.61 | 21.61 | 20.65 |
| Number of cell $N$ | 108 | 104 | 99 | 95 |
| Nominal capacity $S_{BP,nom}$ (kWh) | 23.7 | 22.78 | 21.68 | 20.81 |
| Cell only mass(kg) | 105.84 | 97.57 | 92.86 | 89.13 |
| Battery pack mass $M_{BP}$ (kg) | 182.48 | 175.76 | 167.27 | 160.56 |

From a cost perspective, assuming a battery cost of 100 USD per kWh, this reduction would lead to a cost saving of approximately 300 USD. Additionally, the 20 kg reduction in battery pack mass contributes directly to lowering the overall vehicle weight, which can further enhance energy efficiency, handling performance, and potentially reduce structural and material requirements for the vehicle chassis.

### 4.3.2 Weight and dimension

The above analysis clearly indicates that vehicle mass has a significant impact on overall efficiency. Therefore, in order to achieve the target of reducing the vehicle weight to 70% of its original value, here we discuss how to reduce the vehicle weight.

There are multiple approaches to reducing vehicle weight, such as the use of lightweight materials, decreasing battery mass, and reducing vehicle dimensions.

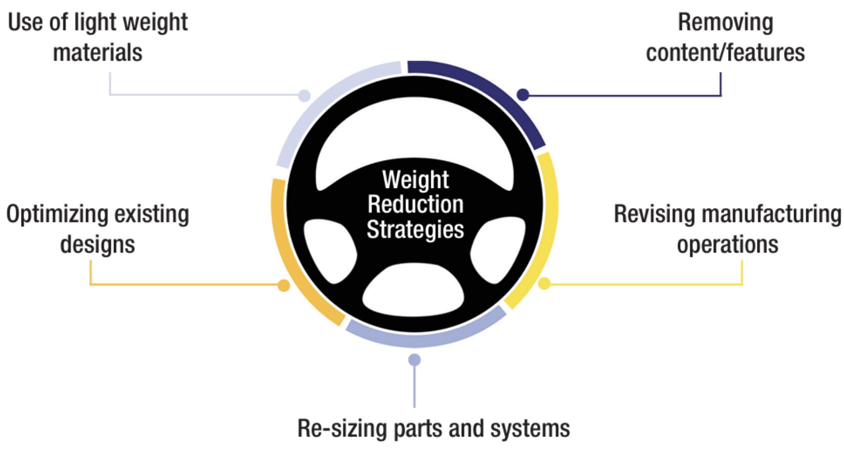



**Figure 4. 15 Weight Redecution Strategies**

*Source: Mhapankar, M. Weight reduction technologies in the automotive industry. Aranca.*

Using the lightweight structural materials, such as carbon fiber, can offer substantial weight reduction, but it often leads to significantly increased costs, which is contrary to the goal of improving efficiency while reducing cost. In addition, using lightweight materials frequently requires the optimization of structural layouts and the integration of reinforcing components to ensure adequate crash resistance[22], thus we will not be further discussed here.

Battery mass reduction has already been discussed in previous sections. Under the condition of maintaining the same driving range and using the same battery technology, reducing the overall vehicle weight enables the use of fewer battery cells, thereby lowering the battery pack mass. Alternatively, batteries with higher energy density can also contribute to weight reduction. However, such batteries are generally more expensive at present, due to the current state of development in the battery industry. As battery technologies continue to evolve, offering improved performance and reduced cost, the feasibility of adopting high-energy-density batteries will increase in the future.

Among all methods, reducing vehicle dimensions represents the most direct and straightforward approach to lowering vehicle mass. Here we present a detailed analysis of the impact of vehicle dimensions on vehicle weight.

As shown in the Figure 4. 15, reducing the overall vehicle dimensions can effectively contribute to weight reduction across multiple subsystems. For example, smaller exterior dimensions lead to reduced glass surface area, which lowers the weight of windows and windshields. Similarly, the body and exterior components become lighter due to the smaller form factor. A shorter chassis results in less structural material, while interior components such as seats, trim, and electronics can also be downsized accordingly. Together, these changes enable a comprehensive reduction in vehicle mass through dimension optimization.

