Risk Analysis of Digital Battery

Application in electric vehicles and power stations

Group 23（Bet on 23）

Company： Volta Institute

Supervisor： Prof. Liao Wang

Group members: Zhang Jiarun, Chen Yutong,
Chen Zhuoyi, Fang Peian,
Gu Yiting, Huang Shuxin,
Lin Xiaojia, Xu Yongbin

Date: 27 May 2024

Outline

Risk analysis

Introduction

MS ENERGY 美克生能源

➢ **Market role:**

a leading domestic safe and low-carbon green energy service provider.

➢ **Products:**

MSE Operating system

Battery pack series

Prognostic Safety System

Portable power station

Household Energy Storage

Industrial & commercial energy storage

VOLTA 伏达研究院

➢ **Market role:**

a non-profit scientific research institute, founded in Shanghai 2022.11

➢ **Research Direction**

BDA (battery design automation) with HKQAI

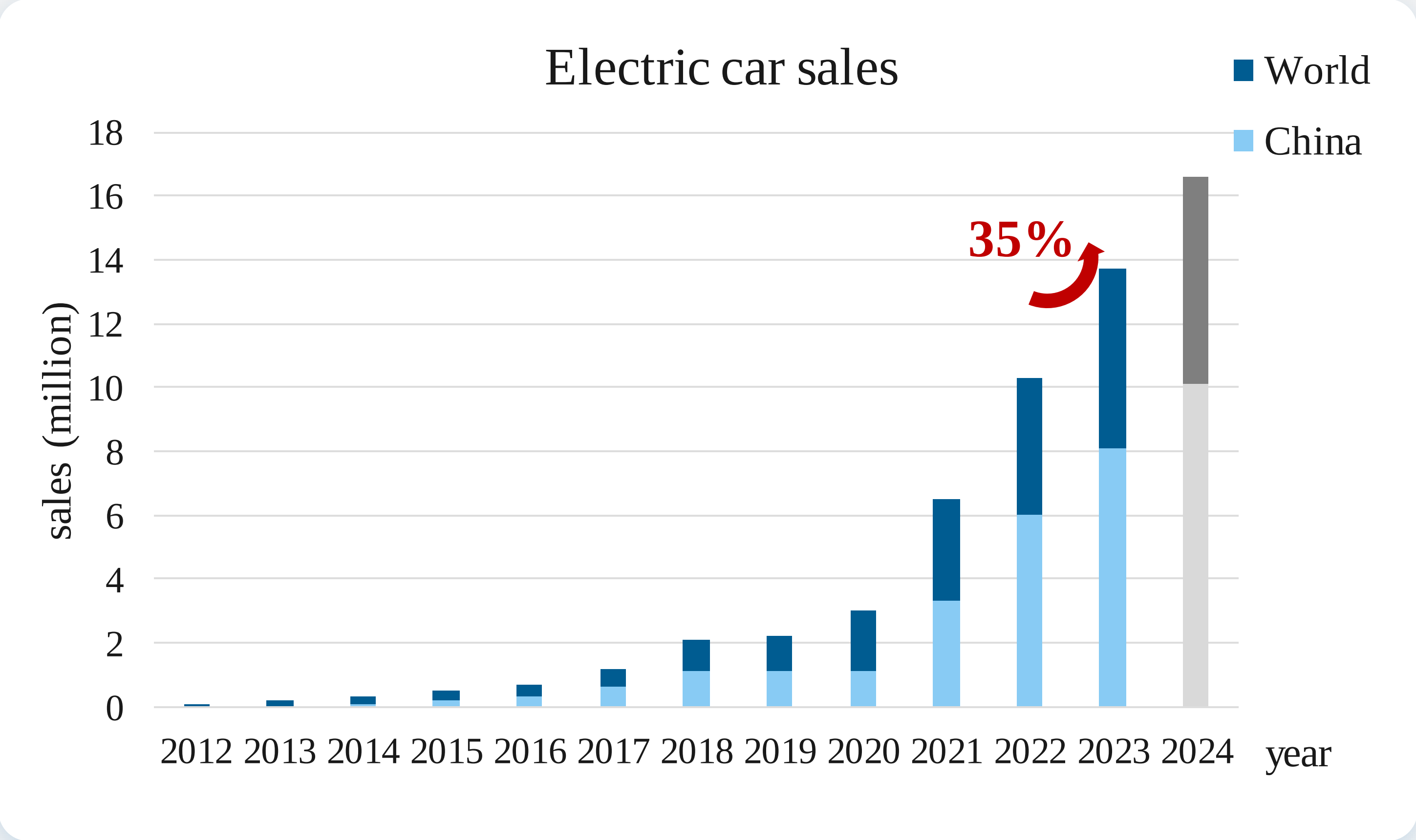
Battery Digital Twins with MS Energy

Virtual Power Plants

Digital **Energy** Finance

Market background

➢ **The market for new Electric Vehicles(EV) is growing rapidly.**



- **In the world:**

14 million new electric cars were registered in 2023.

Electric car sales in 2023 **increase by 35%** in 2022.

- **In China:**

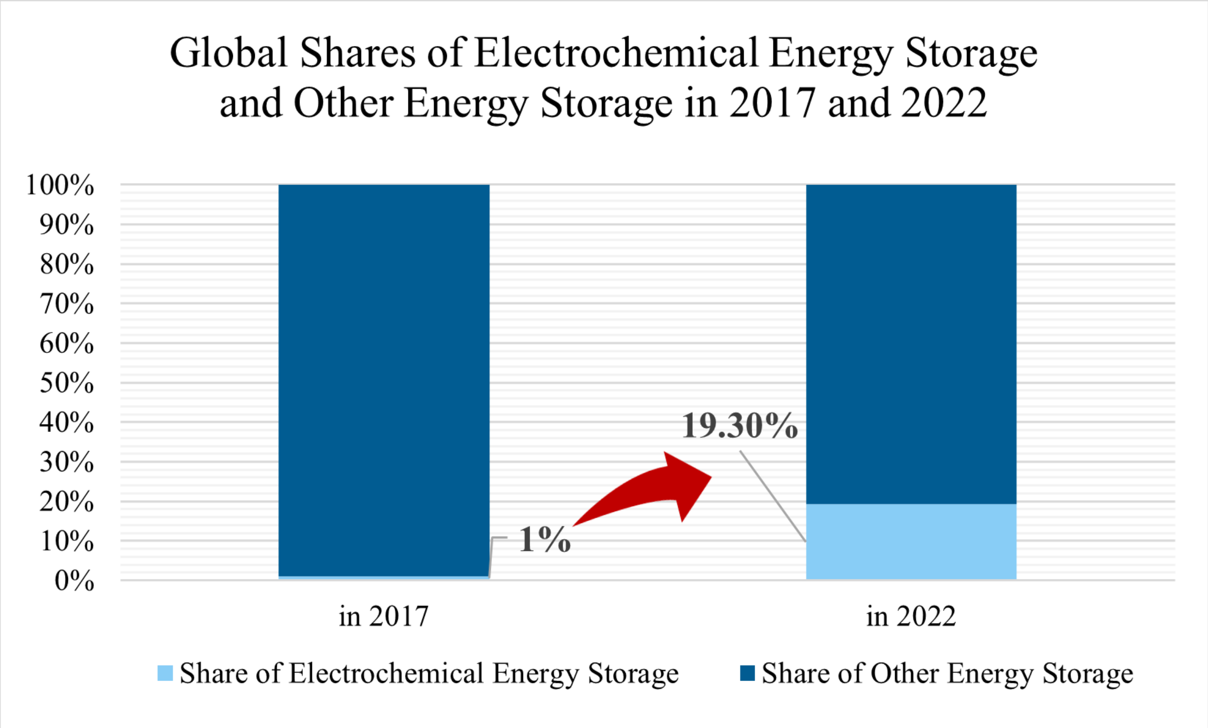
domestic sales of EV in 2023 has an **increase of 6%** from 2022.

