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CARBON COMPLIANCE AND EXPORT COMPETITIVENESS OF LITHIUM BATTERIES BASED ON SPATIOTEMPORAL ELECTRICITY-CARBON ACCOUNTING: A CASE STUDY OF EVE ENERGY'S JINGMEN BASE

MingYang Xi
International Business School, Shanghai University of International Business and Economics, Shanghai 201620, China.

Abstract: Against the backdrop of increasing regulatory attention to lifecycle emissions and product-level traceability, lithium-ion battery exporters need credible carbon footprint information. This study takes the Jingmen base of EVE Energy as a case to analyze how the temporal and spatial resolution of electricity carbon factors affects the visibility of green electricity benefits. The study comprehensively reviews the rooftop photovoltaic and energy storage investments, Hubei grid factors, and third-party verification records reported in the case. The case report shows that the rooftop photovoltaic installed capacity is 92.30 MW, with electricity generation of 104,602.54 MWh, and an estimated emission reduction of 59,654 t CO_2e; after recalculation using refined factors, the carbon emission intensity associated with electricity consumption for energy storage cell production changes from 5.5214 to 3.4477 kg CO_2e/kWh, and the accounting granularity is reported to have improved by 25%. The analysis distinguishes the visibility of carbon accounting from independently verified actual emission reductions, and summarizes the roles of hourly matching, localized grid factors, third-party verification, and digital product records. These measures help improve the auditability of electricity-related performance and enhance export compliance readiness, providing a reference for carbon management optimization for lithium battery exporters.
Keywords: Electricity-carbon factor; Temporal and spatial resolution; Life-cycle carbon footprint; Lithium-ion battery; Export compliance; EVE Energy

1 INTRODUCTION

Recent life-cycle studies have found that the environmental impact of lithium-ion batteries differs in different production areas [1-3], materials and electricity consumption [4]. Provincial analyses also show considerable spatial differences in China's electricity-carbon factors [2, 5-6], and high-resolution accounting shows that the selection of a database can significantly affect estimates of electricity footprints [6]. However, there is limited evidence on how temporal and regional electricity factors, product-level evidence, and independent verification combine at an export-oriented battery site.

Although Green-power investments can reduce electricity-related emissions, annual or large-area factors may mask when and where these benefits occur. A reliable product footprint should have clear boundaries, identifiable environmental attributes and recognised verification. The EU Batteries Regulation sets out staged battery-specific carbon-footprint declaration and passport requirements [5, 7-8]. CBAM is an independent instrument with a small scope that only covers selected products in six sectors; therefore, lithium-ion batteries are not among the covered products in this analysis [8]. The published national electricity carbon-footprint factor was 0.6205 kg CO_2e/kWh in 2023 and decreased to 0.5777 kg CO_2e/kWh in 2024 [9]. Recently, it has been found that there are different electricity-carbon factors in various provinces and how sensitive the estimates of footprints are to the resolution of these factors [2, 6, 10-12]. Few studies have shown how these components work together at an export-oriented battery site. The deficiency mentioned above will result in modifications to the disclosed product information under otherwise unchanged production conditions.

A Descriptive Case Study of the Jingmen Base of EVE Energy is presented in this paper. How do the hourly and localised electricity-carbon factors affect the visibility of green-electricity benefits? What operational and institutional measures support reliable attribution, and what limits restrict transfer to other sites? The four linked components that make up the case evidence are: the photovoltaic and storage portfolio; temporal matching of electricity use and grid factors; regional factor selection; and third-party verification with digital product records. It will retain the reported quantity and accounting result without adding a new life-cycle inventory. A change in the recalculated footprint is considered a modification to carbon attribution, not an actual physical reduction. Based on the above analysis, some of these problems need to be addressed by the exporting company in the future. Given the above evidence, finer accounting can enhance the auditability of low-carbon operations without overstating additional abatement or universal market acceptance at this time.

2 CASE AND ACCOUNTING CONTEXT

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2.1 Site Portfolio and Conventional Accounting

The Jingmen Base of EVE Energy has built an on-site renewable power plant and energy-storage facilities. The company has built a roof-top photovoltaic facility with a capacity of 92.30 MW, generated 104,602.54 MWh of electricity, and reduced about 59,654 t CO_2e in emissions. A storage facility with a nominal capacity of 151 MWh has been added; over 19 demand-response events have participated, saving about 29,566 tonnes of standard coal per year [13-15]. Different accounting methods are used for the above indicators; therefore, they cannot be summed to obtain a total amount of avoided emissions.

