# *Key Elements for Designing the Technology Roadmap for EV Development -A case study in Shanghai*

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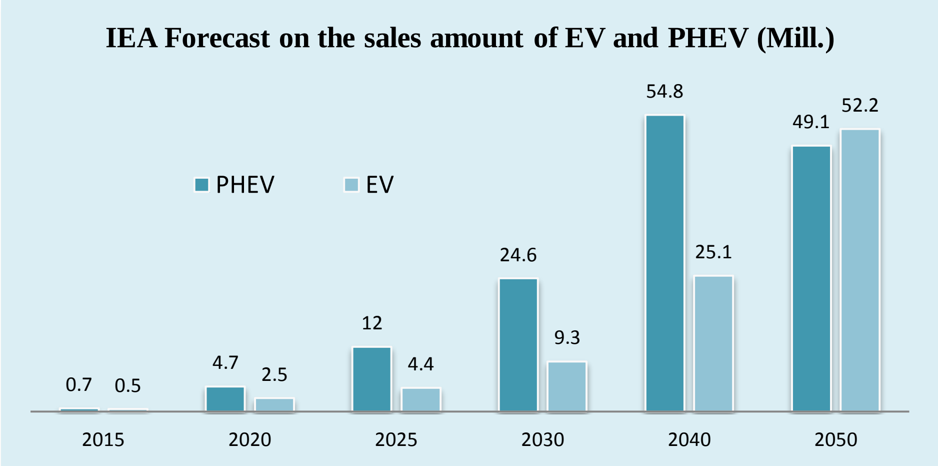
# Background

**Progress**

International




Domestic

**Ministry of Industry and Information：** 《Planning on the development of energy saving and renewable vehicle（2011-2020）》

Commercialize the production of EV and PHEV, By 2020, Scale of production and market size rank the NO.1 in the world . Installed number reach 5 million for renewable energy vehicle

**Ministry of Science and Technology：** 《Specific 12th Five –Year planning on EV technology development》(draft)

- Enlarge the demonstrative scale of EV and PHEV in public service sector and private sector
- Explore the possibilities of various commercial modes: separate battery from car, renting of battery , renting of entire car
- Strengthening the combination of innovation and commercialization
- **Enlarge the technology innovation of recharging infrastructure, strengthening construction, support the market development of recharging equipment**

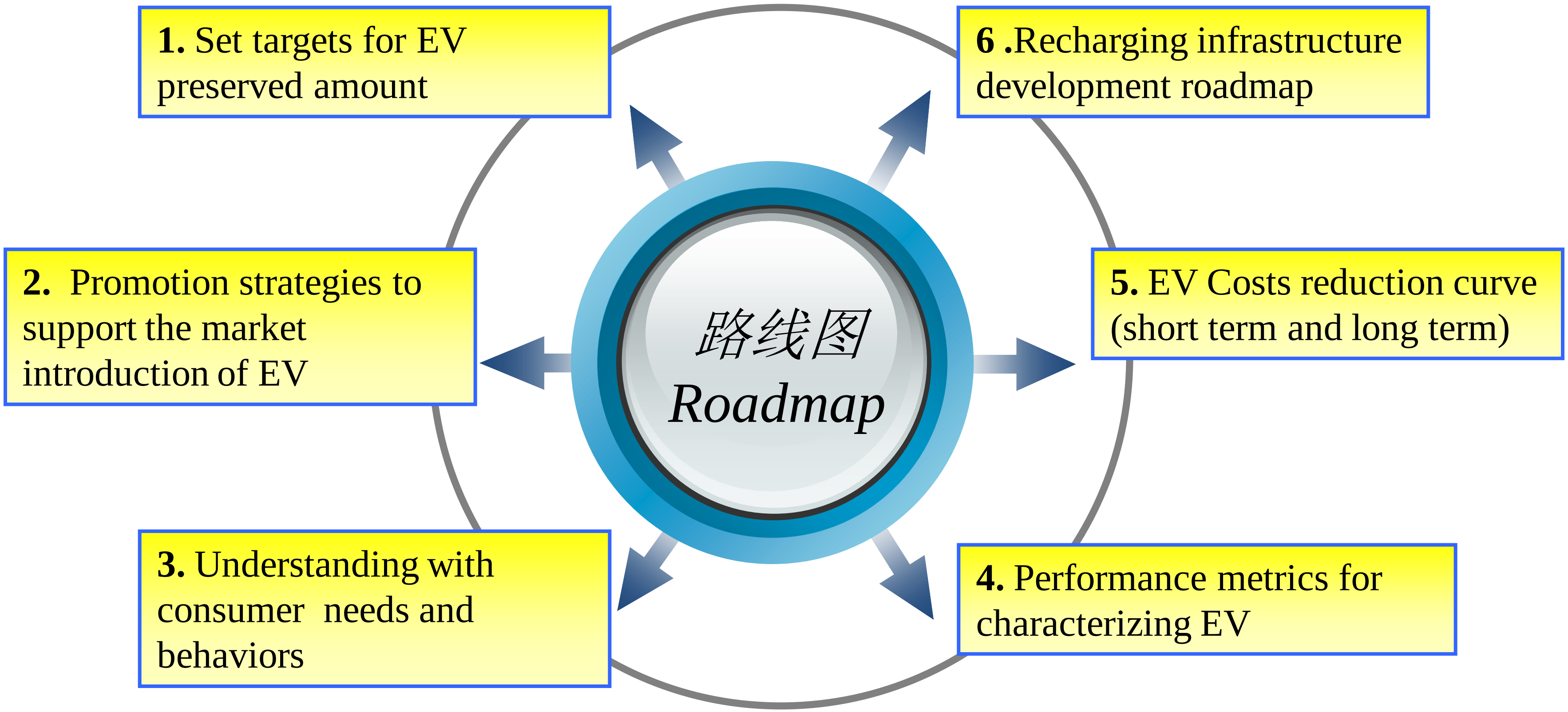
**•Promoting of EV is becoming more promising from the political perspective.**

**•EV and PHEV development are critical for urban transportation system transformation towards low carbonization.**

**•However, how about the demand side characteristics regarding recharging**

# ➢ *Road Map Framework*

● *Road map is essential for reducing uncertainties with the market development. According to the technology roadmap development guideline designed by IEA (2009), we need to conduct researches to look at the following six aspects.*



# *Promotion Strategy for EV*

- *EVs are unlikely to succeed without strong policy support, particularly in two aspects: (1) making vehicles cost-competitive with ICEs and (2) ensuring adequate recharging infrastructure in place*

- *Why should the government support EV? Because it serves the public interests in helping us: (1) reducing oil reliance; (2) conserving energy and reducing emissions; and (3) improving grid efficiency.*

- *To make EVs more cost competitive than ICE vehicles, we calculate the minimum subsidy on investment cost and fuel cost by using TIMES model. We find that the government should subsidize the fuel cost in near-term and investment cost in middle-term. In long term, there is no need for subsidy.*

# Shanghai TIMES Model

***Scenario Analysis of Electric Car Development***

SUB_EV: subsidy for each EV

SUB_ELC: subsidy on electricity for using EV

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Subsidy on car (yuan) | 2,600 | 3,000 | 9,000 | 3,100 |
| Subsidy on electricity in TIMES (million yuan/PJ) | 91 | 185 | 490 | 251 |
| NPV of subsidy per car (yuan) – 20% learning rate | 4,990 | 8,115 | 17,195 | 7,047 |
| NPV of subsidy per car (yuan) – 40% learning rate | 4,990 | 6,086 | 9,672 | 2,973 |
| NPV of subsidy per car (yuan) – 60% learning rate | 4,990 | 4,058 | 4,299 | 881 |

Note: based on the assumption that on average a car runs 15,000 kilometers a year and consumes 5326.63 KWh/year. We compute NPV of subsidy over a 3-year-period with a discount rate of 5%.

