Research on carbon footprint of power batteries for new energy vehicles based on trusted data space technology

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ABSTRACT

To address fragmentation of data and substantial inaccuracy in carbon footprint accounting for traction battery systems of new energy vehicles, as well as to enable precise identification of critical paths for emission reduction across the life cycle, a trustworthy data space architecture was constructed in this work. A systematic analysis of the full-life-cycle carbon footprint of traction batteries was conducted by use of the proposed architecture. It was found that data integration efficiency was increased by over 65 percent through the adopted framework. Carbon footprint accounting error was reduced from 18 percent to below 5.2 percent. Verification pass rate was achieved at 99.3 percent. The average carbon emission of the full life cycle was measured at 850 to 920 kg CO_2e per kWh. The production stage was shown to contribute more than 70 percent of total emissions. Within production, the drying process was identified to account for 32 to 38 percent of total energy consumption, with its share in carbon emission estimated at 29 to 35 percent. Site selection at higher latitudes was observed to lower energy use in this process by 15 to 20 percent. At material level, cobalt-based ternary materials were indicated to generate 105 to 140 percent more emissions than lithium iron phosphate. Upstream material emissions were assessed to represent 45 to 52 percent of the whole-life-cycle carbon output. Support of accurate quantification and scientific basis for decision-making were provided by this study. Contributions were made to low-carbon transition of the traction battery industry, optimization of supply chains, and alignment with international carbon compliance requirements.

Keywords: New energy vehicles, trusted data space, battery, footprint

1. INTRODUCTION

Data indicates that for 2025, China's new energy vehicle production is estimated to be approximately 16.7 to 16.8 million units, with sales around 16.5 to 16.6 million units, representing a year-on-year growth of about 30% to 32%. The market penetration rate is projected to reach about 53% to 54%, accounting for over 65% of global sales [1~2]. Power batteries are considered core components of new energy vehicles. A weight proportion of over 30% is exhibited by them, and a cost proportion exceeding 40% is also shown. The low-carbon attribute of new energy vehicles is directly determined by the carbon emissions across the full lifecycle of power batteries. Multiple stages including mineral extraction, material production, cell manufacturing, battery pack integration, use, and recycling are covered by the full lifecycle of power batteries. Carbon emissions of varying degrees are present in each stage. Precise accounting and management of the carbon footprint are made the cornerstone of the green and low-carbon transition in the new energy vehicle industry. It is estimated by the International Energy Agency (IEA) that about 45 million units of global new energy vehicle sales are required by 2030 to achieve the UN 2030 Sustainable Development Goals. Strong support for global carbon emission reduction is provided by the sustained development of China's new energy vehicle industry, as China is the world's largest new energy vehicle market. The key prerequisite for the effective functioning of this support is seen as precise control of the carbon footprint of power batteries. Variations in carbon emission from battery manufacturing are observed among different countries. As shown in figure 1, the carbon emission of batteries is influenced by the electricity mix in respective nations. Comparisons are made to reveal disparities in emission levels. Data are presented to facilitate an understanding of regional differences. Some inconsistency may be noted owing to local energy structures. Insights are offered into how national contexts shape emission outcomes [3~5].

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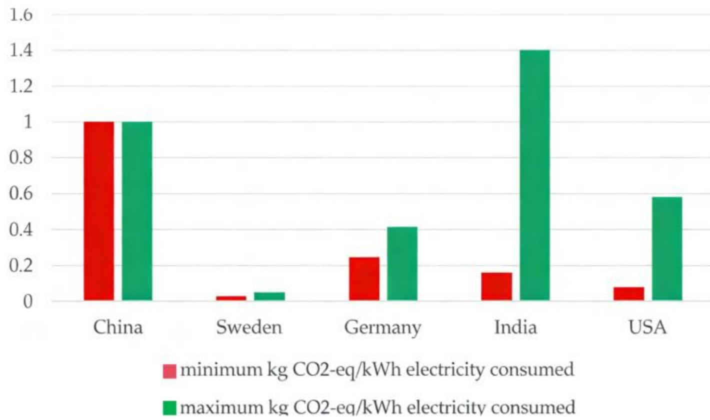

Figure 1. Greenhouse gas emissions from different power generation mixes.