Table 1 collects the site and accounting indicators reported in the case. Values are presented in their original units and refer to different activities, energy-saving measures, and footprint-accounting methods [13, 15].

Table 1 Reported Energy and Carbon-Accounting Indicators for EVE Energy's Jingmen Base

Indicator	Reported value
Rooftop photovoltaic capacity	92.30 MW
Photovoltaic generation	104,602.54 MWh
Estimated avoided greenhouse-gas emissions	Approximately 59,654 t CO_2e
Energy-storage rated capacity	151 MWh
Demand-response participation	More than 19 events
Annual energy-saving benefit	29,566 tonnes of standard coal equivalent
Storage-cell production intensity with conventional factor	5.5214 kg CO_2e/kWh
Storage-cell production intensity after factor refinement	3.4477 kg CO_2e/kWh
Reported improvement in accounting refinement	25%

The above indicators show the scale, but they are not complete and independently reconciled life-cycle inventories. Installed photovoltaic capacity does not equal generation; an avoided-emissions estimate requires a certain electricity baseline and factor; demand-response participation does not specify the duration or magnitude of each event; coal-equivalent energy savings cannot be directly added to CO_2e. The units and calculation bases for self-generation, storage, demand response and purchased green power need to be kept independent in the report.

The two deficiencies of traditional footprint accounting in this case are as follows: Firstly, the international life-cycle dataset may be out of date with changes in China's generation structure. Second, annual national or provincial averages mask differences across hours, seasons and local grid areas. A recent high-resolution assessment showed that international LCA databases may overestimate China's electricity footprint by 23%–29% [6]. Given that electricity is a major component of lithium-ion battery footprints, a different choice of factors will alter the reported product result significantly, even if the actual production process has not changed [1, 4, 10].

Rules for renewable electricity, green-power transactions and certificates need to specify the relevant generation, consumption period, geographic boundary and ownership of the associated claim. Otherwise, the same environmental benefit may be counted multiple times or fail verification. Therefore, this case considers factor resolution and attribute ownership as complementary controls: precise grid data can enhance the match between consumption and generation, and transaction records establish who is entitled to the corresponding environmental benefits.

2.2 Spatiotemporal Factors and Verification

Hubei's time-and-region-specific electricity-carbon factors have been applied to the Jingmen production scenario. Hourly factors distinguish periods with different generation mixes, and regional factors are more localised electricity systems than a national annual average [2, 10-11]. The two kinds of averaging errors in this design are as follows: an annual figure may mask changes within a day or across hydrological seasons; a national figure may hide regional generation differences. State Grid Hubei introduced grid data, industrial application and third-party review [15]. EVE Energy has obtained the TÜV SÜD Mark certificate under Regulation (EU) 2023/1542 independently [14].

Refining the factors, the electricity-related carbon intensity of the storage-cell production stage is adjusted from 5.5214 to 3.4477 kg CO_2e/kWh [15]. The case also shows a 25% improvement in accounting refinement after SGS verification [15]. The above figures are different results; the first is a revised figure and the second is an increase in the accuracy of accounting. A lower recalculated value alone does not prove that there has been a corresponding reduction in actual emissions; such a conclusion would need matched activity data, a consistent boundary, and evidence of operational change.

A Time Match will show when the electricity is used and its carbon consequences. The case shows that energy-intensive production has been scheduled for a time when the grid factor is relatively low, such as during high photovoltaic or wind power generation periods. Spatial matching also considers Hubei's hydroelectric and renewable resources instead of using a national-average factor for the site. Third-party review of the method and data supports the reliability of the resulting product-footprint information in the case report [15].

2.3 Data Provenance and Environmental-Attribute Control

A reproducible result needs to be linked to the battery model by means of a chain of evidence. The grid-side factor describes the electricity conditions in the case pathway, the manufacturing site provides process-level consumption data, and the verification body confirms the method and related records. Then, the calculated footprint is linked to a specific product and its production conditions via the battery product record. Each layer answers a different question: which electricity factor was used, what activity was measured, how the environmental claim was assigned, and whether the reported result can be verified by others.

The case differentiates among self-generated photovoltaic power, storage and demand-response participation, market-based green-power transactions, and certificates. These paths should not be regarded as the same. A transparent report will show whether a value is that of actual production, purchased electricity, an accounting attribute or a recalculated product footprint. It also keeps the relevant time window and geographic scope. This division can be used to examine the same site result independently of other indicators or to avoid assigning a single certificate to multiple products.