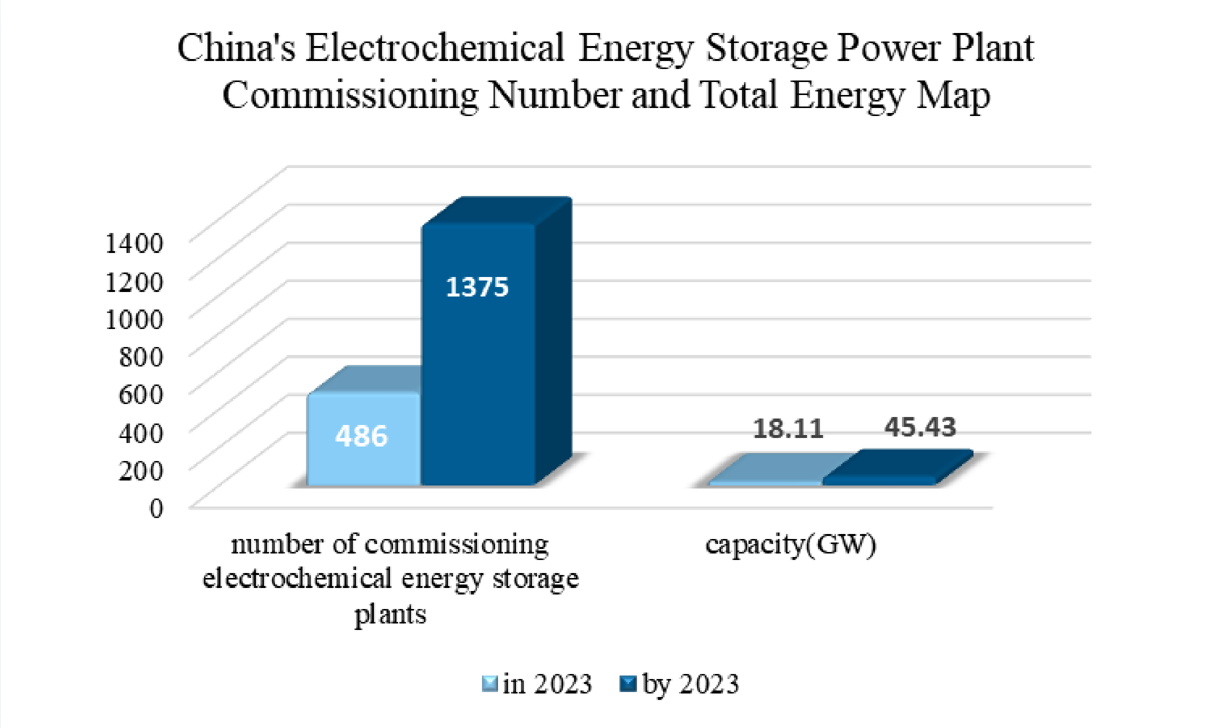
domestic sales of EV **accounted for 31.6%** of total vehicle sales in 2023.

Source:

Market background

- **Electrochemical Energy Storage Power Stations** are experiencing significant growth in the market as an emerging and promising technology.





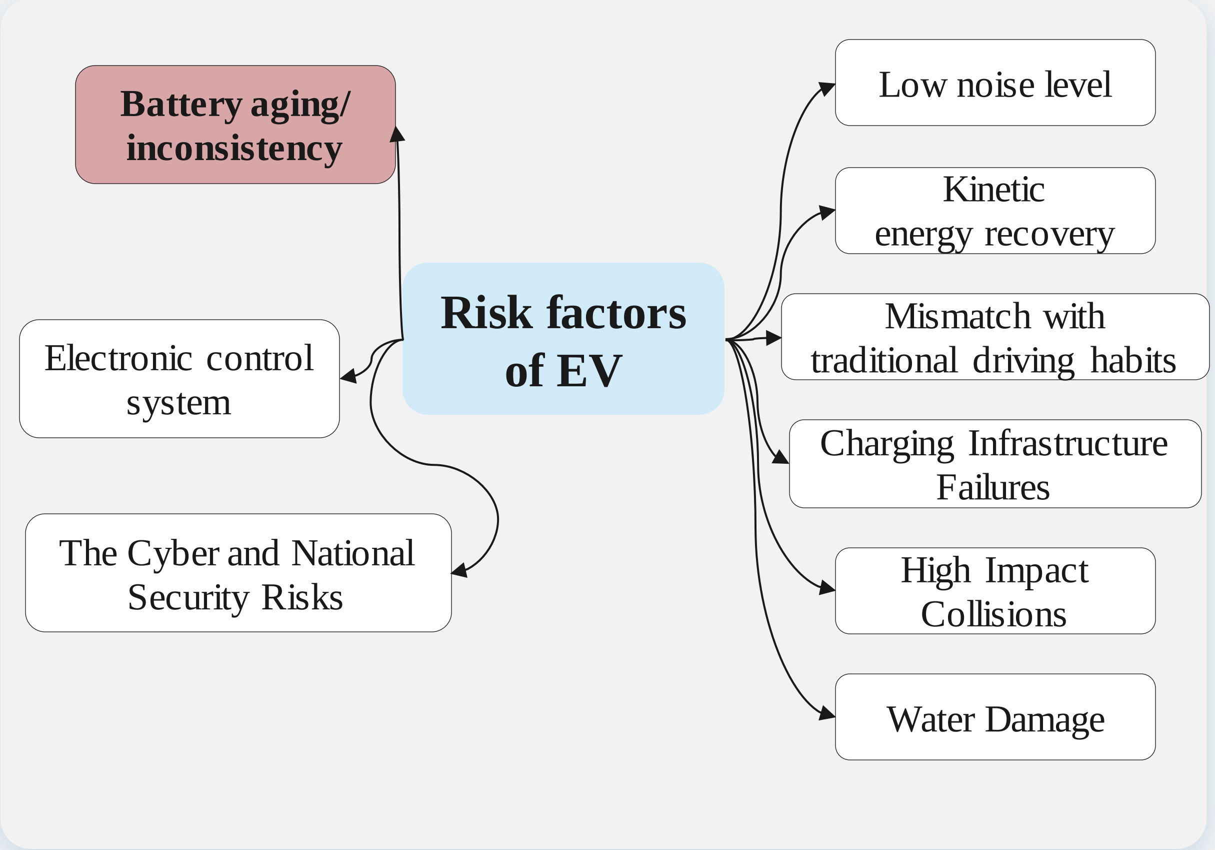
Global market share has grown **from 1% to 19.3%** in five years, showing a remarkable increase.