■ *Conclusion 1:* to encourage the use of electric car, it is more effective for the government to offer a subsidy on vehicles rather than on fuels in 2020. After that, the decision largely depends on the assumption of the learning rate: at 20% level, subsidy on car is cheaper from 2030 to 2050; at 40% level, subsidy on car is cheaper except in 2050; at 60% level, subsidy on electricity becomes cheaper after 2040.

# Shanghai TIMES Model

TPCARELC000: exchange battery model for EV

TPCARELC100: fast recharge model for EV

| | Investment Cost (yuan) | Fix O&M Cost (yuan) | Policy (million yuan/PJ) |
|---|---|---|---|
| Base | 80,600 | 5,000 | No |
| MOD_EX | 75,000 | 5,000 | Tax: 200 |
| MOD_FRC | 100,000 | 8,000 | Subsidy: 100 |

*exchange battery model*


*fast recharge model*


- *Conclusion 2:* the exchange battery model has a cost advantage over the fast recharge model (consistent with the investment plans of State Grid).

Further data calibration: we plan to survey 3,000 families across Shanghai to get more accurate data to compare these two models and the propensity of the consumers among these two models.

# Consumer Preference Surveys

- *Consumer acceptance of EVs is a key factor determining the ultimate success or failure of EV technologies. Consumers will balance between several factors including investment cost, O&M cost, car performance and energy convenience. Such information is inadequate worldwide.*

- *So in this January we conducted a "willingness to pay" survey in Shanghai. We visited 2,000 households across 10 district areas and asked them to choose between four models of cars.*

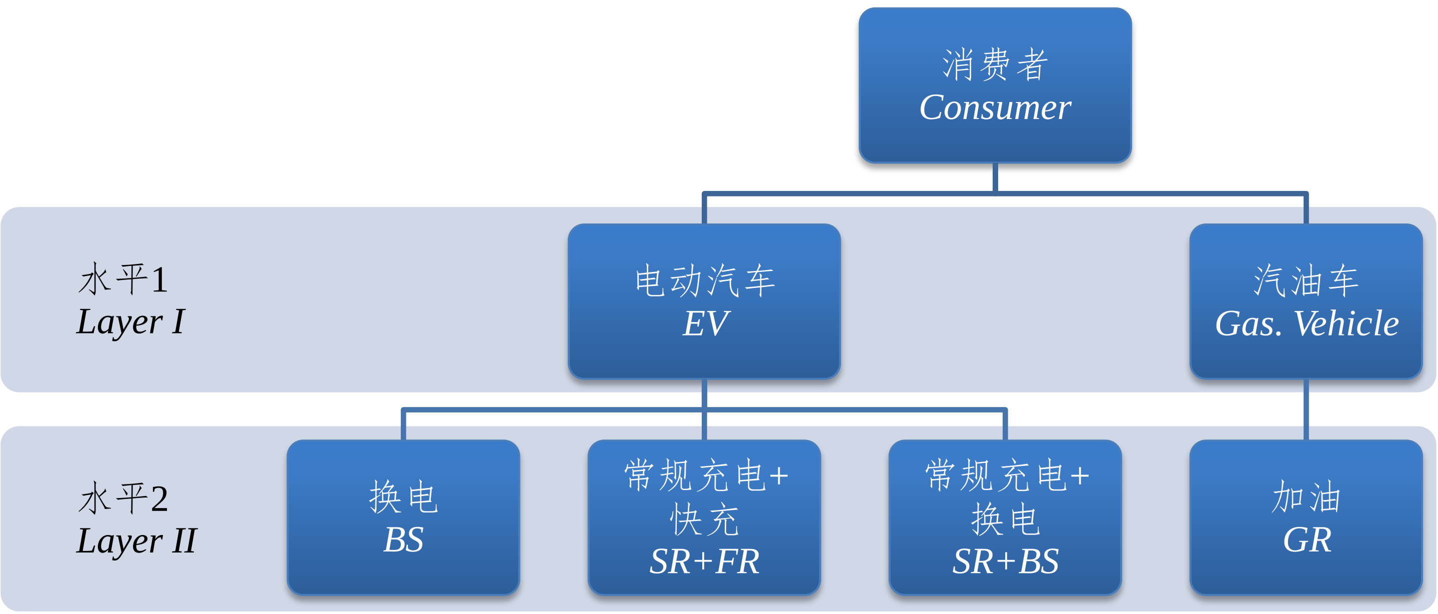
| Car Models | 被选择的次数占总数的比例<br>Percentage of Times Being Choosen |
|---|---|
| Oil cars | **23.49%** |
| EV - battery swapping model | **27.31%** |
| EV - slow recharging model + fast recharging model | **25.46%** |
| EV - slow recharging model + battery swapping model | **23.74%** |

# Demand and Utility Theory

●*Utility Maximization: Consumer maximize their objective utility by choosing from different type of vehicles. With respect to quantified features of each type of vehicle, we can describe the objective utility with mathematical expressions.*

●*Nested Logit Model: Non-linear probability model for utility of multi-layer choice.*

$$P_n(rm) = P_n(r|m)P_n(m) = \frac{e^{\sum_{k=1}^{K_1}\beta_k X_{(r|m)nk}}}{\sum_{r'=1}^{R_{mn}} e^{\sum_{k=1}^{K_1}\beta_k X_{(r'|m)nk}}} \cdot \frac{e^{\lambda_2\left(\sum_{k=1}^{K_2}\theta_k X_{mnk} + \ln\sum_{r=1}^{R_{mn}} e^{V_{(r|m)n}}\right)}}{\sum_{m'=1}^{M_n} e^{\lambda_2\left(\sum_{k=1}^{K_2}\theta_k X_{m'nk} + \ln\sum_{r=1}^{R_{mn}} e^{V_{(r|m')n}}\right)}}$$



# Demand Features of EVs

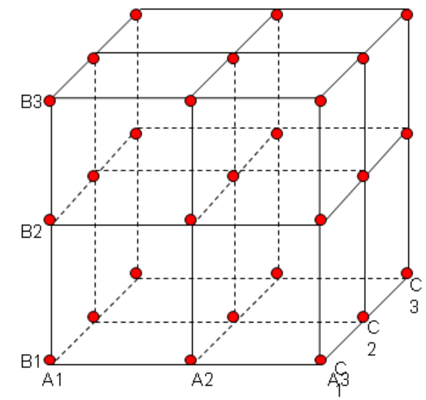
**Features of EVs**

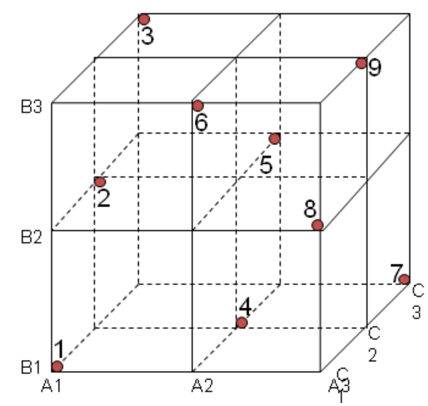
- *Cost related factors*
  - *Vehicle price*
  - *Fuel cost*
  - *OM cost*
- *Technical performance related factors*
  - *Recharge time*
  - *Recharge convenience (electronic guiding system)*
  - *Mileage*
- *Policy Related factors*
  - *Charge/taxation preference (traffic jam)*
  - *Preserved parking space*
  - Pre-paied recharge card

# • *Questionnaire Design*

- *Consumers' utility is determined by the selective frequencies regarding hundreds of possible combination of aforementioned features. 3^6=729. Specific methodologies are definitely needed*