Third-party reviews can increase credibility but are not consistently applied in all areas. The SGS verification of factor-based accounting and the TÜV SÜD certification under the EU battery framework refer to different assurance functions in the case described [5, 14-15]. The idea of a digital record can retain the link between internal calculations and product documentation; however, it cannot address disputes over system boundaries, attribute ownership or applicable factor methods. Specific rules and supporting evidence need to be provided for these.

2.4 Internal Carbon Management and Product Records

The case also shows the organisation's mechanism for linking carbon information to management decisions. Battery-passport research has identified the demand for value-chain data, and the EU Batteries Regulation requires battery-specific carbon-footprint declarations and product information [3, 7]. EVE Energy's TÜV SÜD Mark certification under the regulation is an example of external conformity assessment [14]. These are governance and information-management measures; neither one alone can show a reduction in actual electricity use or guarantee recognition of a carbon claim by an outside regulator.

The mechanisms operate at different control levels. Electricity factors are used to allocate carbon intensity in the supply chain; plant meters record consumption, set an internal carbon price as a decision signal, and have a third party confirm the evidence; finally, a passport links this information to product records. Maintain the division of these roles and determine which ones support the claim and need further confirmation.

3 ANALYSIS AND DISCUSSION

3.1 How Resolution Makes Carbon Benefits Visible

A three-part accounting system is used in this case. Temporal resolution links a period of electricity consumption to the relevant grid-intensity value. Spatial resolution allocates the consumption to a particular electricity system instead of using a China-wide average. Verification will determine whether the data, factor selection and environmental-attribute claims have been adequately documented for an external reviewer. Together, these steps can convert a general statement that a factory uses green electricity into a traceable product-level calculation.

Therefore, the quality and compatibility of the underlying data will also be affected. Hourly production and electricity records must have a common time basis with the factor series; location and grid-boundary definitions should remain consistent; green-power claims need to be supported by evidence that cannot be duplicated. Based on the present research and the Hubei case, there are both temporal and regional divisions [2, 10-12, 15]. Digital product records can keep the connection among product identity, manufacturing information and carbon data in the supply chain [3, 7].

Accounting comparison is more suitable when the product boundary, functional unit and production activities are unchanged but only the electricity factor changes. Under this comparison, the difference between a national annual factor and a local hourly factor indicates how much of the reported footprint is sensitive to grid representation; it does not isolate the effect of a changed production schedule. A separate operational comparison needs to pair consumption records before and after the scheduling change with the same factor method; otherwise, the effect of improved measurement and the effect of changed operations will remain confounded.

The Temporal Mechanism of Jingmen is based on the daily and seasonal changes of the local grid. Photovoltaic power generation occurs during the day, and according to the case, wind power output is relatively high at night; both may be below the daily average electricity-carbon factor. Match flexible, energy-intensive operations with this period to reduce the carbon intensity of production electricity. Storage and demand response can support power-system balancing, but the case does not report a production schedule or quantify how much load was shifted. Therefore, the resulting footprint benefit should be considered as an operational opportunity supported by factor data rather than a measured scheduling result.

Measurement and Mitigation are different concepts. More specific factors will change the amount allocated to a product because they more precisely show where and when electricity was used. Actual Emissions Only Drop if Energy Use, Generation or Other Physical Drivers Change. Operational scheduling may cause such a change; however, production can be shifted to a lower-intensity period, and the case has not quantified the controlled before-and-after production shift. Therefore, the reported recalculated footprint is evidence of accounting sensitivity and improved attribution, but it is not a causal estimate of abatement alone.

3.2 Implications for Export Compliance

A battery factory that exports cannot meet the compliance requirements by purchasing green electricity alone. The company needs product-specific inventory, factor data suitable for the manufacturing location and time, records of renewable attributes, and a reproducible verification path. The EU battery framework links manufacturing-plant and battery-model information with carbon-footprint declarations [5, 7]. Therefore, the case's path of grid data, industrial application, independent review and digital records meets an actual demand for information management.

The case also shows that local electricity conditions may lead to differences at the site level. Hubei's resource mix and the reported use of regional factors can make a facility's electricity footprint different from the national average. This may be relevant to export competitiveness because a verifiable low-carbon footprint can enhance the quality of product information provided to consumers and regulators. However, the case has not disclosed the extent of the price increase, changes in export volume or measured competitive advantage. A narrower defensible conclusion is that more detailed accounting will provide stronger support for demonstrating carbon performance and meet market demands.