In 2023, new electrochemical energy storage power plants in China represented **35.3%** of the total commissioned plants up to that year.

Risk factors

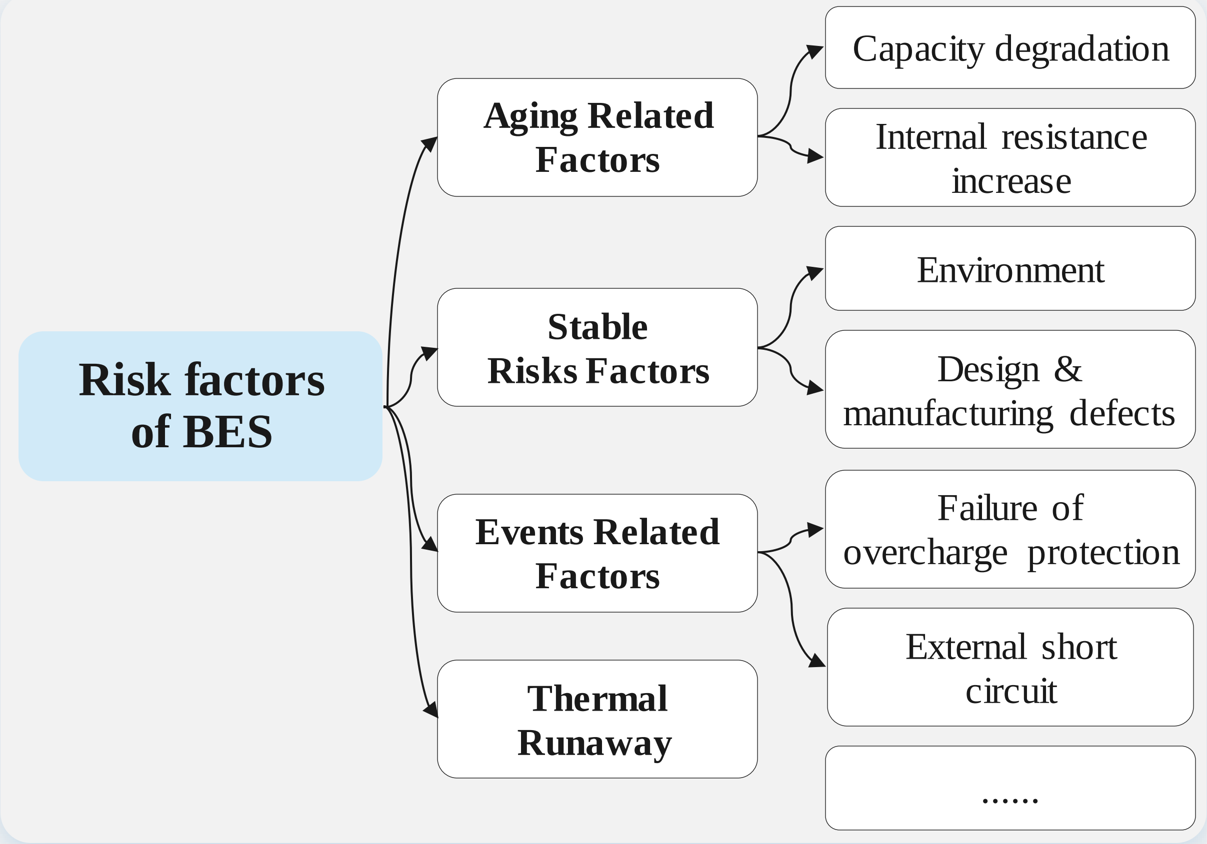
Electric vehicles

➤ Electric vehicles' structure, characteristics and driving modes significantly differ from those of traditional fuel vehicles, leading to changes in risk factors.



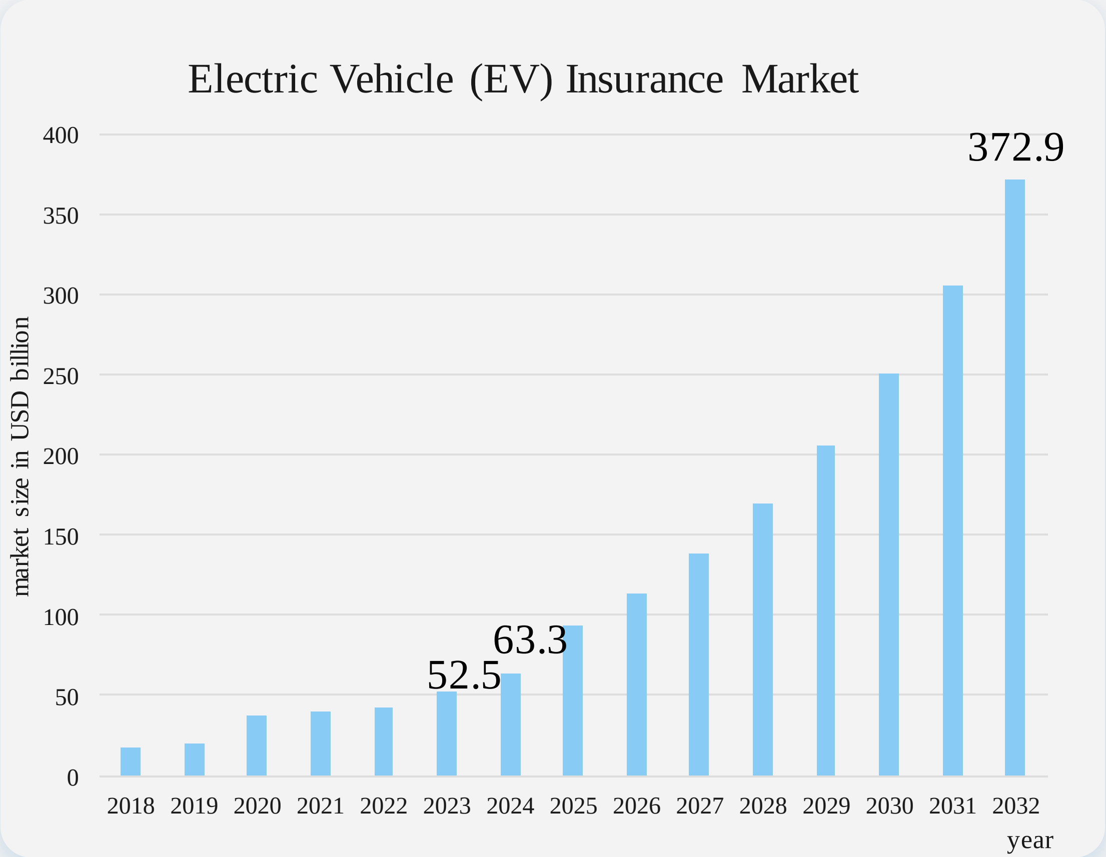
Battery energy storage

➤ Electrochemical energy storage, as a rapidly developing emerging technology, has its unique operational and safety challenges.