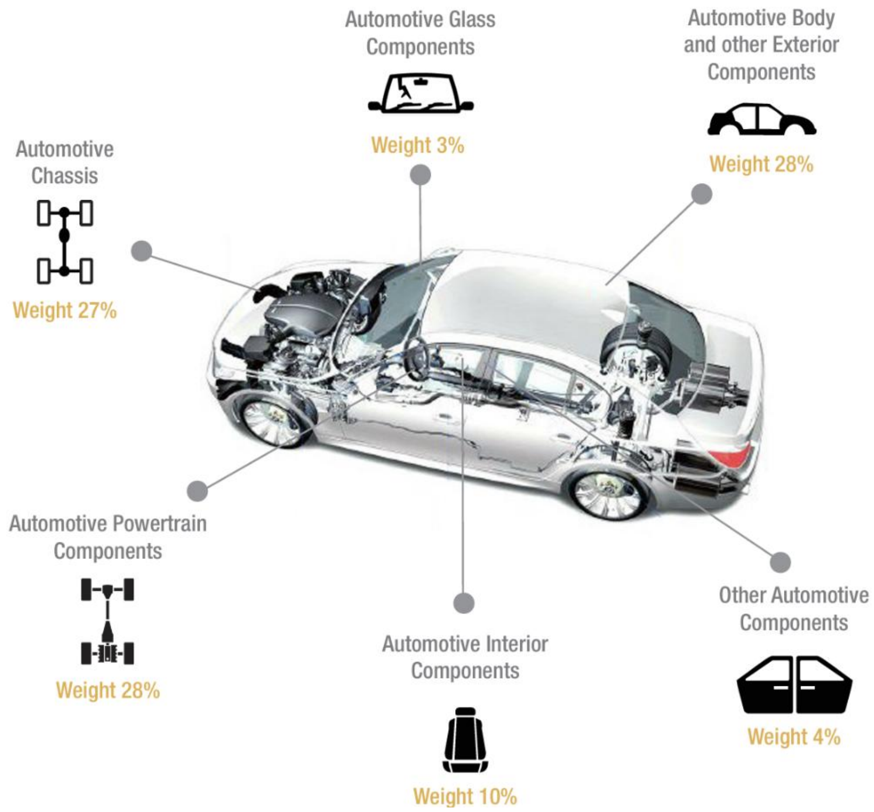



**Figure 4. 16 Automotive Component Weight Statistics**

*Source: Mhapankar, M. Weight reduction technologies in the automotive industry. Aranca.*

The compact body design of micro electric vehicles plays a crucial role in reducing overall vehicle weight. Shorter body length and narrower width directly reduce material usage in structural components.

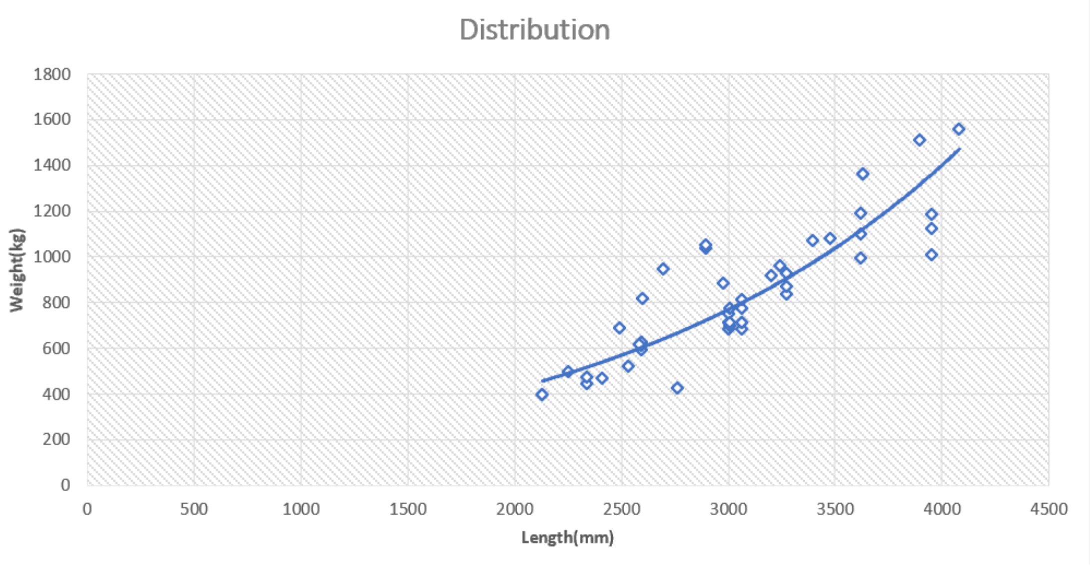



**Figure 4. 17 Vehicle Weight and Length Distribution**

This scatter plot demonstrates a strong positive correlation between vehicle length and curb weight among a wide range of electric micro and compact vehicles. The fitted curve reveals a nonlinear trend, with weight increasing more rapidly in longer vehicles, especially beyond 3500 mm. Most micro EVs cluster below 2800 mm in length and under 750 kg in weight, supporting the principle that compact design significantly contributes to lightweight construction.