- *Orthogonality experiential methodology: arrange the experiment according to the mathematics principles. This methodology have obvious merits overcoming the overall experiential methodology and simple comparative methodology. This methodology can ensure the representative of sampling and reduce the number of experiments to a great extent*




正交实验法实验分布图

# Questionnaire Design

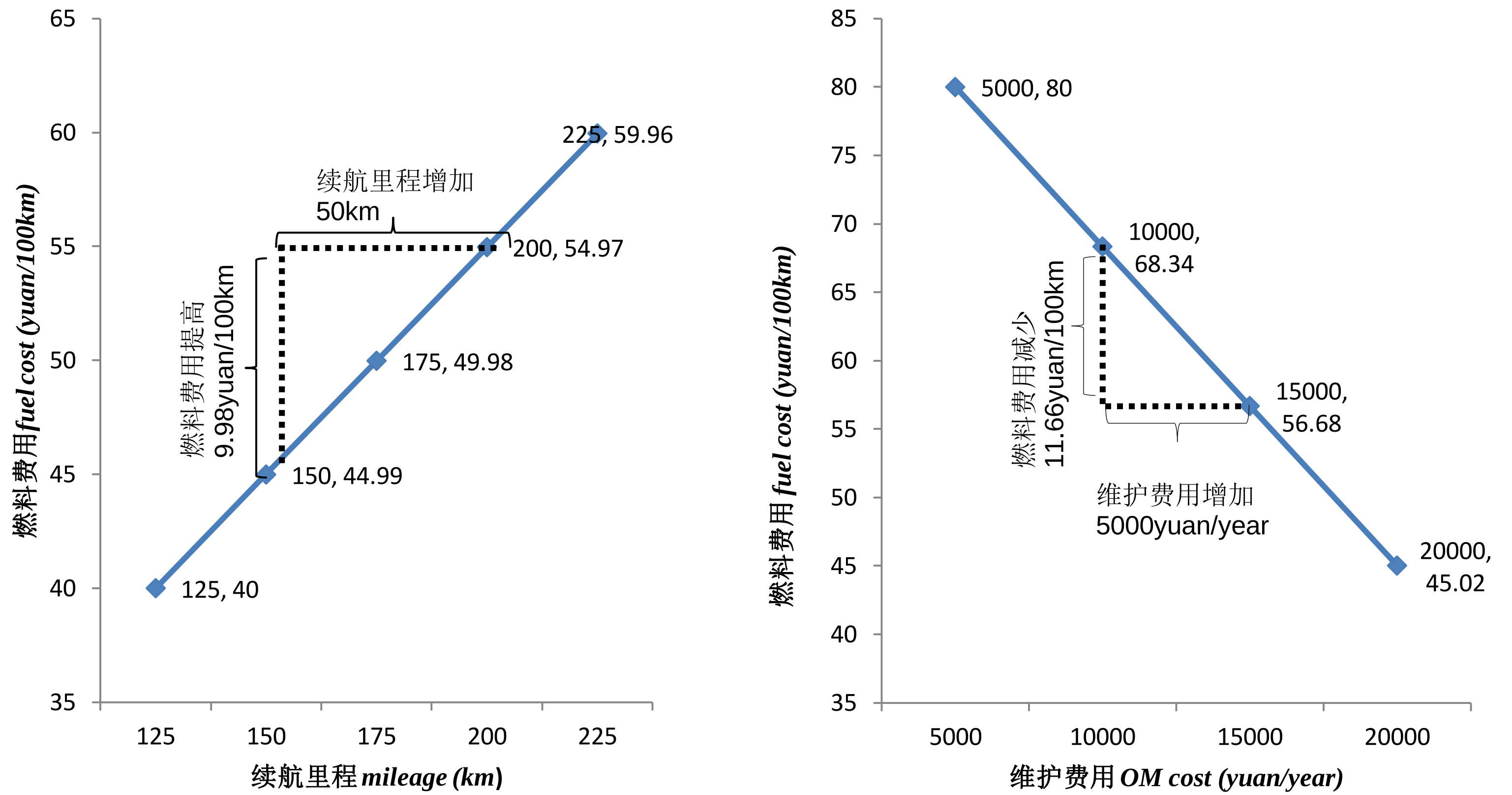
| | 汽油车<br>Gas. Vehicle | 换电<br>BS | 快充+常规<br>FR+SR | 换电+常规<br>BS+SR |
|---|---|---|---|---|
| Vehicle price<br>(10^4 Yuan) | 15 | 5 | 15 | 5 |
| | | 7.5 | 20 | 7.5 |
| | | 10 | 25 | 10 |
| Fuel cost<br>(Yuan/kilometer) | 0.8 | 0.4 | 0.1 | 0.3 |
| | | 0.6 | 0.15 | 0.4 |
| | | 0.8 | 0.2 | 0.5 |
| OM cost<br>(Yuan/Year) | 10000 | 6000 | 30000 | 8000 |
| | | 5000 | 20000 | 7000 |
| | | 4000 | 10000 | 6000 |
| Recharge convenience<br>(% of current gas station) | 100% | 10% | Car park 100% +<br>Gas station 10% | Car park 100% +<br>Gas station 10% |
| | | 50% | Car park 80% +<br>Gas station 30% | Car park 80% +<br>Gas station 25% |
| | | 70% | Car park 50% +<br>Gas station 50% | Car park 50% +<br>Gas station 55% |
| Recharge time | 5min | 5min | 5min 充满50% + 5H | 3H + 3min |
| | | 10min | 10min充满50% + 5H | 5H + 3min |
| | | 15min | 15min充满50% + 5H | 8H + 3min |
| Policy preference | non | non | non | non |
| | | Pre-paied card | Pre-paied card | Pre-paied card |
| | | Preserved park | Preserved park | Preserved park |

# Estimated Results

*Willingness to Pay (substitute for fuel cost/100 km)*

| | 降低购买价格 *Reduce vehicle price 10000 yuan* | 节约维护费用 *Reduce OM cost 5000yuan/year* | 增加续航里程 *Increase mileage 50km* | 减少常规加能耗时 *Reduce slow recharge time 60min* |
|---|---|---|---|---|
| 全样本*(General)* | * | 11.66 | 9.98 | 10.75 |
| 中收入*(mid-income)* | * | 14.11 | 8.83 | * |
| 高收入*(high-income)* | * | 9.71 | 9.71 | 14.03 |
| | | | | |
| 拥有私家车*(Car Possess)* | * | 10.45 | 9.00 | 3.21 |
| 其中*(among which)*: | | | | |
| 低收入*(low-income)* | 3.99 | * | 12.38 | 41.61 |
| 中收入*(mid-income)* | * | 8.39 | 7.38 | * |
| 高收入*(high-income)* | 3.07 | 28.59 | 24.52 | 35.00 |
| 不拥有私家车*(non car possess)* | * | 12.63 | 10.33 | 19.01 |