Insurance market

- Data indicates that these insurance products currently have a substantial market, and are expected to continue rising in the future.



The market was valued at **USD 52.02 billion** in 2022.

Market is expected to exhibit a **CAGR of 21.8%** during the forecast period (2023 - 2032).

Premium for EV insurance in 2023 has an **increase of 58.86%** from 2022 in China.

By 2025, the domestic premium for EV insurance in China is expected to **account for 17.9%** of the total vehicle insurance premiums.

鼎和保险
DINGHE INSURANCE

Over **¥ 3.5 billion** insured

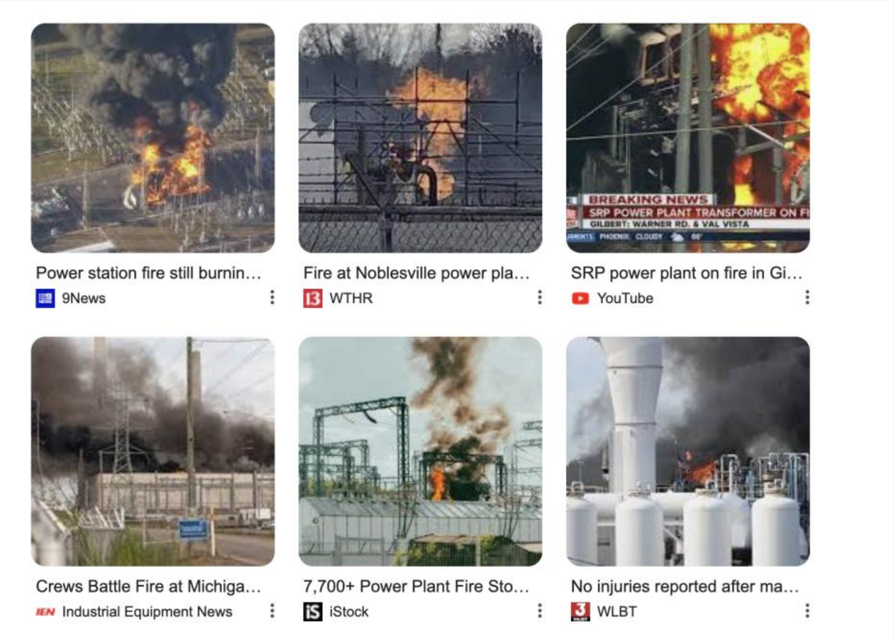
PICC
中国人民保险

平安产险
PING AN PROPERTY INSURANCE

Problems statement

1 Predict the health of the battery

Batteries represent one of the significant risks in new energy vehicles and energy storage stations. By predicting the health of the battery, we can identify and manage the risks.



2 Quantify uncertainty of power station profits

By calculating the Conditional Value at Risk (CVaR) for a power station's daily revenues, we can improve operation management of power stations.

Data

➢ Electric vehicle

A dataset **indicating battery's voltage changes of an electric vehicle at each moment**
Data size: 355271 rows * 169 columns

Fields	• Vehicle status: speed, current, etc • Voltage of 97 cells
Time interval	• From 2017-06-09 to 2021-06-30 • Multiple time points on each date • Include 955 days • Not continuous on daily basis

➢ Power station

A dataset **indicating voltage changes of a power station in Shanghai at each moment**
Data size: 1048575 rows * 7 columns

Fields	• Station status: power quantity, current, etc • Voltage of 240 cells
Time interval	• From 2021-12-01 to 2023-02-04 • Multiple time points on each date • Include 343 days • Not continuous on daily basis

Metrics

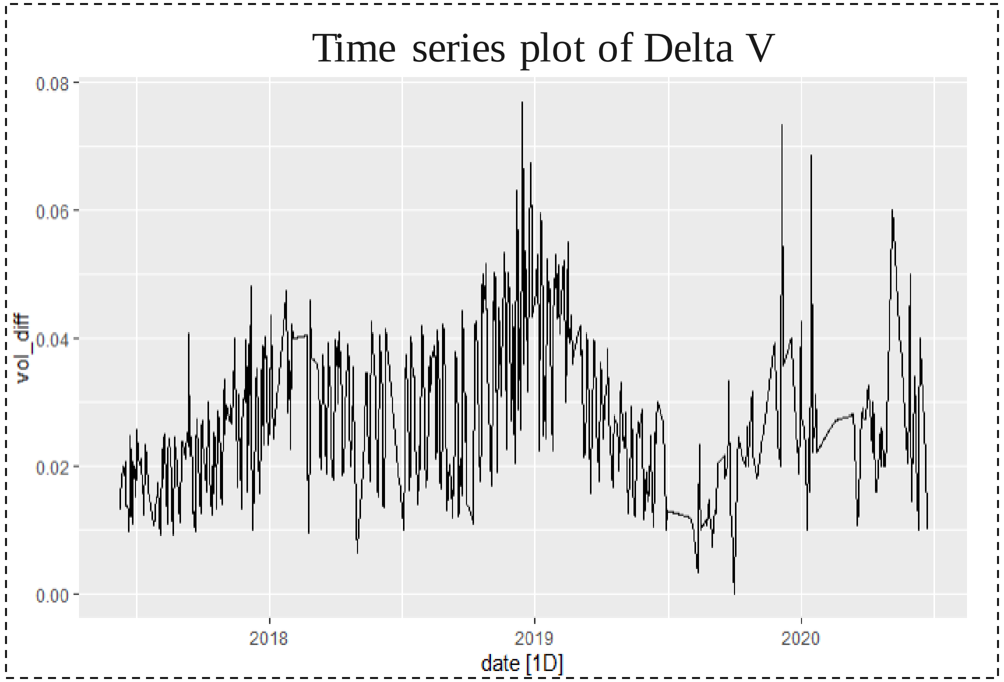
Construction of 3 metrics

- **Purpose :** Measure performance of battery package to recognize the abnormal cell

Delta V (V)	Voltage difference in a battery pack.
Delta T (s)	Time difference between the first cell and the other cells to reach the cut-off voltage.
SOH (%)	State of Health, defined as the current charging capacity.