Taking the SGMW Mini EV as an example, its body structure clearly illustrates a lightweight yet robust design strategy. As shown in the Figure 4. 18, the vehicle adopts a hybrid frame composed primarily of high-strength steel for the critical load-bearing areas—such as the A-pillar, B-pillar roof, rails, and side sills—which are highlighted in red. These reinforcements ensure occupant protection and structural rigidity during collisions[23]. Meanwhile, stamped aluminum alloy components are selectively used in non-critical zones, such as interior panels and floor supports, to further reduce weight without compromising integrity. Compared to a conventional all-steel body, this multi-material structural approach enables a 20–30% reduction in vehicle frame weight while maintaining the same cabin space and crash performance[24]. This reduction is crucial in the micro EV segment, where lower curb weight directly translates into improved energy efficiency, extended range, and reduced battery size.

**Figure 4. 18 SGMW Mini EV Frame**

Due to space constraints and the minimalist design philosophy of micro EVs, many conventional automotive components are either scaled down or completely redesigned for compactness and efficiency. For instance, smaller and thinner seats are used, typically without heavy mechanical adjustments or seat heating modules, reducing the weight per seat from 15–20 kg (in regular vehicles) to about 8–10 kg. The HVAC system is also simplified, often using low-capacity air circulation or fixed cooling-only modules instead of full climate control systems, saving around 10–15 kg[24]. Likewise, shorter electrical wiring harnesses—due to the reduced cabin length—can cut down 5–10 kg of copper and insulation weight. Additionally, components such as wheel and tire sizes are scaled down (e.g., 12-inch wheels instead of standard 16–18 inches), glass surface area is minimized, and manual or minimal-power window regulators replace full motorized systems. Even door structures are smaller and lighter, with simpler trim and fewer integrated features like speakers or sensors. At the end, both the number and the physical volume of parts are reduced, leading to an estimated total weight reduction of 80–150 kg.

With reference to Chinese A00 and A0 segment vehicles, it is reasonable to assume that the curb weight of a compact vehicle should lie between 700 kg and 1000 kg. This aligns with the informal European concept of the M0 vehicle class, which targets vehicles with a curb weight below 1000 kg.

Vehicles that are too small or too light may raise concerns regarding safety and structural integrity. Larger and heavier vehicles generally offer superior crash protection compared to smaller, lighter ones, assuming all other factors remain constant. The structural area between the front bumper and the passenger cabin can absorb impact energy through controlled deformation. Consequently, vehicles with longer front ends are typically more effective at mitigating forces in frontal collisions. Additionally, heavier vehicles are less likely to continue moving forward in crashes with lighter vehicles and other obstacles, which reduces the amount of force transmitted to their occupants[25]. While those that are too large or heavy tend to exhibit poor energy efficiency. Therefore, a target curb weight of 875 kg, corresponding to 70% of the original Fiat 500e's mass, represents a balanced compromise between efficiency and safety.

Our target curb weight is 70% of the original Fiat 500e's mass (875kg), and a driving range of about 200 km. For this reference, several Chinese vehicles with similar curb weights and driving ranges include the SGMW Air EV(4 seats) has a curb weight of 888 kg, a wheelbase of 2010 mm, and a WLTC range of approximately 240 km. Similarly, the Changan Lumin features a wheelbase of 1980 mm. Based on these comparisons, to achieve the 70% weight target while maintaining a comparable range and energy efficiency, the Fiat 500e’s wheelbase should also be reduced to approximately 2000 mm.