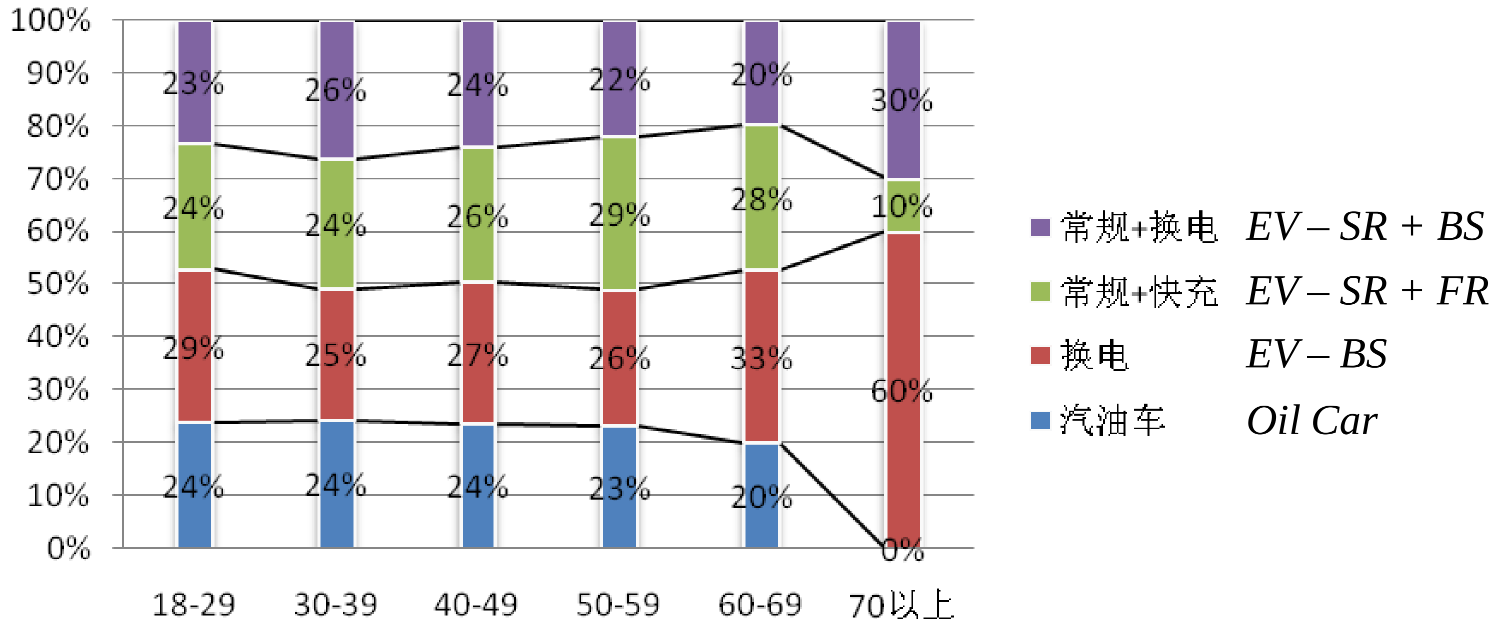
# Economic implications regarding WTP




Investment analysis based on WTP: R&D investment lower than 33.63 million yuan would be profitable (WTP of consumer is 9.98yuan/100km in order to improve the mileage by 50 kilometer, optimistic forecast of EV possession is 36700 to 2015, 10000km/year for each EV => total WTP for 50km increase of mileage would be 36700*10000*9.98/100=3363)

# Consumer Surveys

电动汽车充电模式选择的年龄分布 *The Age Distribution*

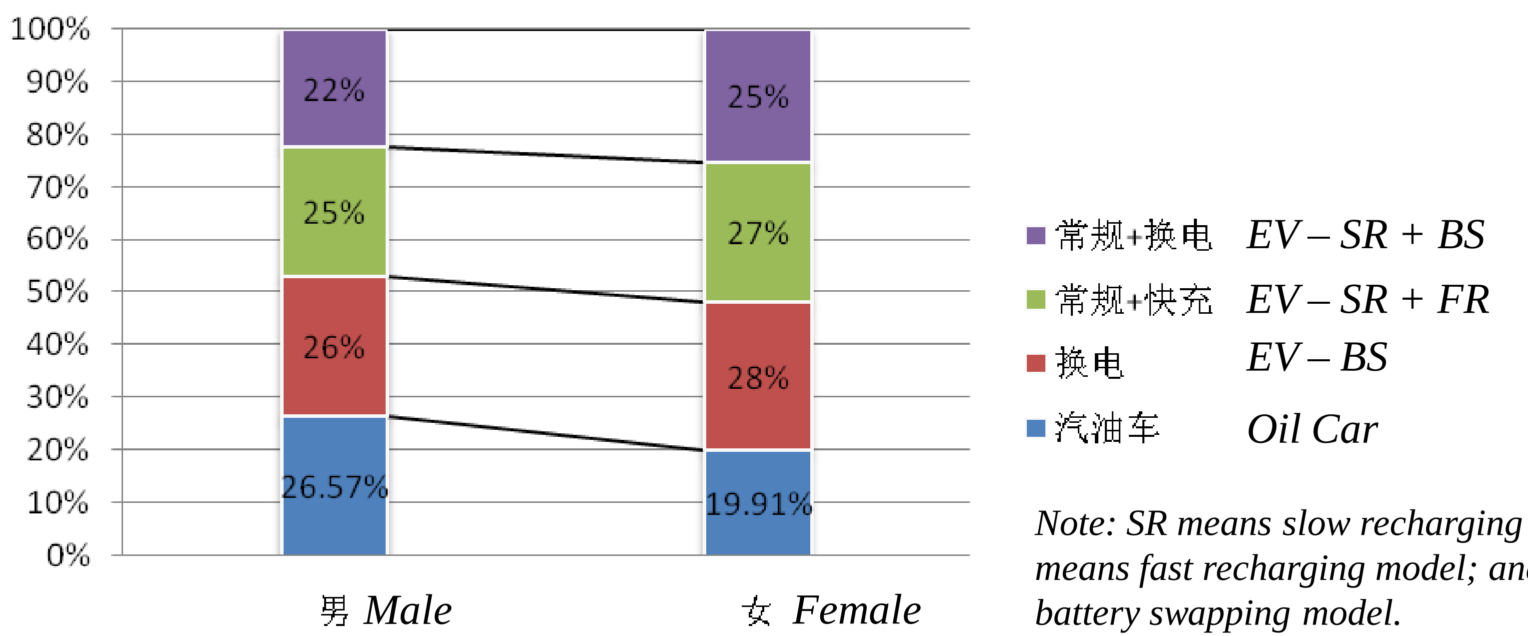



*Key Findings:*

■ Consumers under age 50 are the main forces to buy EV in the future. EV with battery swapping model dominates the group of age 18-29 and age 40-49, while EV with slow recharging and battery swapping model dominates the group of age 30-39. So EV with battery swapping model is most popular among the potential consumers.

# Consumer Surveys

电动汽车充电模式选择的性别分布 *The Gender Distribution*



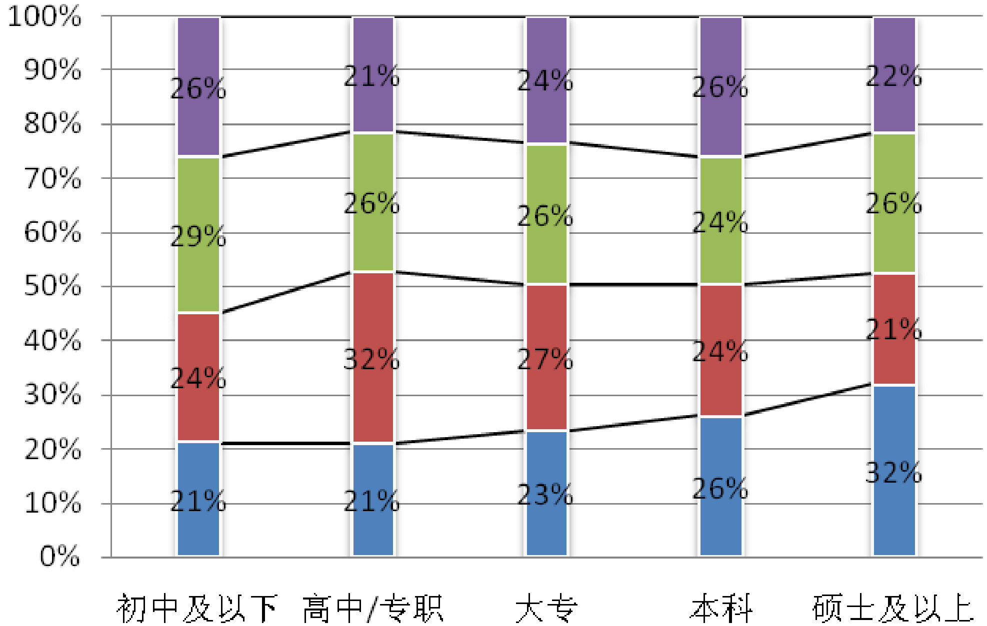

*Note: SR means slow recharging model; FS means fast recharging model; and BS means battery swapping model.*

*Key Findings:*

■ Female is more willing to choose EV than male, mainly because male is more familiar with the car performance thus more difficult to give up oil cars.