The green and low-carbon transition of the power battery industry is confronted not only with external international compliance pressures but also with internal dilemmas in carbon footprint accounting and data circulation. The advancement of collaborative carbon reduction in the industry has been directly constrained by this dilemma. Complexity in accounting is first highlighted. A complete chain covering mineral extraction, material production, cell manufacturing, pack integration, use, and recycling is encompassed in the entire life cycle of power batteries. Hundreds of upstream and downstream enterprises are involved. From upstream enterprises engaged in mining lithium, nickel, and other mineral resources, through midstream producers of key materials like positive/negative electrode materials and electrolytes, to downstream cell manufacturers, pack integrators, as well as end-use new energy vehicle enterprises and recyclers, a complex industrial ecosystem is formed.

Significant differences in carbon emission sources across different stages are observed. Energy consumption and emissions related to ecological damage are primarily involved in the mineral extraction stage. Dominance of energy consumption and process emissions is seen in the material production and cell manufacturing stages. A close correlation with energy structure is shown in the use stage. Energy consumption and emissions from recycling processes are involved in the recycling stage. Data sources at each stage are found to be highly dispersed with heterogeneous features. Both structured production energy consumption data and unstructured process parameter records are included. The difficulty of carbon footprint accounting is thereby increased. Attention is next drawn to the significance of data silos and a deficit in trust. Constraints are imposed on data exchange by multiple concerns, such as ownership of data sovereignty, protection of commercial confidentiality, and avoidance of compliance risk. A tendency toward data protection is widely exhibited across entities at various stages of the industrial chain. As a result, formidable barriers to data access are formed [6~7].

In the conventional mode of centralized data pooling, aggregation of core production data and carbon emission data is required to be carried out by each enterprise, with uploading being directed to a unified platform. In this mode, leakage of commercial confidentiality is readily induced, while effective safeguarding of data sovereignty is rendered difficult. Thus, secure, trustworthy, and efficient convergence and sharing of data are hard to be achieved. Core technical parameters are regarded as vital commercial secrets by enterprises. Examples are mining efficiency and energy consumption data of mineral extraction firms, process parameters and cost data of material producers, and energy density and cycle life figures of cell manufacturers. Motivation for data sharing is commonly lacked by enterprises. Owing to the presence of data silos, aggregation of data essential to carbon footprint accounting is hindered from being accomplished effectively. Integrity of whole-chain carbon footprint accounting is thereby impeded from being advanced thoroughly. Realization of collaborative decarbonization across the industry is constrained from being fulfilled. Finally, the credibility and mutual recognition of accounting results present significant challenges. The current carbon footprint accounting for power batteries lacks credibility and struggles to gain international recognition due to insufficient authoritative, transparent, and traceable data support [8~10]. International mutual recognition of accounting results was promoted. Barriers in international green trade faced by Chinese power battery enterprises were mitigated. Coordinated carbon reduction among firms at various stages of the industrial chain was facilitated. The low-carbon and green development level of the industry was elevated. Strong support was provided for the new energy vehicle sector in pursuit of the dual-carbon goal. Contributions of theoretical relevance and practical implication were demonstrated. Insights gained were expected to inform both policy design and operational practice. Limitations inherent in existing approaches were acknowledged. Directions for further inquiry were suggested [9~11]. Trustworthiness of data could be enhanced when appropriate architectures were adopted. Challenges in data integration were lessened through cross-chain harmonisation. Relevance of findings was regarded as heightened in the light of global climate commitments. Some viewpoints might remain subject to refinement as more evidence becomes available.

2. MODEL CONSTRUCTION

Challenges of data circulation in carbon footprint accounting for power batteries and international compliance are confronted. Traditional data management models and technical means have been found difficult to effectively address these challenges. An urgent need exists for exploring new paradigms of data infrastructure. Trusted data spaces, as an emerging data infrastructure, are characterized by core features such as “data remains stationary while models move,” “availability without visibility, controllability with measurability, and full traceability”. Theoretical and technical possibilities are provided by them for resolving the aforementioned dilemmas. The architecture of trusted data space is showed in figure 2. Secure circulation and value transformation of data are achieved by trusted data spaces through establishing operational mechanisms with clear ownership and explicit rules. Under the premise that data sovereignty is retained by enterprises, these processes are enabled. Its core advantage is seen in the absence of centralized data storage. Availability without visibility of data is realized via technical means such as privacy computing and blockchain. Security of corporate trade secrets is thus ensured, while collaborative utilization of data is simultaneously accomplished.