### 4.3.3 Weight vs. Electrical Efficiency Analysis (CLTC Cycle)

According to the method described in Section 4.3.1, we applied the CLTC driving cycle to the defined maneuver. The resulting data are presented below

**Table 16 Simulation and Computation Results (CLTC)**

| Vehicle mass | 100%mass (1250kg) | 90%mass (1125kg) | 80%mass (1000kg) | 70%mass (875kg) |
|---|---|---|---|---|
| Power*eta<br>max(Shaft_Power_max)*0.9 | 42565 | 42565 | 42565 | 42565 |
| PMR | 34.0522 | 37.8358 | 42.5653 | 48.6461 |
| Cycle | CLTC-P | CLTC-P | CLTC-P | CLTC-P |
| Electrical Efficiency-CLTC (kWh/100km) | 8 | 7.578 | 7.17 | 6.78 |
| Range(km)-CLTC | 266.25 | 281.077 | 297.07 | 314.16 |
| Range(km)-WLTC | 211.1 | 220.95 | 231.2 | 241.94 |
| Ratio | 0.793 | 0.786 | 0.778 | 0.77 |

As shown in the table, the CLTC driving range is consistently higher than that of WLTC, with the ratio between the two cycles being close to 0.8. Moreover, it is observed that this ratio tends to decrease as the vehicle curb weight decreases. This phenomenon can be attributed to the nature of the CLTC cycle, which is characterized by lower average speeds, gentler acceleration profiles, and longer periods of low-load operation compared to WLTC, shown as Table 17. These conditions favor lighter vehicles, whose energy consumption becomes even lower under mild driving conditions, resulting in a proportionally greater CLTC range.

**Table 17 Characteristics of WLTC and CLTC cycle**

| | **WLTC** | **CLTC** |
|---|---|---|
| Condition | low-medium-high-ultra high | Slow-medium-fast |
| Cycle duration(s) | 1800 | 1800 |
| Idle duration(s) | 228 (12.67%) | 398 (22.11 %) |
| Total distance(km) | 23.21 | 14.48 |
| Max speed(km/h) | 131.3 | 114 |
| Average speed(km/h) *with stop | 46.42 | 28.96 |
| Running average speed(km/h) *without stop | 53.2 | 37.18 |
| MAX acceleration($m/s^2$) | 1.58 | 1.47 |
| MAX deceleration($m/s^2$) | -1.49 | -1.47 |
| Average acceleration ($m/s^2$) | 0.53 | 0.45 |
| Average deceleration ($m/s^2$) | -0.58 | -0.49 |

*Adapted from Liu et al. (2021), E3S Web of Conferences, 241, 02002.* [https://doi.org/10.1051/e3sconf/202124102002](https://doi.org/10.1051/e3sconf/202124102002)

One of the advantages of the CLTC cycle is that it better reflects urban driving patterns in China, particularly for compact and lightweight electric vehicles. It thus provides a more optimistic estimate of achievable range under typical city usage.

Similarly, following the method described in Section 4.3.1, we used the WLTC range of 211.1 km as a reference and applied it in reverse calculation to the CLTC cycle. Through this process, we calculated the required battery capacity and the corresponding number of cells. The results are presented below.

**Table 18 Computation Results of the Battery (WLTC)**

| Vehicle mass | 100%mass (1250kg) | 90%mass (1125kg) | 80%mass (1000kg) | 70%mass (875kg) |
|---|---|---|---|---|
| Power*eta<br>max(Shaft_Power_max)*0.9 | 42565 | 42565 | 42565 | 42565 |
| PMR | 34.0522 | 37.8358 | 42.5653 | 48.6461 |
| Driving Cycle | CLTC-P | CLTC-P | CLTC-P | CLTC-P |
| Electrical Efficiency-CLTC (kWh/100km) | 8 | 7.578 | 7.17 | 6.78 |
| Range(km)-CLTC | 211.1 | 211.1 | 211.1 | 211.1 |
| Required Energy (kWh) | 16.89 | 16 | 15.14 | 14.31 |
| Nominal capacity required (kWh) | 18.77 | 17.78 | 16.82 | 15.9 |
| Number of cell $N_{CLTC}$ | 86 | 82 | 77 | 73 |
| Number of cell $N_{WLTC}$<br>*with 211.1km WLTC range | 108 | 104 | 99 | 95 |
| Delta | 22 | 22 | 22 | 22 |

The results indicate that if the CLTC cycle range is used as the design basis instead of the WLTC range, a vehicle like the Fiat 500e we tested targeting a 211.1 km range could reduce the number of battery cells by 22. This corresponds to a savings of approximately 37.17 kg in battery pack mass.