Time series analysis

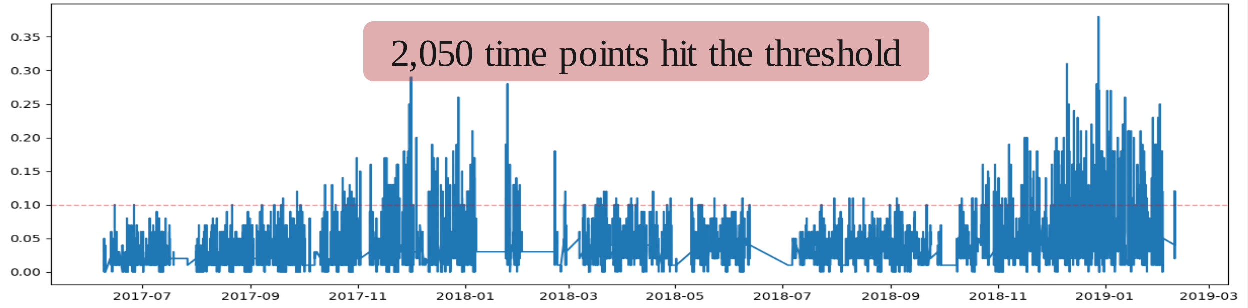
- **Purpose:** Forecast the future performance



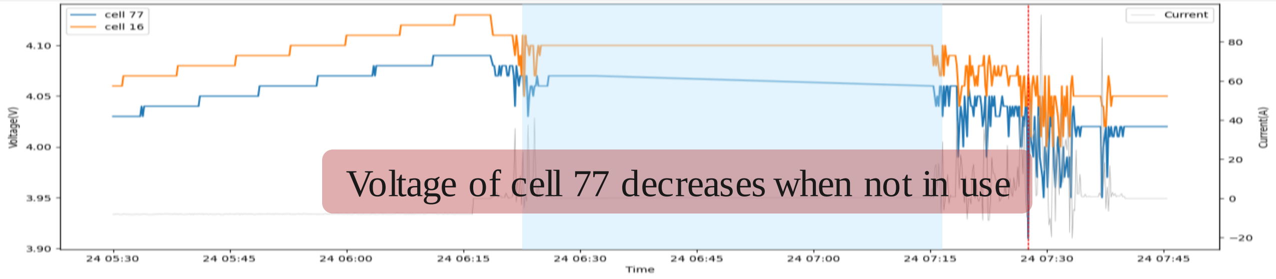
Metric 1 - Delta V

$$\boldsymbol{Delta\ V} = V_{middle} - V_{min}$$

Measures the voltage inconsistency of the electric vehicle battery



Delta V Over Time From 2017 to 2019



Voltage comparison between cell 77 and 16 on 2017-11-24

Multiple self-discharge processes of Cell 77

Date	Voltage decline	Duration	Rate
2017-11-24	0.01v (10mV)	45 min (0.75 h)	13.3 mV/h
2019-05-20	0.03v (30mV)	35 min (0.58 h)	51.7 mV/h

Insights

Abnormal cell 77

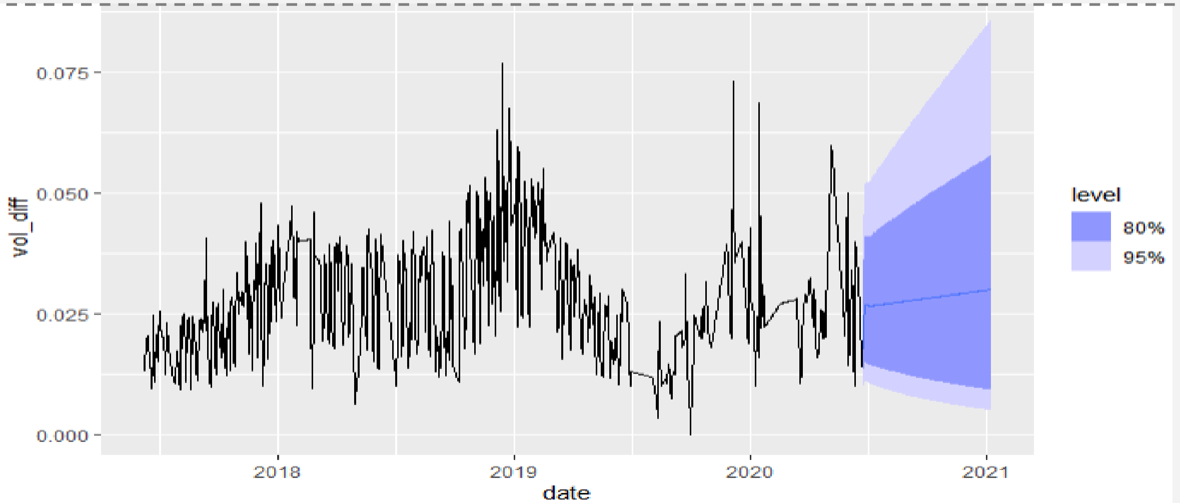
- Reached V_{min} many times
- Existed self-discharge processes
- Increased self-discharge rate

Significance

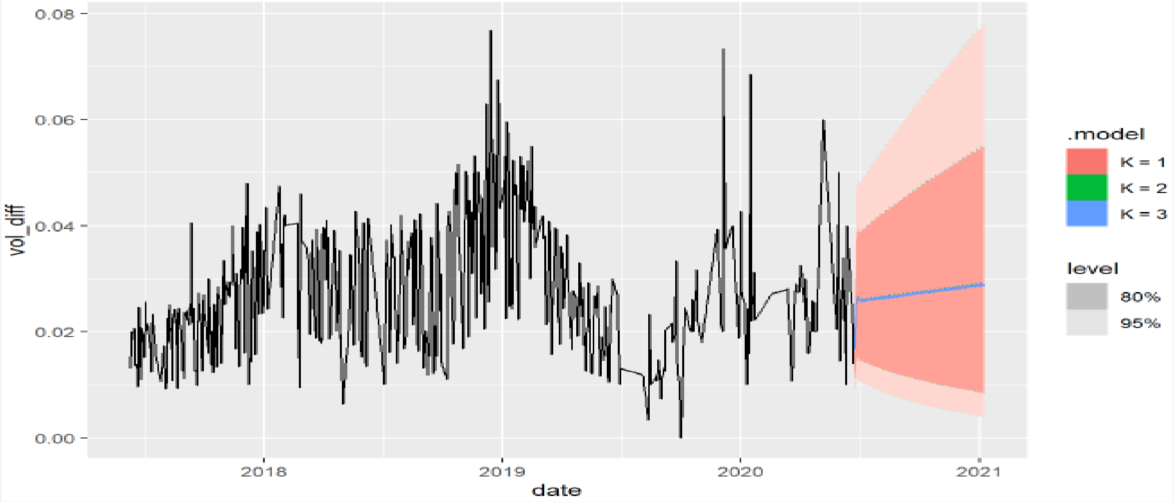
- Possible to detect abnormal cells, and further analyze their self-discharge processes
- Helps to monitor battery performance, enable preemptive intervention, and reduce safety risks

Metric 1 - Delta V

Delta V 200 days forecasting



ARIMA (2, 1, 2)



Dynamic harmonic regression with Fourier pairs 1 to 3

Insights

- Voltage inconsistency of the battery increases with time.
- The performance of the battery will decrease.

Significance

- **Electric vehicle owners** can maintain the battery in advance to reduce potential risks.