# •Consumer Surveys

电动汽车充电模式选择的学历分布　　*The Education Level Distribution*



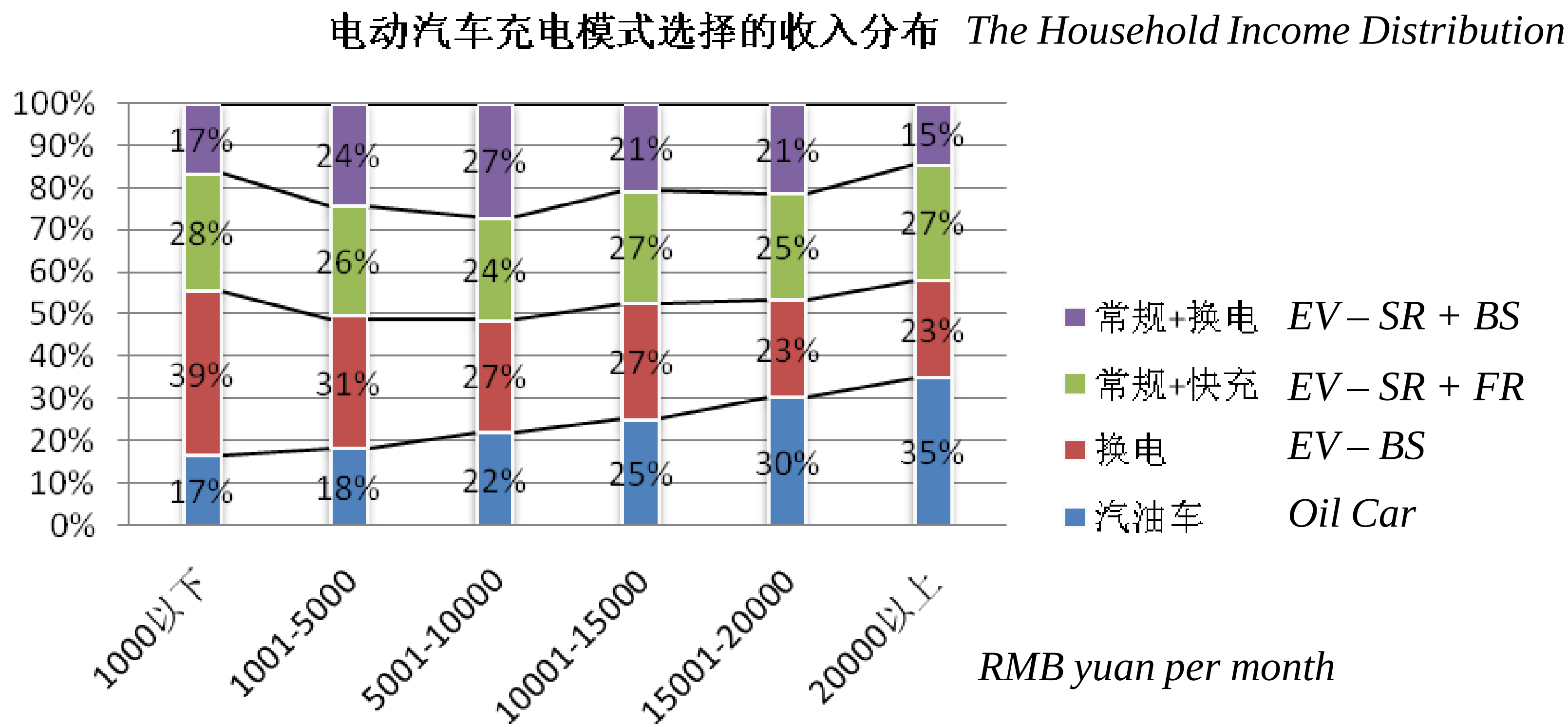

| | |
|---|---|
| ■ 常规+换电 | *EV – SR + BS* |
| ■ 常规+快充 | *EV – SR + FR* |
| ■ 换电 | *EV – BS* |
| ■ 汽油车 | *Oil Car* |

*From left to right: Junior high school or below; high school; junior college; college; graduate school or above.*

*Key Findings:*

■ People with higher education level are more likely to choose oil cars, mainly because they usually have higher income and are less sensitive to prices. They tend to pursue the driving performance and brand effect, thus more reluctant to use EVs.

# Consumer Surveys




*Key Findings:*

- People with higher income are more likely to choose oil cars, mainly because they are less sensitive to prices and tend to pursue the driving performance and brand effect.
- People with lower income prefer to use EV with battery swapping model, which reflects the cost advantage of this model.

# Consumer Surveys

| Main Factors | 影响因子/Coefficient | 显著性/significance |
|---|---|---|
| Investment cost | -0.00000402% | **No** |
| Fuel cost | -0.7292% | **Yes** |
| Maintenance cost | -0.0017% | **Yes** |
| Driving range | 0.1455% | **Yes** |
| Energy supply convenience of EV-SR | 19.78% | **No** |
| Energy supply convenience of EV-FR/BS | -24.80% | **No** |
| Waiting time for EV-SR | -0.13% | **Yes** |
| Waiting time for EV-FR/BS | -8.66% | **No** |
| Administrative measures | NA | **No** |

*Key Findings:*

- Investment cost is not significant but fuel cost and maintenance cost are, which means consumers are more concerned about long-term cost than one-off cost. So the government should subsidize fuel cost and maintenance cost in order to foster the use of EVs.

- Only those who own cars and have lower income tend to consider investment cost as a significant factor when buying cars.

# ➤ Performance Metrics

● *EVs will need to meet various performance-related criteria in order to maximize their market potential. It is urgent for us to identify specific performance metrics in China.*

<table>
<tr><th>Performance Metrics</th><th>IEA’s metrics</th><th>Our metrics</th></tr>
<tr><td>Leverage</td><td>100 km</td><td>150 km</td></tr>
<tr><td>Efficiency</td><td>0.2 kwh/km</td><td>0.3551 kwh/km</td></tr>
<tr><td>Fuel cost</td><td>ICE: USD 0.06/km<br>EV: USD 0.03/km</td><td>ICE: RMB 0.8/km<br>EV-BS: RMB 0.6/km<br>EV-SR+FR: RMB 0.15/km<br>EV-SR+BS: RMB 0.4/km</td></tr>
<tr><td>Acceleration</td><td rowspan="3">should match or exceed that for similar ICE vehicles</td><td rowspan="2">inferior to similar IEC vehicles</td></tr>
<tr><td>Safety</td></tr>
<tr><td>Maintenance cost</td><td>ICE: RMB 10,000/km<br>EV-BS: RMB 5,000/km<br>EV-SR+FR: RMB 20,000/km<br>EV-SR+BS: RMB 7,000/km</td></tr>
</table>