From the company's perspective, adopting the CLTC range as the standard can offer significant cost advantages. For instance, based on an estimated battery cost of 100 USD/kWh, the elimination of 22 battery cells—equivalent to approximately 4.818 kWh—would result in a cost saving of around 481.8 USD per vehicle.

In addition to cost reduction, presenting the CLTC range instead of the WLTC range can also be more appealing from a marketing standpoint. For non-expert consumers, the visibly higher range figures under CLTC conditions may create a stronger impression of performance and practicality, thereby offering a competitive advantage in the market.

## 4.4 Conclusion

This chapter comprehensively examined the impact of the vehicle weight, on the energy efficiency and battery requirements of electric vehicles, using a Fiat 500e-based model as a representative case. And examined the impact of different driving cycles.

Based on the simulations and calculations conducted using the Fiat 500e as a case study, we find that reducing vehicle weight within the range of 100% to 70% of its original curb weight yields tangible improvements in energy efficiency. While more significant weight reduction leads to greater efficiency gains, it also presents increasing challenges in terms of design feasibility, structural integrity, and safety.

Taking these trade-offs into account, a curb weight in the range of 700 to 1000 kg appears to be a practical and balanced target for compact electric vehicles. Correspondingly, a wheelbase of approximately 2.0 to 2.3 meters is deemed suitable. Vehicles designed within these parameters are expected to offer enhanced energy efficiency without compromising safety or functionality, making them highly competitive in the urban mobility market. Such a configuration is advantageous both from the perspective of manufacturers, who seeking cost-effective and efficient designs, and for consumers, who value range, affordability, and urban practicality.

On the other hand, while the WLTC provides a more rigorous and globally recognized assessment for high-performance vehicles, the CLTC cycle is more appropriate for compact urban EVs—especially those targeting cost-sensitive markets. By aligning driving cycle selection, weight reduction strategies, and dimensional optimization, manufacturers can improve both the technical and economic performance of small electric vehicles.

# Chapter 5

# Conclusion and Discussion

## 5.1 Conclusion

This study aimed to explore optimization strategies for micro-EVs in terms of vehicle dimensions, curb weight, battery energy configuration, driving range, and market adaptability, with the overarching goal of reducing overall energy consumption and production cost, ultimately enhancing vehicle competitiveness in diverse global markets.

Through a cross-regional comparative analysis of 46 micro-EV models from China, Europe, and Japan, the research identified significant regional disparities in design approaches and performance priorities. A key contribution of the study is the development of a three-dimensional estimation cube, mapping vehicle mass (650–1250 kg), energy efficiency (8.4–15.0 kWh/100 km), and power-to-mass ratio (PMR, 23–78 W/kg). This design space provides a practical framework for optimizing future micro-EV configurations across performance and efficiency dimensions.

Using the Fiat 500e as a reference vehicle, a simulation model was constructed to assess the impact of incremental mass reduction on energy consumption. The analysis demonstrated that reducing the curb weight to 70–100% of the original mass yields notable energy efficiency improvements. While greater reductions in weight correlate with further efficiency gains, they also introduce significant challenges related to structural integrity, design feasibility, and passenger safety. Taking these trade-offs into account, the study suggests that European small EVs would benefit from targeting a curb weight range of 700–1000 kg and a wheelbase of approximately 2.0–2.3 meters. These values are largely consistent with the informal European M0-class vehicle design targets, which aim to keep curb weight under 1000 kg.

Furthermore, the simulation results demonstrate that the ratio between WLTC range and CLTC range for micro electric vehicles is approximately 0.8, and this ratio tends to decrease as vehicle curb weight is reduced. Thus, according to the simulation results and characteristic data based on the CLTC, we suggest that the CLTC may better reflect the real-world urban driving conditions of small commuter EVs. For European manufacturers aiming to reduce vehicle cost or expand into cost-sensitive markets such as China, battery sizing based on CLTC estimated range can offer flexibility and further cost reduction by avoiding unnecessary excess capacity.

## 5.2 Limitations Statement

Despite the comprehensiveness of this analysis, the study does have several limitations. The simulation was based on a single reference platform (Fiat 500e), and while informative, does not capture the wide diversity of drivetrain configurations or user behavior. The collected data, though rich, are drawn primarily from publicly available sources, meaning some vehicle specifications may be approximated or rounded. Additionally, external factors such as traffic patterns, weather conditions, and terrain profiles were not modeled, though they can have a significant impact on real-world energy consumption. Incorporating real-world driving data and conducting full vehicle-in-loop testing would provide further granularity and validity in future research.