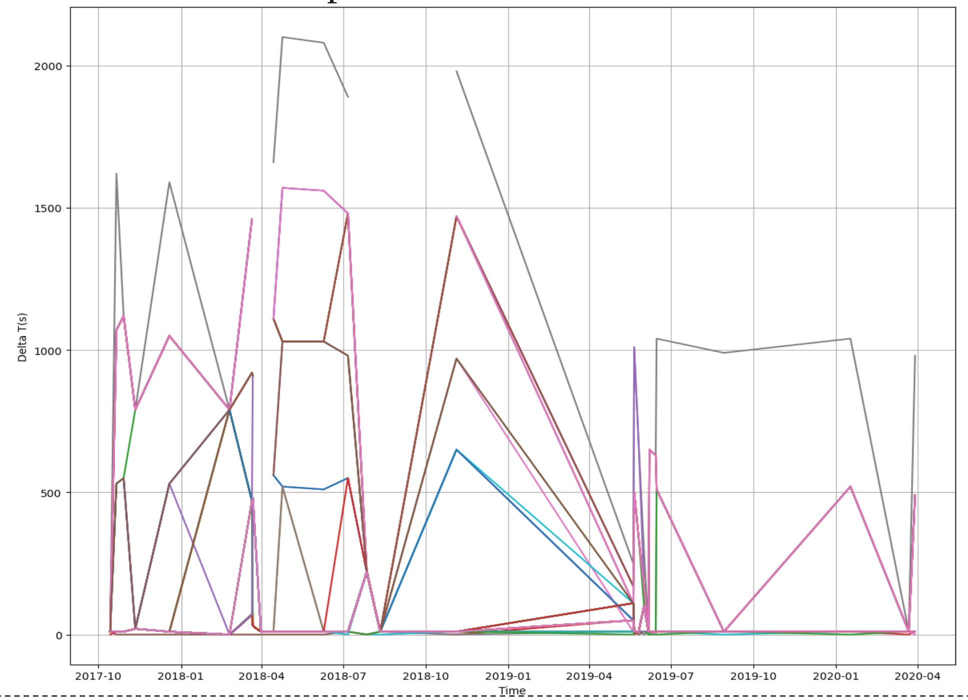
- **Insurance companies** can better manage the insurance plans given the risk identification and forecasting of the battery performance.

Metric 2 - Delta T

Overview

Definition:
time difference between the first cell and the other cells to reach the cut-off voltage.

Time series plot of the Delta T of each cell



Limitation

1. Insufficient data

Fail to **extract a proper charging process** on each date to calculate delta T of the electric vehicle.

2. Poor indicator

Low data volume, discontinuity in time, and high volatility, lead to its limitation as an indicator to **forecast future risk.**

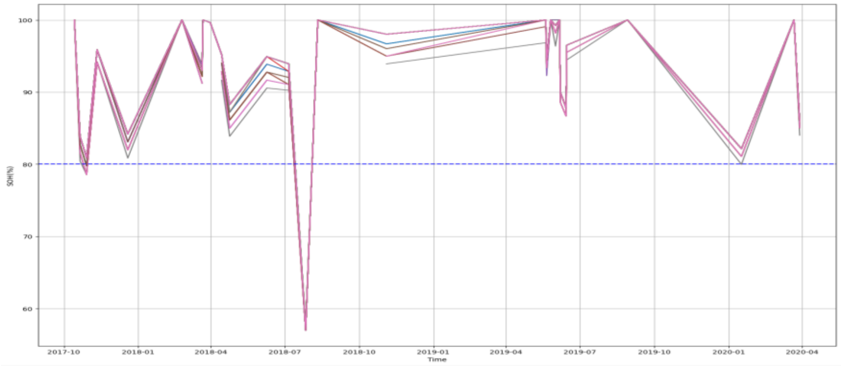
Metric 3 - SOH

Overview

Definition:

SOH (state of health) shows the current charging capacity of the battery package.

SOH variation of each cell



Calculation logic：

For the first cell reaching the cutoff voltage,

$$\int_{t_0}^{t_1} I\,dt = Q_1, C_1 = \frac{Q_1}{SOC_1 - SOC_0}, SOH_1 = \frac{C_1}{C_0} \times 100\%$$

For the other cells (cell i),

$$Q_i = Q_1 + I \times \text{Delta Ti},$$

$$C_i = \frac{Qi}{SOC_1 - SOC_0}, SOH_i = \frac{C_i}{C_0} \times 100\%$$

where Ci refers to the capacity of cell i, C_0 refers to the rated capacity

Limitation

1. Low accuracy in SOH calculation

Due to the uncertainty in the metric State of Charge (SOC) provided by the BMS, the SOH calculation has low credibility.

2. High Volatility in SOH

Despite the possibility of some accidents and repairs, SOH calculated **has huge volatility.**

CVaR of power station's profits

Background: Power stations earn by discharging (selling electricity) with high electricity prices and charging (buying electricity) with low prices

Goal: Quantify the uncertainty of plant profits for risk reduction management

Task: 1) Derive profit from peak load dispatching; 2) Explore relationship between conditional value at risk (CVaR) for profit, confidence level, and plant operating index

Stakeholder: 1) Insurance product manager; 2) Investors with different risk appetites; 3) Power plant operators

Daily profit from peak load

Recognize daily **discharging and charging cycles** and work out the **energy** (voltage × current) **integrals** respectively, then multiplied by **electricity price** and take the difference.

Energy Integral

Mark Status

- **Charging:** cluStatus=2, current<0, voltage↑
- **Discharging:** cluStatus=3, current>0, voltage↓
- **Neither**: cluStatus=4, current=0, idle→

⇩

Define a Cycle

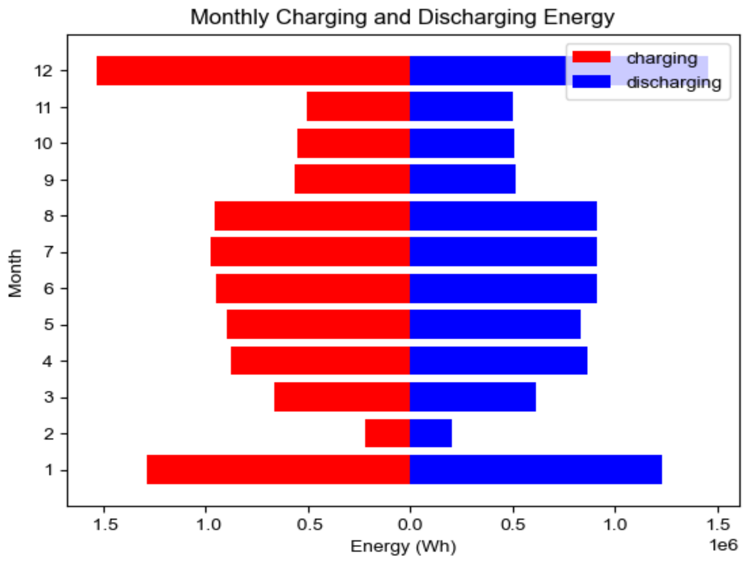
- Large currents tend to be followed by tiny currents → Take **10s as an interval.**
- Status the same for less than 10 sec, accumulate
- Interval > 10 sec, restart time and integral