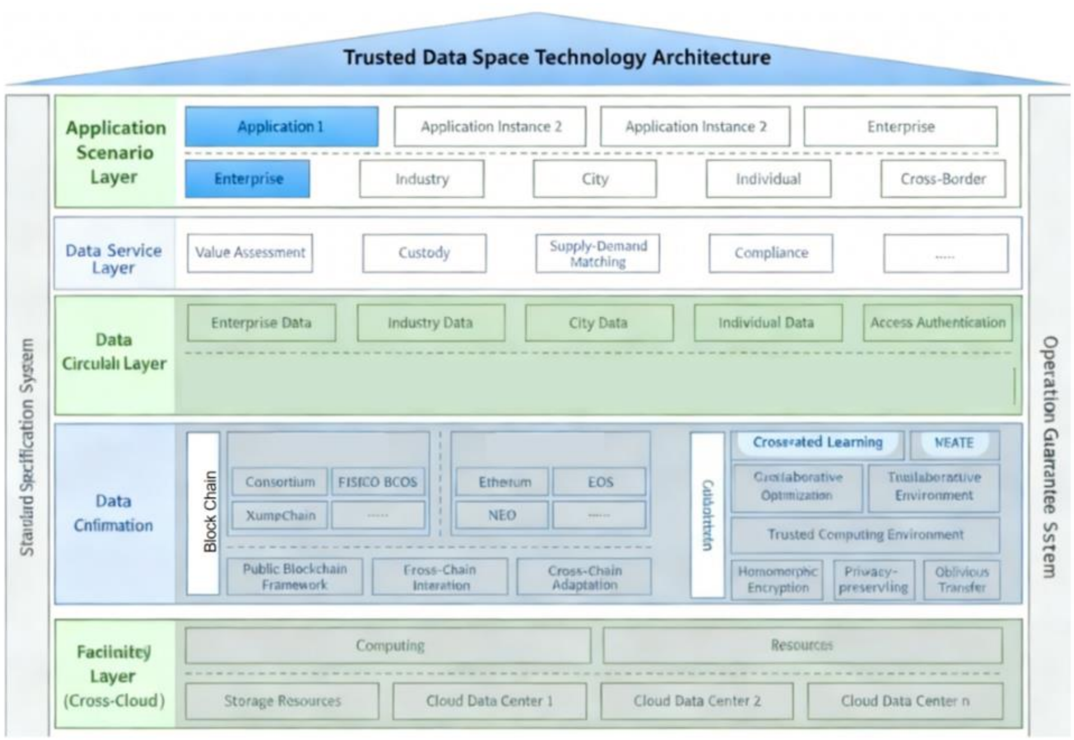

Figure 2. Trusted data space architecture.

3. RESULTS AND ANALYSIS

In this study, a result of 77 kg CO_2-eq/kWh was obtained through comparison with modeled Nickel Manganese Cobalt 111 (NMC 111) battery packs. NMC 111, equivalent to NMC 333, refers to a cathode chemistry where nickel, manganese, and cobalt each constitute approximately one-third of the cathode material. However, the global warming potential (GWP) value provided by the Product Environmental Footprint Category Rules (PEFCR) is based on a

European benchmark. This benchmark cathode contains manganese, nickel, cobalt, and aluminum, representing a mix of typical cathode chemistries, and excludes lithium iron phosphate (LFP). The estimation for this value employs the European energy mix for the cell production and pack assembly stages. This introduces methodological uncertainty related to battery chemistry. Nevertheless, given the widespread application of NMC 333 batteries and the fact that energy consumption for cell production is largely determined by the energy demand of drying rooms, this uncertainty is deemed acceptable for deriving approximate results. The relationship between the GWP from upstream raw material acquisition, as reported in the PEFCR benchmark, and the GWP from cell production and pack assembly is illustrated in figure 3.

Figure 3. Relation between the upstream materials acquisition versus the cell production and pack assembly.

Figure 3 presents the cradle-to-gate GWP for the NMC 111 battery, encompassing raw material procurement, cell production, and pack manufacturing, recalculated based on the 2018 PEFCR. Since the PEFCR assesses the full life cycle of a battery electric vehicle (BEV) battery, the value was recalculated in this study using a different functional unit: the kilowatt-hour of energy delivered over the total lifetime energy output of the battery system. Within this recalculated value, the GWP contribution from the raw material procurement stage accounts for 26% of the total.