Additionally, as autonomous and connected features become increasingly embedded in small EVs, the energy consumption associated with onboard computing, sensors, and communication modules should be added to energy modeling frameworks.

In conclusion, this thesis highlights that reducing energy consumption in micro-EVs is not solely a question of weight or battery size, it is a multi-dimensional design challenge. Manufacturers must harmonize vehicle mass, battery chemistry, regulatory requirements, performance expectations, and cost structures to reach optimal solutions. For European companies that will to enter the Chinese market, the path forward lies in adapting to localized energy efficiency demands through lightweight platforms, modular battery design, and strategic compromises between performance and economy. By focusing on energy consumption not as a constraint, but as a design driver, the next generation of micro-EVs can become the benchmark of intelligent, low-carbon urban mobility.

## 5.3 Personal Reflections and Strategic Insights

Refocusing our research on energy optimization in micro-EV was not an arbitrary academic choice, but rather a deliberate decision rooted in personal observation, professional training, and deep reflection on the future of urban mobility. Our automotive engineering education in Europe, combined with long-term exposure to China's market dynamics, led us to question a fundamental issue: “Are we truly designing vehicles for urban needs, or are we duplicating products from traditional automotive model?”. The initial spark for this research came from a simple yet pervasive observation: most cars on the road today are over designed for actual urban usage. Despite short daily commutes and speed restricted environments reasons, many EVs still feature oversized batteries, excessive power, and unnecessary cabin space. In contrast, China’s rapidly growing micro-EV market demonstrates a design philosophy that aligns precisely with urban mobility’s core demands: sufficient, energy efficiency, compactness, and affordability. This current situation inspired me that if we could redefine appropriate electric mobility through data optimization?

Many European automakers struggle to adapt micro-EV for China’s market, often misaligning product and user needs. By integrating comparative data, simulation, and policy analysis, this work seeks to guide market feedback design decisions. In the end, this research is more than just about technology, it’s about a way of thinking in engineering. The future of transportation isn’t about making cars faster or more powerful, but about designing the right kind of vehicles for cities and people. In the world of micro-EVs, which is growing fast but still lacks clear rules, saving energy is still the most important step.

Many European micro-EVs adopt relatively large battery packs like 30 to 40 kWh or more, not because users need to drive 300 km per day, but because range has become a selling point. But in real life, most urban commutes in Chinese cities are under 50 km per day. Oversizing the battery not only adds weight and cost but also wastes embedded energy in production and extends charge cycles unnecessarily. Designing smaller, right-sized batteries aligned with urban usage would result in more meaningful energy savings than simply reduce weight of the chassis or structure which could also result in safety reduction. From this perspective, we argue that energy efficiency must be understood in context. In urban markets, especially those like China where stop-and-go traffic and short trips dominate, energy saving design should prioritize efficiency for every single trip, not per kilometer. A system that treats energy, weight, range, and cost as interlinked variables rather than isolated is essential for designing vehicles that are both sustainable and purpose fit.

We personally hold deep respect for the engineering philosophy embedded in European automotive manufacturing, the European manufacturers have long adhered to strict design standards and highly integrated engineering processes. Their vehicles reflect a commitment to redundancy, lifecycle durability, and universal compliance, which ensures exceptional stability in performance, adaptability across diverse environments. From battery management systems to crash safety protocols, the European approach represents a mature and complete vision of vehicular design base in decades of engineering refinement.

However, this same commitment to "completeness" often creates a structural mismatch when applied to the Chinese micro-EV market. In our point of view, the design logic that prioritizes feature diversity, layered complexity, and high-level materials may be excessive and even counterproductive. On the contrast, the Chinese market is not driven by technical overachievement, but rather by functional adequacy and subjective tradeoffs. For example, Chinese consumers are more concerned with whether the vehicle fits daily commuting distances, whether it can be easily parked in dense cities, and whether the pricing delivers visible value. Features like panoramic sunroofs, advanced multi-mode driving systems, or overengineered safety layers are often seen as unnecessary additions that inflate costs without enhancing perceived value. Especially in the area of low-price vehicles.