Production-scheduling consequences are conditional and not automatic. The case proposes to carry out energy-intensive operations during periods of low factors, but does not provide a production schedule, a quantified shift in electricity consumption, or a controlled estimate of the resulting physical reduction. Therefore, exporters can use the hourly factor as an operating signal for planning and retrospective attribution, and only report actual emission reductions if modifications to energy and production records show that the operation has changed.

The record of the product should also keep the boundary of the declaration. The EU Batteries Regulation specifies battery-specific information at the battery-model and manufacturing-plant levels and requires supporting footprint data [3, 5, 7]. A corporate renewable-energy percentage cannot replace this product-level record because different models, plants and production periods may have used different electricity mixes. Export readiness is therefore dependent on retaining meter data, factor versions, allocation rules and verification records in a form that can be retrieved for the relevant product rather than only for the company as a whole.

Digital battery passports and other records can provide support for this path by linking carbon declarations with product and production data. They should be full-data, have uniform definitions, controlled access, and clear responsibilities for suppliers and manufacturers [3, 7]. A passport alone cannot resolve the dispute over calculation boundaries or recognition rules. Interoperable methods and recognised verification are still required to ensure the reliable cross-organisation and cross-region transmission of carbon data.

3.3 Transfer Conditions and Limitations

The findings are limited to a single manufacturing base in Hubei, and hydroelectric and renewable resources are relatively available there. The same regional factor advantage cannot be assumed for coal-dominant grids or other provinces. Replication is also limited by the availability of detailed grid data, reliable plant-level metering and an independent verifier of the selected method. Although the Hubei model introduced in this case study has been discussed for wider application in industry, no multi-site comparison to verify consistent performance across all sites was presented in the paper [10-11, 15].

The source case has also held independent single-product demonstrations in Zhejiang and Anhui. The reporting boundaries and baselines do not show that they are consistent with the Jingmen case; therefore, these examples cannot establish an equivalent reduction rate. The Hubei initiative was described as a planned extension to 19 major foreign-trade enterprises, but multi-site validation had not been completed [15].

To determine transferability, the electricity boundary, time period, function unit, factor vintage and verification method at each location need to be consistent [10-12, 15]. In the absence of comparable evidence, the case supports an accounting approach for improved attribution and does not forecast the amount of carbon reduction that any particular exporter will achieve.

The accounting boundary is another restriction. The case only considers electricity-related emissions in battery production and does not include all material, logistics and end-of-life emissions in the product life cycle. Time- and region-specific electricity factors cannot address these other sources. Therefore, a full-product assessment should also keep material, logistics and recycling inventories; it cannot use electricity accounting as a substitute for full-life-cycle assessment [1, 4, 10].

Finally, the regulatory approval will also change over time and by method. The discussion in the case of which electricity claims qualify should be read against the calculation rules at that time, and it is not a permanent statement of current EU practice. Verify whether the relevant delegated acts, implementing rules, product category and verifier requirements apply before using a factor-based claim in a statement. More multi-site work needs to be carried out to test transferability, compare different grid boundaries, and quantify the physical effect of production scheduling independently of changes in accounting factors.

4 CONCLUSION

The EVE Energy Jingmen case shows how to add more details on the electricity part of a lithium-battery footprint according to when and where the power is used in production. According to the revised calculation, the production strength of storage cells has fallen from 5.5214 to 3.4477 kg CO_2e/kWh, and after third-party verification, the case has

achieved a 25% increase in accounting accuracy [15]. Therefore, these findings provide better visibility for carbon accounting and should not be considered actual measured reductions at the same time.

In practice, it is to use interval electricity data, local grid factors, documented renewable attributes, independent verification and product-linked digital records [7, 9, 12, 14-15]. Strengthen the auditability of carbon claims and provide support for export-compliance preparation. They have a certain scope for application and need specific systems and rules in line with the relevant market.

The evidence is only available at one Hubei base and for electricity-related accounting in the wider life cycle. Material sourcing, transportation and end-of-life emissions need to be considered separately; therefore, different regions with other generation mixes or weaker data infrastructure may have different results. Therefore, the case provides a transferable accounting logic but not a universal emission factor or a quantified claim of competitive advantage.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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