Periodic Electricity Price

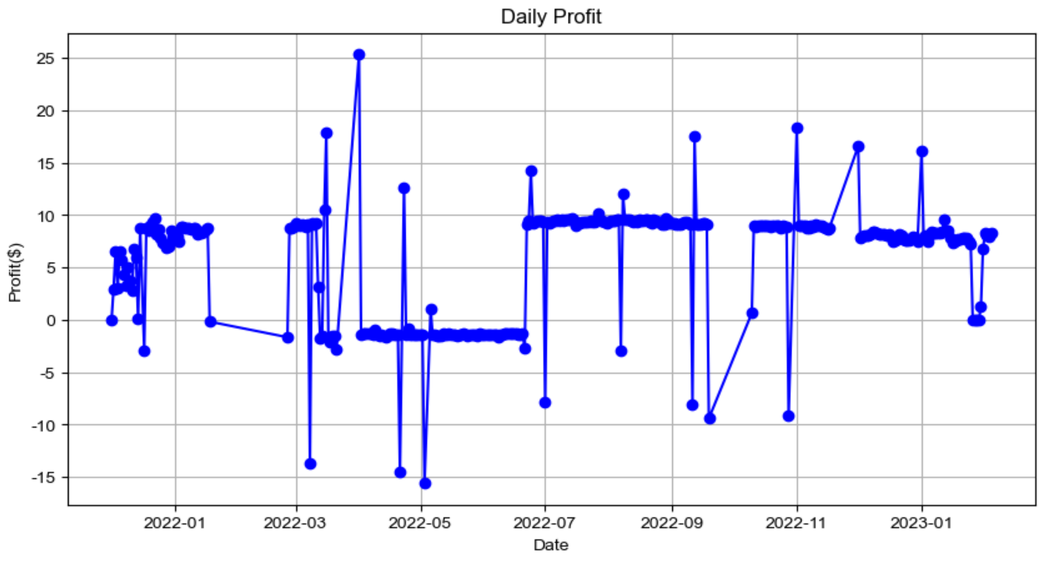
Shanghai industrial & commercial electricity tariff table

¥ / kWh	**Peak Time** (6:00-22:00)	**Off-peak Time** (22:00-6:00)
Summer (Jul, Aug, Sep)	0.853	0.423
Other seasons	0.825	0.396

Daily profit CVaR



Monthly energy utilization rate (discharge/charge ratio) is about **95%**



Monthly

Jul, Aug, Nov most profitable.
Mar, Apr most fluctuated.

Daily

Top 20

- 11 in summer;
- Utilization at least 0.96;
- 97% dischargings (revenue) done in peak

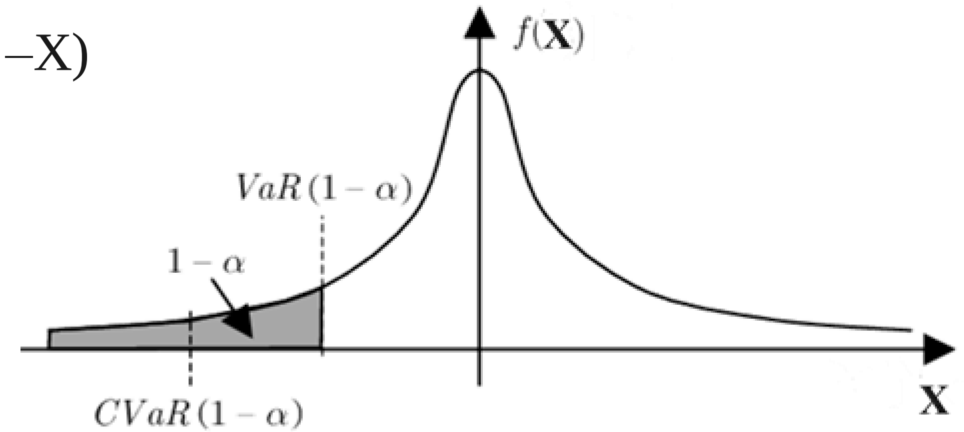
Bottom 20

- Most utilization below 0.5;
- 87% chargings (cost) done in peak

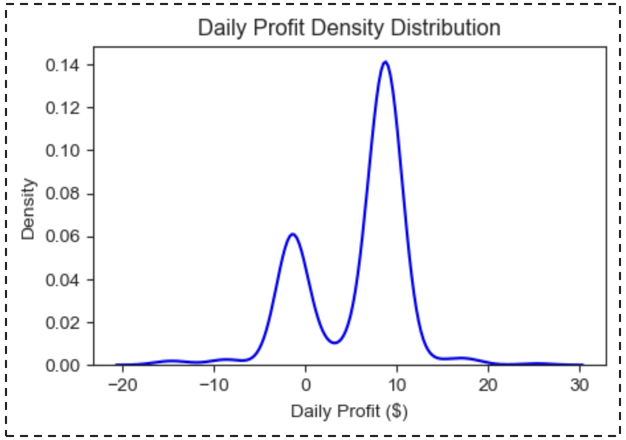
Assume that daily **loss** is the random variable X (daily profit is –X)

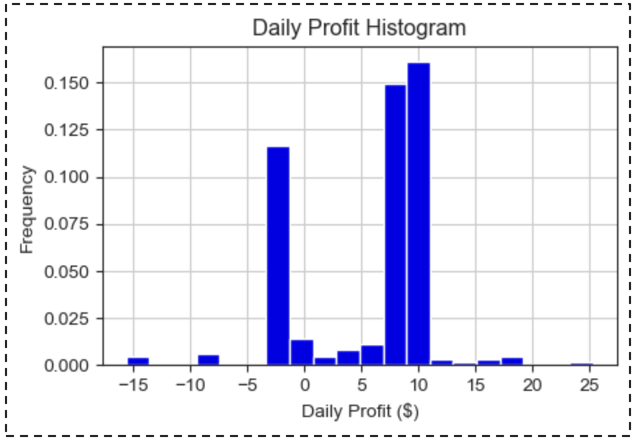
VaR — **The minimum loss** of a random variable at a given confidence level 1-α.

CVaR — **The expected loss** of a random variable that **exceeds VAR** at confidence level 1-α.