More fundamentally, we believe China's micro-EV is evolving around a logic of "urban minimalism," where mobility solutions are shaped by compact space, short-range needs, and increasingly digital daily life. The success of this sector depends less on conforming to legacy automotive ideals and more on addressing the local user experience through ways for simplification. In contrast, European vehicle segmentation shows an overly polarized structure. L-class vehicles are excessively simplified, leading to compromised safety and practicality. Most of these models are not designed to meet China’s mandatory crash safety and battery protection standards and thus are not legally registrable on road. For instance, vehicles like the Renault Twizy, with compact and lack of enclosed doors and standard glass windows, falling short of China’s homologation requirements. Meanwhile, M1 class vehicles in both China and Europe follow broadly similar passive safety regulations, though European protocols such as ECE R94 and R95 impose stricter test conditions. Frontal impact speeds in European standards are higher, and side impact tests contain heavier barriers for testing, reflecting a more demanding safety threshold. As a result, for urban commute EVs in Europe the L class segment offers very limited passive protection, while M1 class models are safer but often over designed for low-speed urban use. Therefore, a gap in the market like lack of a well-balanced vehicle category that truly aligns with city level mobility and regulatory demands.

Beyond the physical vehicle structure, battery chemistry also plays a vital role in energy consumption. Chinese manufacturers heavily favor LFP (Lithium Iron Phosphate) batteries due to their lower cost, superior thermal stability, and longer cycle life. Despite their lower energy density compared to NMC or NCA chemistries commonly used in Europe, LFP batteries provide sufficient range for city commuting while enhancing safety and reducing costs. This makes them highly suited for low-cost micro-EVs. European reliance on NMC or NCA batteries, although effective for delivering longer range, contributes to higher vehicle cost and potentially excessive energy capacity for urban usage. A potential solution would be the modularization of battery systems, allowing European vehicles to scale down battery capacity for specific markets like China, where cost and compactness are more important than range.

As for the cost, it remains one of the major barriers for European manufacturers aiming to compete in the micro-EV segment. European brands typically rely on high-cost labor and less integrated supply chains, while their Chinese counterparts benefit from localized production ecosystems, efficient battery sourcing, and strong economies of scale. Without a localized supply base or production footprint, European manufacturers are unlikely to compete effectively on pricing.

To bridge this gap, establishing local design teams and partnerships with Chinese firms is essential. These collaborations can help European brands understand evolving consumer expectations or even in user interface preferences. Equally important is building a robust sales and after-service network, which Chinese consumers heavily rely on when making purchase decisions. Without reliable service accessibility and parts availability, even a well-engineered vehicle may struggle to build trust to customers.

More broadly, market understanding should not be viewed merely as a commercial task, it should inform upstream engineering decisions. By integrating real user feedback into product development cycles, European engineers can better tailor platform architecture, battery modularity, and vehicle features to local demands. This reverse influence where marketing and customer intelligence reshape engineering that represents a crucial shift for global brands aiming to remain relevant in the world’s most dynamic EV market.

European engineering precision can be effectively complemented by China's speed in prototyping and scale manufacturing. Joint ventures focusing on urban micro-EV could allow European firms to test cost sensitive innovations in China, while Chinese brands benefit from mature safety systems and compliance expertise from Europe.

This research journey has been more than a technical exploration—it has been a formative experience in how we understand engineering, sustainability, and the real world demands of emerging mobility systems. Investigating micro-EV in the context of China, Europe, and Japan revealed how vehicle design is not solely an engineering problem but a dynamic intersection of user behavior.

Through data analysis, simulation modeling, and cross-market comparison, we had come to realize the importance of system-level thinking. A vehicle's efficiency is not just defined by its motor or battery, but by how well it integrates with the broader ecosystem—urban design, charging networks, consumer habits, and environmental goals. This understanding has reshaped how our view engineering decisions: not as isolated optimizations, but as value judgments that reflect trade-offs, priorities, and ethical considerations. I believe the future of the automotive industry will be shaped by those who can design "just enough"—vehicles that are not overengineered but responsibly crafted to meet specific needs with minimal resource input. This principle is especially relevant for micro-EVs, where efficiency, affordability, and scalability outweigh maximal performance or luxury.

Reflecting on this thesis, we believe this process has helped us grow both as researchers and as critical thinkers. we had learned to question assumptions, evaluate trade-offs, and embrace imperfections in real-world systems. We hope that international collaboration, data-driven design, and urban-focused mobility strategies will converge to redefine how we move in cities. We committed to contributing to that not just as engineers, but as responsible participants in shaping a more efficient transportation future.

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