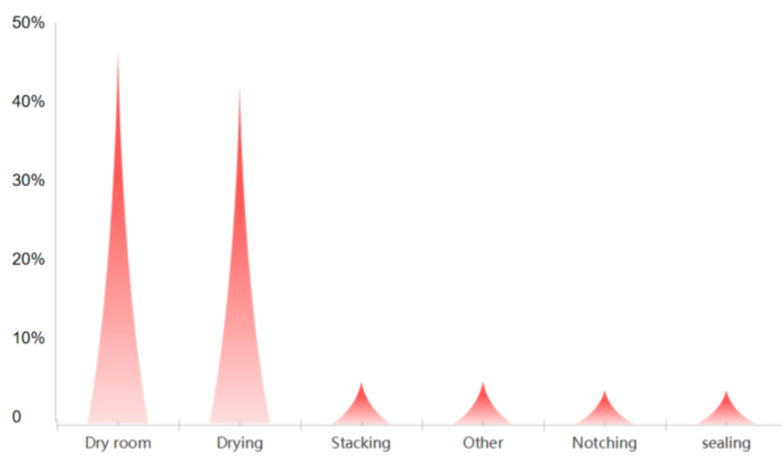

Figure 4. Proportion of energy consumption contributions of battery.

Figure 4 showed the proportion of energy consumption contributions from different energy sources to the total energy consumption of battery cell production and battery pack assembly. It is revealed by the energy consumption proportion distribution of process steps that the Dry room step accounts for a high share, ranging from 45 to 50 percent. The Drying step is observed to contribute approximately 40 percent. Together, dominance is shown by them in accounting for over 90 percent of total energy use in cell manufacturing. In contrast, shares are exhibited by other steps, such as Stacking, Notching, and Sealing, which are found to be below 5 percent each. A direct impression is thus provided that drying-related operations are recognized as the primary high-energy units in cell production.

Attention has been drawn by studies to air volume required, which is identified as the most critical factor accounting for variation in energy use of dry rooms. Given that half of total energy consumption is occupied by dry rooms, a deduction is made that if volume of a dry room is expanded by 10 percent, air handling amount is increased correspondingly by 10 percent. As a result, energy use of the dry room itself is raised by 10 percent, and an immediate lift is produced in total energy consumption of cell making by around 5 percent. A direct positive correlation is indicated between outdoor air humidity and dehumidification energy use in dry rooms. By reference to regional disparity across China, it is seen that outdoor humidity during rainy seasons in South China tends to be 30 to 40 percent higher than that in arid North China. An increase is thereby caused in dehumidification energy use of dry rooms by 20 to 30 percent. A rise is induced in total cell manufacturing energy use by 10 to 15 percent accordingly. Meanwhile, contributions are made jointly by Dry room and drying to 90 percent of total energy use. Dependence is acknowledged in both on heat pumps and condensers for temperature and humidity control. In warm-humid regions, loads are experienced by these devices that are 40 to 50 percent higher than those in cold-dry areas. Increases are triggered in energy use of these two core steps by 40 to 50 percent. Consequently, a gain is achieved in total cell production energy use by 36 to 45 percent.

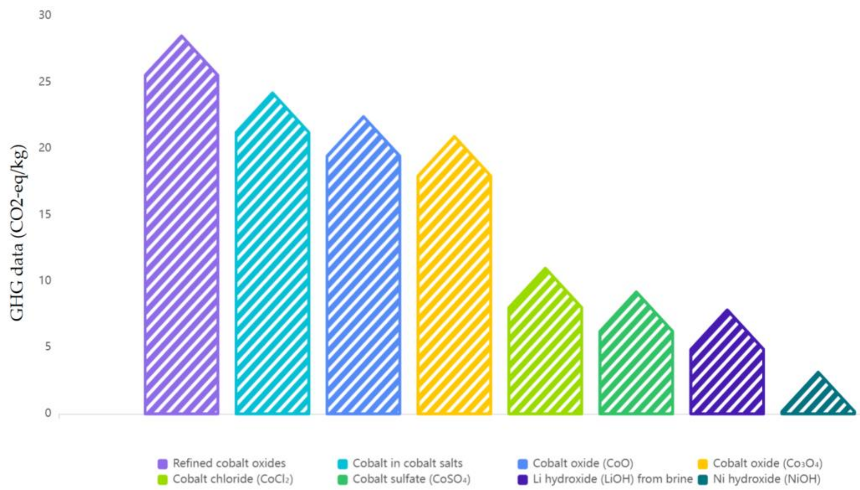

Figure 5. GHG data for production of metals and compounds.