# ➢ Cost reduction criteria

●*The biggest obstacle for developing EVs is the high cost, especially in battery. We need to set targets for the RD&D in battery technologies.*

| 指标 Metrics | IEA设定的目标 | Targets set by IEA |
|---|---|---|
| 比能量 Energy Density | 体积：200 瓦/升<br>重量：100 瓦/千克 | Volume: 200 Wh/litre<br>Weight: 100 Wh/kg |
| 比功率 Power Density | 美国制定的目标是600瓦/升 | U.S. target: 600 W/L |
| 充放要求 Charge Limits | 实现重复深度放电的同时，尽可能降低对电池寿命的损耗 | Designs should allow for repeated deep discharges with minimum battery deterioration |
| 充电耗时 Battery recharge time | 10分钟快充能行驶100公里 | 10 minutes charging for 100 km |
| 电池寿命 Battery life | 2,000-3,000次放电，一般能使用10-15年 | 2,000-3,000 discharge cycles and calendar life of 10-15 years |
| 电池成本 Battery cost | 锂电池成本在2012-15年达到300-600美元/千瓦时，一辆电池容量为20千瓦时的电动汽车，成本造价为6,000-12,000美元 | By 2012-15, lithium-icon battery costs for EVs range from USD 300 to USD 600 per kwh. For EVs with 20kwh of capacity, this yields a vehicle cost of USD 6,000-12,000. |

# preserve scale forecast of EV –case in Shanghai

| 时间 Year | 运营公交车（辆） Bus | 出租车（辆） Taxi | 民用载客汽车（万辆） Car | 常住人口（万人） Residents | 人均收入（元） Distributed Income per capita |
|---|---|---|---|---|---|
| 1996 | 13323 | 38554 | 19.7 | 1451.0 | 8 159 |
| 1997 | 14207 | 40977 | 22.7 | 1489.0 | 8 439 |
| 1998 | 15282 | 41183 | 24.4 | 1527.0 | 8 773 |
| 1999 | 16661 | 42056 | 27.7 | 1567.0 | 10 932 |
| 2000 | 17939 | 42943 | 32.7 | 1608.6 | 11 718 |
| 2001 | 18083 | 46921 | 37.2 | 1614.0 | 12 883 |
| 2002 | 18541 | 47509 | 45.1 | 1625.0 | 13 250 |
| 2003 | 18625 | 48672 | 54.0 | 1711.0 | 14 867 |
| 2004 | 18186 | 44415 | 64.7 | 1742.2 | 16 683 |
| 2005 | 17985 | 47794 | 76.0 | 1778.4 | 18 645 |
| 2006 | 17284 | 48022 | 87.1 | 1815.3 | 20 668 |
| 2007 | 16944 | 48614 | 98.9 | 1858.1 | 23 623 |
| 2008 | 16573 | 48059 | 110.7 | 1888.5 | 26 675 |
| 2009 | 16272 | 49111 | 124.9 | 1921.3 | 28 838 |

**Step 1: Forecast the targeted market size**

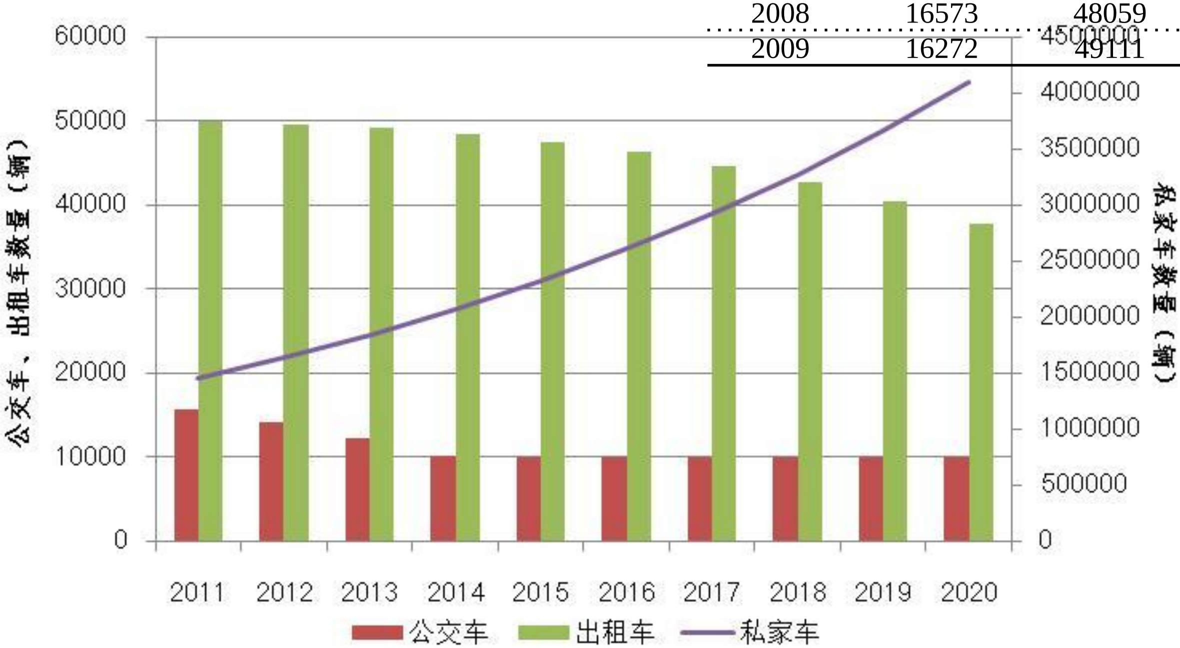
$$BUS = 37.746*POP - 0.76*IN - 34600.564$$

$$TAXI = 39.944*POP - 0.461*IN - 14596.905$$

$$CAR = 0.0217*POP + 0.00469*IN - 52.703$$

$$POP = 36.365*N + 794.519$$

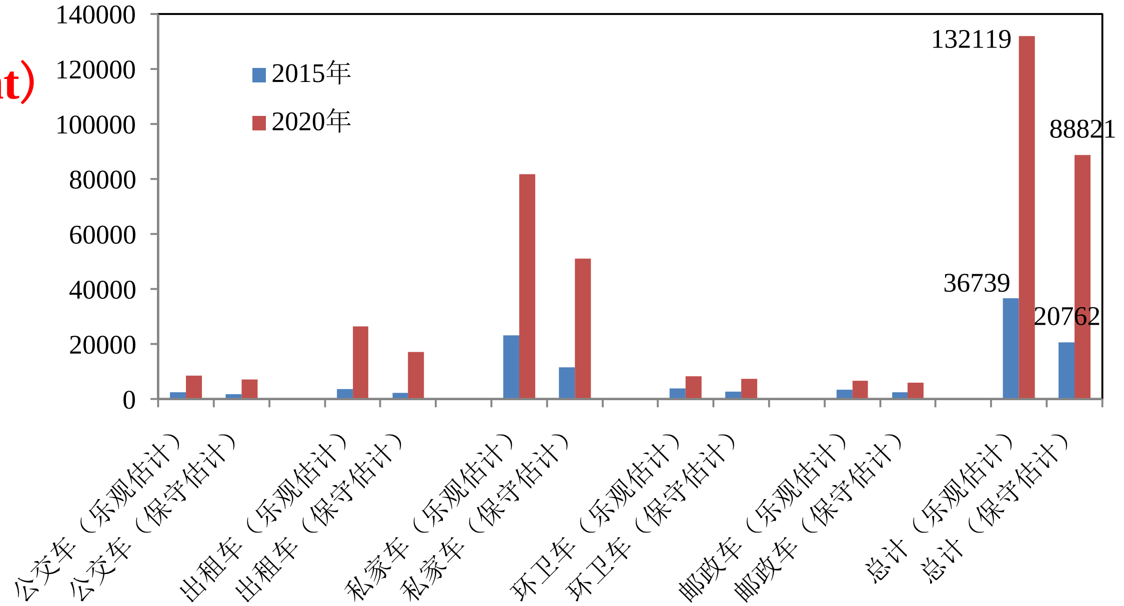
$$IN = 1.118* IN_{t-1} - 190.3671326$$



## 步骤二：保有率预测(Forecast the preserve ratio)

| Target market | | 2010年 | 2015年 | 2020年 |
|---|---|---|---|---|
| taxi | Optimistic | 0.29% | 7.60% | 70.45% |
| | Pessimistic | 0.25% | 4.64% | 45.29% |
| bus | Optimistic | 1.06% | 26.06% | 86.14% |
| | Pessimistic | 0.93% | 17.46% | 71.92% |
| Private car | Optimistic | 0.02% | 1.00% | 2.00% |
| | Pessimistic | 0.01% | 0.50% | 1.25% |

