Suppliers Carbon Footprint Investigation and Factors Comparative Analysis and Management: A Case Study of Metal Parts

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Abstract
This article examines data accuracy's impact on supply chain investigations using the Steel Electro-galvanized Cold Coil example. Results show that using coefficient databases can double errors, even in simple supply chains. We propose a model base on case study for managing carbon emission data that balances completeness with investigation feasibility.

Author Keywords
Product carbon footprint; supply chain management; coefficient databases.

1. Introduction
The calculation and analysis of product carbon footprints help consumers and businesses understand the carbon emissions amount and distribution at each phases of a product's lifecycle. This understanding allows for the formulation of reduction strategies and the tracking of carbon reduction efforts within the company or supply chain. In light of the international trend toward net-zero, major brands are increasingly responding to the Paris Agreement by committing to net-zero targets, which extend the scope of these commitments to include Scope 3 emissions that encompass the full range of corporate impacts. This means that, in addition to direct emissions and indirect emissions from energy, companies must also account for the other indirect emissions associated products life cycle. Existing literature and greenhouse gas inventory reports disclosed by electronics brands have clearly indicated that the carbon emissions from Scope 1 and 2, which are directly controlled by companies, are significantly lower than Scope 3 [1,2]. This disparity arises because brands primarily engage in product design and marketing, while the actual assembly and manufacturing of products are typically outsourced to assembly plants and component suppliers.

Product carbon footprints not only provides consumers with environmentally friendly options and purchasing references, but it also facilitates the analysis of carbon emission hotspots, serving as a basis for reducing product carbon emissions. Given this necessity, the accuracy of product carbon footprint calculations and the actual carbon emission conditions within the supply chain are critical for effective carbon reduction efforts. If the information used in these calculations is limited or contains substantial errors, it can lead to distorted results, ultimately affecting the direction and effectiveness of carbon reduction initiatives.

Generally, sources of material carbon coefficients can be categorized into national coefficients, coefficients from databases, and coefficients developed internally by manufacturers, among others. The calculations often rely on the international coefficient databases, which are often influenced by factors such as the timing of data collection and geographical variances, which can result in discrepancies between the calculated values and actual conditions, leading to inaccurate results. Thus, coefficients derived from supply chain information investigations, which are closer to the actual status of the supply chain, can enhance the relevance and accuracy of product carbon footprint calculations. Furthermore, such coefficients can also reflect the effectiveness of carbon emission management within the supply chain and encourage collaborative efforts to promote low-carbon cooperation and development. However, calculating product carbon footprints is constrained by the high complexity of electronic product. Detailed and comprehensive assessments conducted in accordance with standards such as ISO 14067:2018 often require considerable human resources and costs, which can be a heavy burden for suppliers. Additionally, the diversity of products limits the effectiveness of such assessments. For manufacturers relying on data, the sheer number of components and suppliers making it difficult to establish comprehensive supply chain coefficient information necessary for carbon footprint calculations and management.

In this paper, we will use the metal backplane component of panel backlight modules as a case study to explore the differences between results obtained using coefficients from a database and those derived from a full supply chain traceability investigation. Based on this difference analysis, we will propose a supply chain carbon emission information assessment and management model that balances data completeness with the feasibility of investigation.

2. Differences between carbon footprint assessment framework and practical calculation
According to the definition provided by ISO 14067:2018, the carbon footprint of a product is determined as 'sum of GHG emissions and GHG removals in a product system, expressed as CO_2equivalents and based on a life cycle assessment using the single impact category of climate change. '

However, electronic components such as panels, backplanes, and power cables serve as integral parts of end products, within the 5 phases of the product life cycle: materials, manufacturing, transportation, use, and disposal. They face challenges in use phase calculating as they are not the end products themselves. Additionally, due to the inability to trace the disposal flow of the product at the end of its life, it is also not feasible to calculate disposal phase emissions disposal phase. Consequently, carbon footprint assessments for these components are often confined to the cradle-to-gate scope, focusing on emissions generated from raw material extraction through to production and transportation.

Further, electronic products are typically manufactured within designated industrial zones and do not involve greenhouse gas removal processes. Therefore, there is no need to account for emissions from land use changes or greenhouse gas removals associated with production activities. The carbon footprint of the target product can be defined as the cumulative emissions resulting from direct operations within the supply chain attributable to manufacturing processes, transportation, and emissions derived from materials. The materials can be further broken down into emissions arising from the direct operations associated with own manufacturing processes, transportation, and emissions related to the materials themselves—up to and including the emissions produced during the extraction, processing, and transportation

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phases of the primary product or materials. In summary, the carbon footprint of the target product encompasses the total emissions from all participants involved in manufacturing and transportation activities within the supply chain, as Figure 1.