The GHG data for production of metals and compounds are showed in figure 5. Data on global warming potential GWP for key upstream raw materials in battery-grade production are presented. Emissions are expressed as carbon dioxide equivalent CO2-eq per kilogram. A range of materials is covered, including refined cobalt oxides, cobalt contained in cobalt salts, different cobalt oxides like CoO and Co3O4, along with cobalt chloride, cobalt sulfate, lithium hydroxide LiOH, and nickel hydroxide NiOH. Significant variations in carbon emissions are observed across these materials. The highest emissions are recorded for refined cobalt oxides, with GWP approaching 30 kg CO2-eq per kg. This is followed by cobalt in cobalt salts, at approximately 25 kg CO2-eq per kg. Values for cobalt oxide CoO and cobalt oxide Co3O4 are found to be around 22 and 20 kg CO2-eq per kg, respectively. The emission data shown form specific constituents of this overall value. From a comparative perspective, a dual disparity is observed in the carbon emissions of battery. The magnitude-level gap in emissions exists among materials within the chart. A carbon emission exceeding six times that of nickel hydroxide is exhibited by refined cobalt oxides. It is implied that an emission equivalent to producing over 6 kg of nickel hydroxide is generated by producing 1 kg of refined cobalt oxides. The origin of this disparity is attributed to the complexity of material production processes. High-energy-consuming procedures including high-temperature purification and multi-step separation are required for refined cobalt oxides. In contrast, simplified processes with lower energy consumption and pollutant treatment costs are involved in the preparation of nickel hydroxide.

4. CONCLUSIONS

This research is grounded in trusted data space technology, focuses on carbon footprint of power batteries for new energy vehicles. The conclusions are drawn as followed:

(1) A trusted data space architecture for the full lifecycle of power batteries was constructed in this study. Efficient integration and trustworthy traceability of data across all stages were enabled. Data integration efficiency was enhanced by more than 65%, and carbon footprint accounting errors were reduced from 18% in conventional approaches to under 5.2%. A precise quantitative basis for identifying key emission reduction stages in subsequent efforts was thus provided.

(2) It is indicated by quantitative analysis of energy consumption and carbon emissions across production stages of power batteries that the drying stage is a core high-energy unit. Its energy consumption is accounted for 32% – 38% of total production energy use.

(3) It is found by the study through quantitative measurement of carbon emissions from 12 mainstream battery-grade materials that significant differences exist among material types. A unit mass carbon emission of 820 – 880 $kgCO_2e/t$ is exhibited by cobalt-based ternary materials.

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REFERENCES

[1] International Organization for Standardization, "ISO 14040: Environmental management - Life cycle assessment - Principles and framework," (2006). https://www.iso.org/standard/37456.html

[2] Messagie, M., et al., "Life cycle analysis of the climate impact of electric vehicles," Transport & Environment. (2017). https://www.transportenvironment.org/uploads/files/TE20-20draft20report20v04.pdf

[3] Rosado da Cruz, A. M., Santos, F., et al., "Blockchain-based Traceability of Carbon Footprint: A Solidity Smart Contract for Ethereum," Proceedings of the 22nd International Conference on Enterprise Information Systems (ICEIS 2020) 2, 258-268 (2020)

[4] International Organization for Standardization, "ISO 14044: 2006, Environmental management - Life cycle assessment - Requirements and guidelines," (2006). https://www.iso.org/standard/38498.html

[5] International Energy Agency., "Global EV outlook 2024," Paris: International Energy Agency (2024). https://www.iea.org/reports/global-ev-outlook-2024

[6] SNE Research, "Global EV Battery Supply Chain 2023," Seoul: SNE Research (2023). https://www.sneresearch.com/en/

[7] Zhao, P., Liu, J., Chen, W., "Impact of ultra-fast charging stations on urban power grid load characteristics," Applied Energy 345, 121123 (2024).

[8] Zhang, L., Wang, H., Li, C., "Grid impacts of electric vehicle charging: A review of challenges and mitigation strategies," Energies 18(14), 3807-3832 (2025).

[9] Ma, H. F, Wu, X. Y., Yuan, P., "Technologies and industrial status quo of recycling and utilization of waste lithium batteries from new energy vehicles," Recyclable Resources and Circular Economy 18(08), 31-37 (2025).

[10] Miller, A., Davis, K., Thompson, R., "Electric vehicle scheduling and vehicle-to-grid integration in microgrids," arXiv, 2508.06752 (2025).

[11] Zheng, W., Li, J., Zhang, Y., "V2G scheduling and control strategy based on virtual synchronization," Southern Energy Construction 11(2), 117-126 (2024).