## 步骤三：保有量总额预测(forecast the preserve amount)



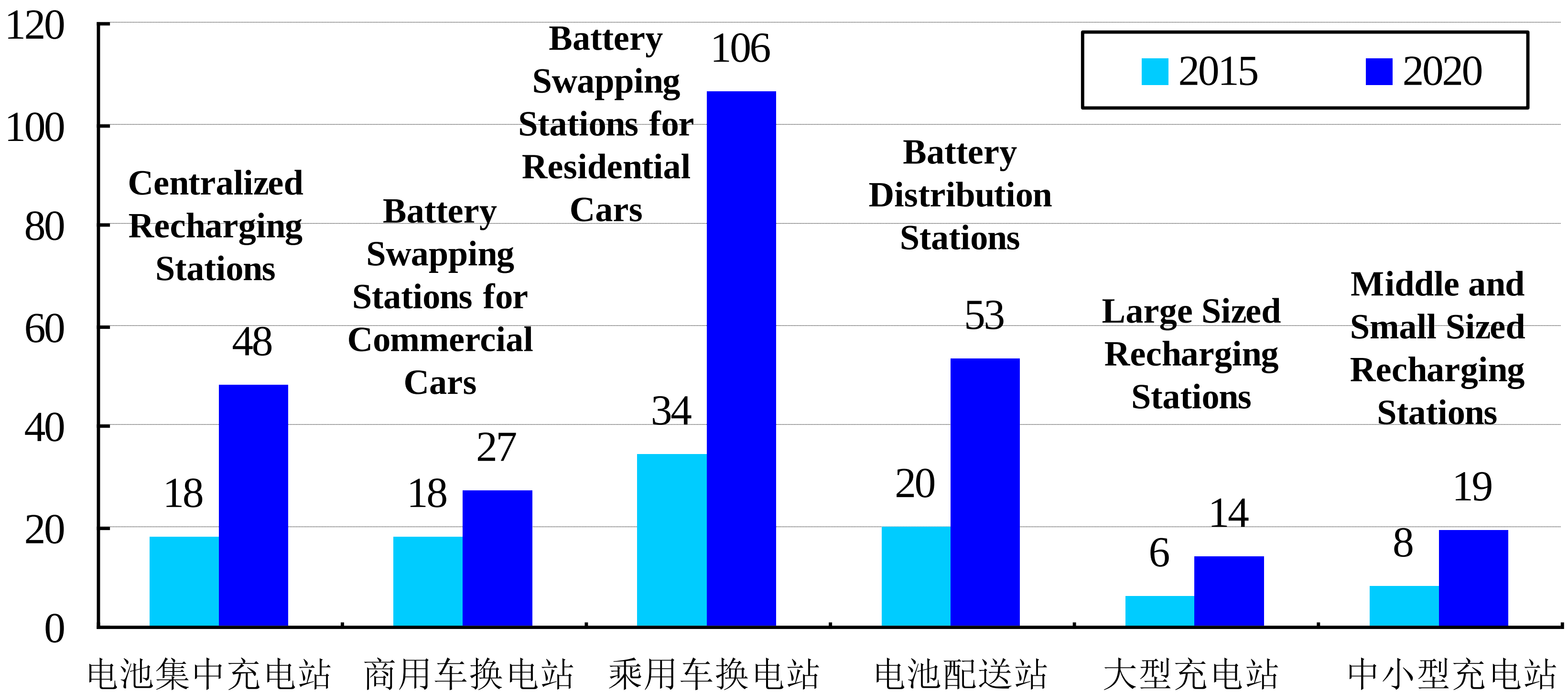
# Recharging Infrastructure

●*Shanghai government plans to improve the infrastructure system to support 20,000 EVs by 2012 and set up a demonstration project in Jiading District to support 30,000 new energy cars by 2015.*

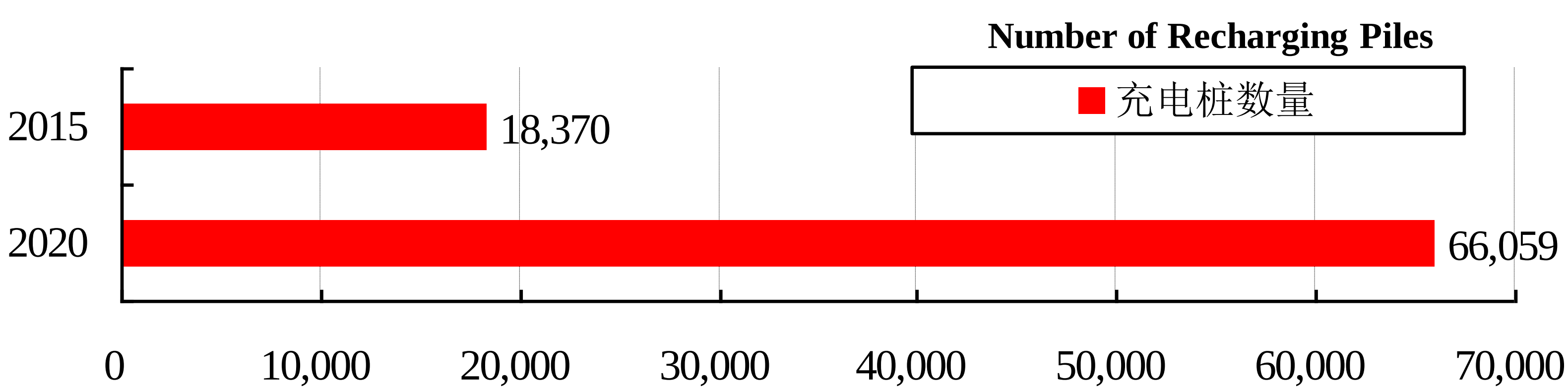
| **2015年上海电力需求预测**<br>**Electricity Demand in 2015** | 公交车<br>Bus | 环卫车<br>Sanitation Car | 邮政车<br>Mail Car | 出租车<br>Taxi | 私家车<br>Car |
|---|---|---|---|---|---|
| 数量 Number | 2,606 | 3,836 | 3,476 | 3,606 | 23,215 |
| 每日行驶里程（公里）<br>Daily driving range (km) | 200 | 40 | 40 | 300 | 40 |
| 续航里程（公里）<br>Driving range of battery (km) | 120 | 120 | 120 | 120 | 120 |
| 出勤率<br>Availability | 0.9 | 0.8 | 0.8 | 0.95 | 0.8 |
| 换电池比例<br>Battery swapping demand | 70% | 55% | 55% | 70% | 40% |
| 每日换电次数<br>Daily swapping times | 1.67 | 0.33 | 0.33 | 2.5 | 0.33 |

| **2020年上海电力需求预测 Electricity Demand in 2020** | 公交车 Bus | 环卫车 Sanitation Car | 邮政车 Mail Car | 出租车 Taxi | 私家车 Car |
|---|---|---|---|---|---|
| 数量 Number | 8,614 | 8,367 | 6,705 | 26,539 | 81,894 |
| 每日行驶里程 （公里） Daily driving range (km) | 200 | 40 | 40 | 300 | 40 |
| 续航里程 （公里） Driving range of battery (km) | 240 | 240 | 240 | 240 | 240 |
| 出勤率 Availability | 0.9 | 0.8 | 0.8 | 0.95 | 0.8 |
| 换电池比例 Battery swapping demand | 70% | 55% | 55% | 70% | 40% |
| 每日换电次数 Daily swapping times | 0.83 | 0.17 | 0.17 | 1.25 | 0.17 |