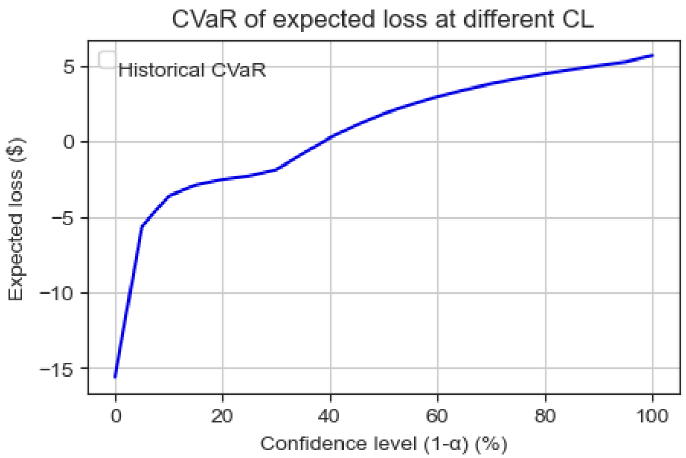


Relation between CVaR & CL

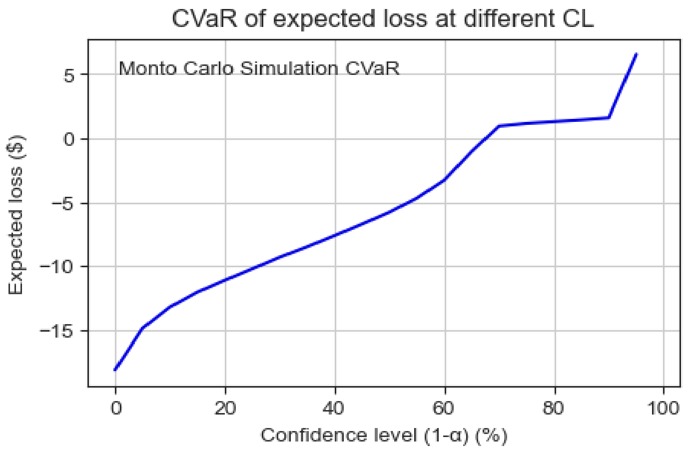




Method 1. Use historical profit



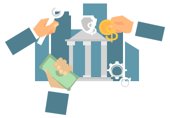
Method 2. Assume distribution is Mixed Normal, iterate best parameters using GMM



Insights

Investor: A **small upward** trend after 30% CI for M1; high tail risk within 95%-100% CI for M2.

Operator: alarm bell for **demand or battery performance** changes; emergency plan for high CL

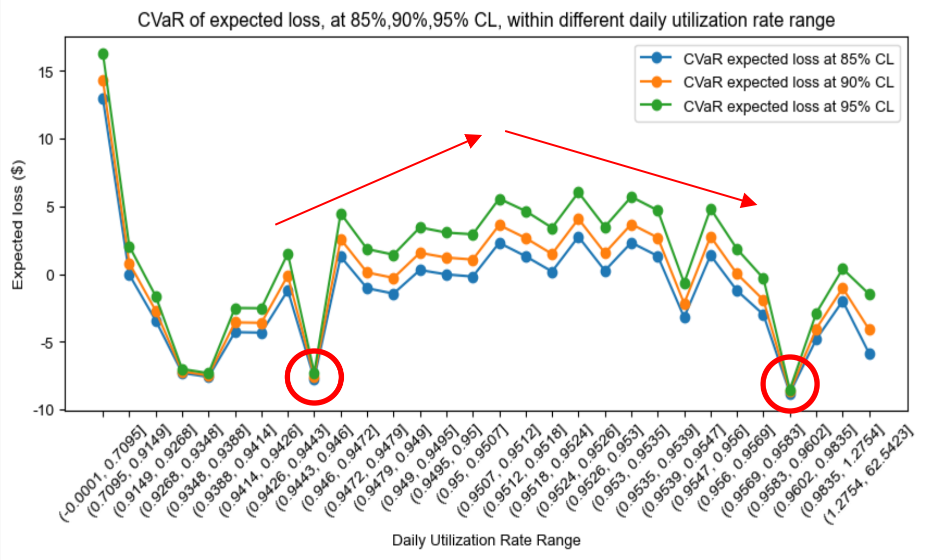


Manager: hedging strategy; peak regulation strategy to balance returns and risks

Relation between CVaR & Operation

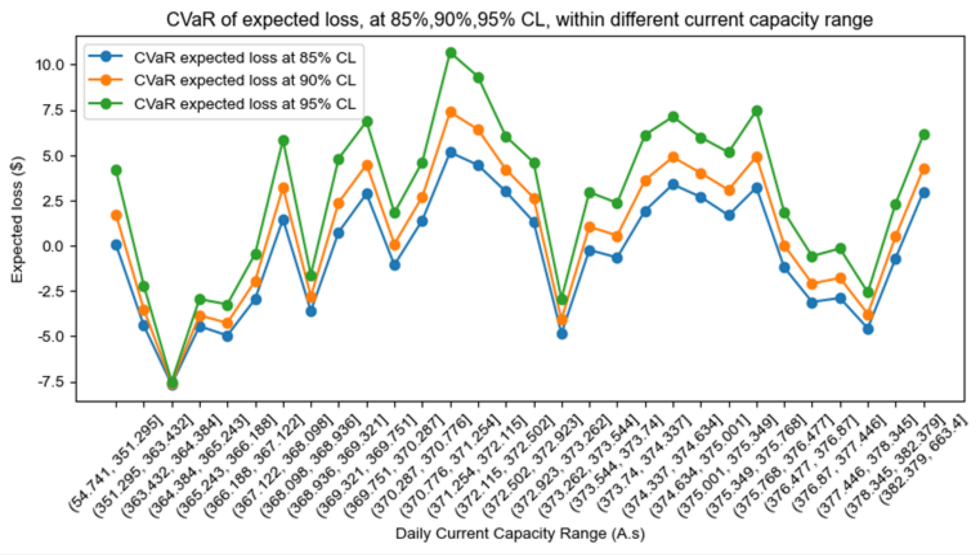
➢ CVaR and utilization rate (UR)

Sort daily utilization rate (discharge/charge), then group by quantiles. Calculate CVaR within each sub-group.



➢ CVaR and current capacity (CC)

Extract the longest daily charging period and get current battery capacity (current integral divided by delta SOC).



Insights

- **Two earning points:** the dates are close, draw lessons from charging-discharging strategies.
- **Non-linear relation:** increase utilization not necessarily increases profits, due to market fluctuations. Consider dynamic charging-discharging strategy to balance profit and utilization.

Insights

- Expected loss surges at **two ends** of battery health ranges, requiring more frequent maintenance.
- **Overall fluctuated:** only 0.23% of the dates are fully charged, could maintain durable charging process to find optimal battery capacity; and develop more reasonable charging rules to smooth profit fluctuation.

Conclusion

Our work

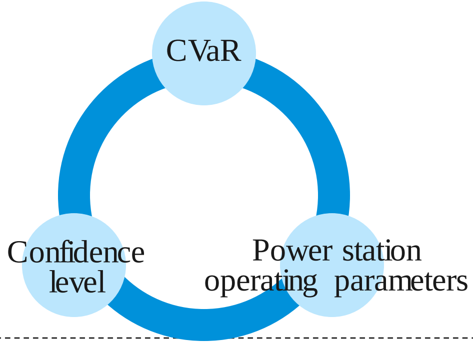
➢ **Construction of risk factors of electric vehicles and battery energy storage**

➢ **Prediction of battery health level**

Times Series Analysis

Delta V | Delta T | SOH

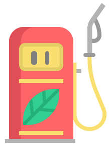
➢ **CVaR analysis of power station profit**



Significance

For insurance company:
- Precise identify and control battery risks
- Improve business screening and pricing

For electric vehicle owners:
- Regular alerts for vehicle anomalies
- Reduce the likelihood of incidents like fires



For energy storage station operators:
- Revenue monitoring, early warning
- Optimize operation: charge and discharge rates, and battery capacity

For energy storage station investors:
- Indicator for the risk level of investment projects
- Better allocate resources to improve ROI

Thanks for listening!

Group 23（Bet on 23）