*EV infrastructure includes centralized recharging stations, battery swapping stations for commercial/residential cars, battery distribution stations, large/middle/small sized recharging stations and recharging piles.*



120
100
80
60
40
20
0
2015
2020
Centralized Recharging Stations
Battery Swapping Stations for Commercial Cars
Battery Swapping Stations for Residential Cars
Battery Distribution Stations
Large Sized Recharging Stations
Middle and Small Sized Recharging Stations
18
48
18
27
34
106
20
53
6
14
8
19
电池集中充电站
商用车换电站
乘用车换电站
电池配送站
大型充电站
中小型充电站

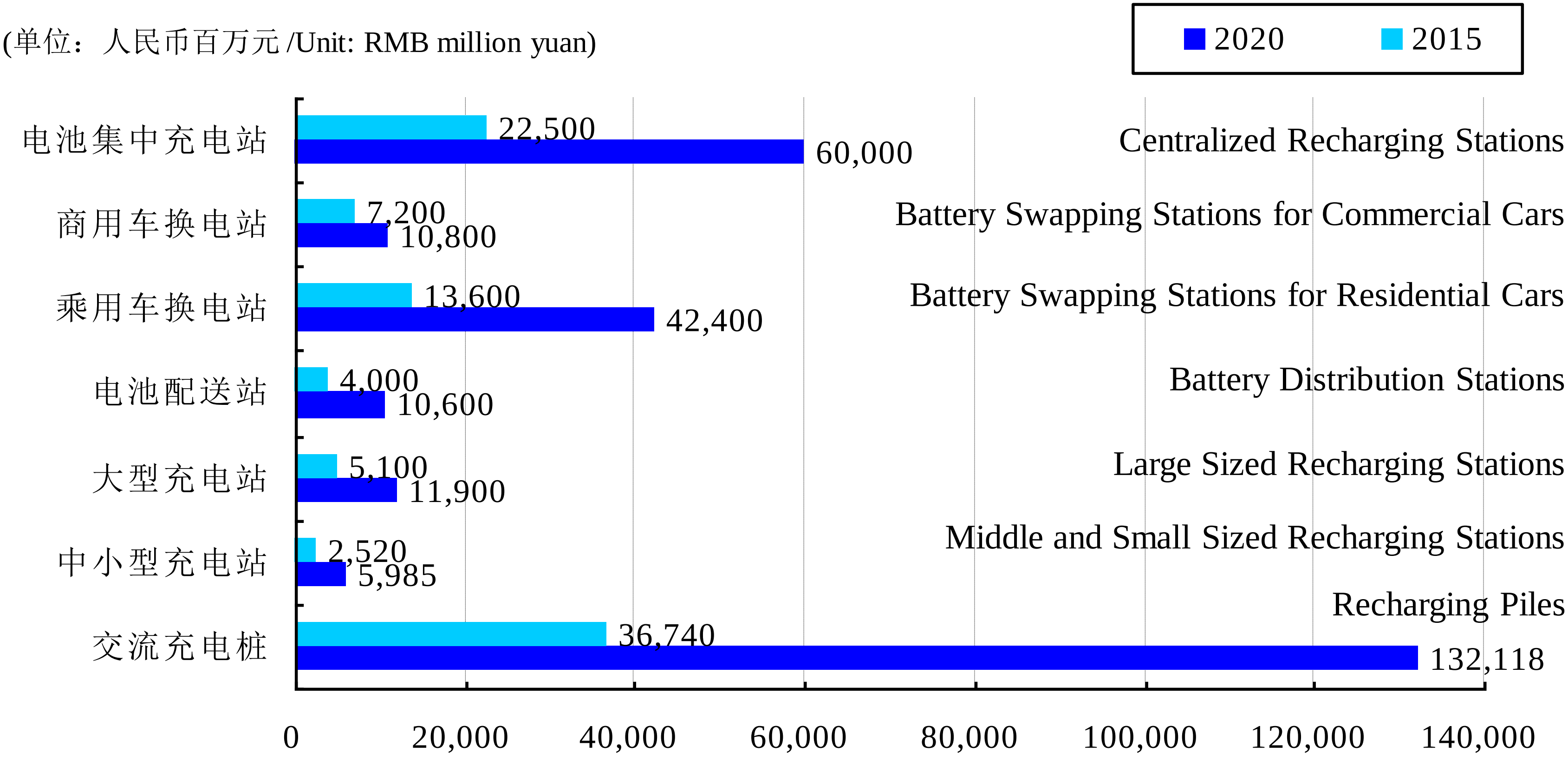



Number of Recharging Piles
充电桩数量
2015
2020
18,370
66,059
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000

● 根据充电设施的数量预测，我们进一步估算出完成这些充电设施建设所需的投资额，在2015年和2020年将分别达到5.5亿元和27.4亿元。

*According to the predicted number of recharging infrastructures, we estimate that the investment needed to build up these infrastructures in 2015 and 2020 will reach 0.55 and 2.74 billion yuan.*

(单位：人民币百万元 /Unit: RMB million yuan)



# ●Promotion model of recharging system

*The construction of EV recharging infrastructures is featured by high one-off investment cost, low returns, long circle and spill-over effect, making these infrastructures more like public utilities. We believe there are three possible business models to build and operate these infrastructures.*

<table>
<tr><th colspan="2">I. Government Dominated Model</th></tr>
<tr><td colspan="2">The government has a leading role in the construction and operation of EV recharging infrastructure.</td></tr>
<tr><td>Pros:</td><td>Cons:</td></tr>
<tr><td>■ Funding guarantee and risk elusion in the earlier stage of project<br>■ Can quickly get human resource, materials and money</td><td>■ Large financial pressure to the government in the later stage of project<br>■ Low efficiency of the recharging station due to little demand in economic interest</td></tr>
</table>

# ●Promotion model of recharging system

| II. Power Company Dominated Model | |
|---|---|
| Power companies include power plants, grid companies and EV-related equipment R&D/production companies.<br>Power companies own the property right of the infrastructure. They can operate the stations by themselves or ask other special agencies to do that.<br>The model also needs the government to support by providing land resources, subsidies or tax reductions. | |
| Pros: | Cons: |
| ■ Extends the investment channel and reduces the financial pressure of the government<br>■ EV-related equipment R&D companies can learn by doing business to improve technology<br>■ Power companies can use current power stations to reduce investment cost and develop smart grid | ■ High investment cost and little customer demand in the earlier stage of project |

# ●Promotion model of recharging system

| II. Oil Company Dominated Model | |
|---|---|
| Oil companies such as Petro China and Sinopec can build recharging stations on the basis of current oil stations. | |
| Pros: | Cons: |
| ■ The location choice of the recharging stations can meet the needs of local car users<br>■ Lower investment cost | ■ Oil companies have less experience in building and operating power infrastructures<br>■ Security risks |

●*We conclude that the power company dominated model is the best way to build and operate the EV recharging infrastructures, while government should give policy support to it and oil companies may attend the construction process. We should also encourage consumers to properly make use of these infrastructures and build up a good environment for EV development in our society.*

***Thank you!***