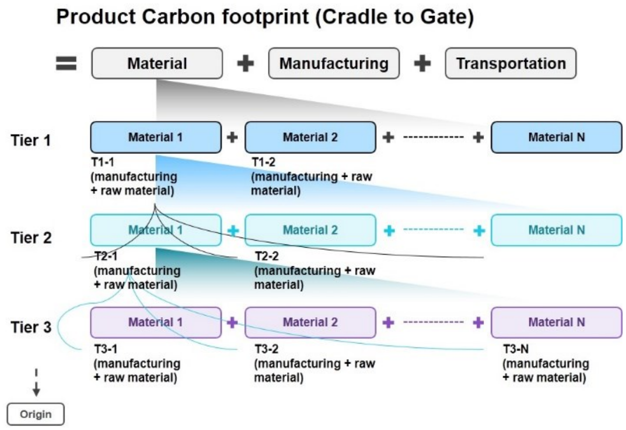

Figure 1. Product carbon footprint composition

However, due to the high complexity of electronic products, a single end product can consist of hundreds components, each with corresponding suppliers. The globalized and specialized processing associated with these various materials results in a supply chain that is not only extensive but also complex, making it difficult for effectively communicate in supply chain and challenges in comprehensively investigating. As a result, in the actual calculation of product carbon footprints, carbon emission coefficients is often used as a substitute for collecting data on upstream activities. The calculation can be summarized as Figure 2 [3], where the coefficients have been converted into carbon dioxide equivalents (CO_2e) by Global Warming Potential (GWP) values, facilitating quantification and aggregation.

$$Product\ carbon\ footprint = \sum_{i=1}^{n} Activity\ data_i \times Carbon\ emission\ factor_i$$

Figure 2. Product carbon footprint formula

3. SECC metal backplane manufacturing process and investigation methods

In this investigation, considering the number of suppliers and levels involved in investigation, as well as the high usage of materials in panel products, we chose the SECC metal backplane as a case study. Depending on product design variations, the metal backplane constitutes approximately 20% to 40% of the total weight of the panel module, and its manufacturing process and composition are relatively straightforward.

The manufacturing process for this study, the SECC metal backplane used by AUO is sourced from 4 suppliers and divided into 5 processing segments: 1) mining companies providing raw materials for steelmaking, 2) steel plants producing steel ingots, 3) rolling into galvanized steel coils, 4) processing plant cutting, and 5) stamping plants executing the stamping process. Supplier investigation were conducted at each stage to confirm manufacturing processes and associated carbon emissions for the products. The principal approach was to allocate the total organizational emissions to obtain per-unit manufacturing carbon emissions, either based on reasonable distribution or according to the ISO 14067 calculations provided by the suppliers. Since the mining source involves overseas enterprises, relevant information was obtained with the assistance of the steel plants.

Past experiences indicates that the transportation phase typically contributes significantly less than the materials and manufacturing phases. For example, this investigation results show that the carbon emissions from the transportation of stamped products to the receiving location amount to 0.0039 kg CO_2e/kg, which is markedly lower than other phase, thus having a minimal impact. As a result, subsequent comparisons and analyses will omit the transportation phase; however, actual data collection should still retain this information to maintain the completeness of the product's carbon footprint assessment.

To compare the differences between the coefficient substitution and supply chain investigations, each appropriate coefficients of process segments was also collected. Considering the regional and temporal relevance of the product, priority was given to using carbon coefficients publicly available from Taiwan's Ministry of Environment Carbon Footprint Information Platform, such as those for steel ingots and galvanized steel coils. However, due to the absence of reference coefficients for metal cutting and stamping in the aforementioned platform, the Ecoinvent 3 database was utilized, for metal working.

4. Supply chain full investigation and coefficient substitution difference analysis

After contacting and interviewing suppliers at each processing stage, investigation result, substitute coefficient for each stage and deviation ratio, are shown in Table 1.

Table 1. SECC metal backplane investigation results

Unit: Kg CO_2e/Kg

Processing stage	Stamping	Cutting	Rolling	Smelting	Sourcing	Total	Deviation Ratio
Full Investigate	0.8001	0.0034	1.067	0.899	1.013	3.7825	0%
Source	100% Supplier Investigation						
Tier1~3 Investigate	0.8001	0.0034	1.067	2.27		3.8395	9%
Source	45% Supplier Investigation			55% Coefficient substitution			
Tier1~2 Investigate	0.8001	0.0034	3.16			3.9635	5%
Source	20% Supplier Investigation		80% Coefficient substitution				
Tier1 Investigate	0.8001	4.12	3.16			8.0801	114%
Source	10% Supplier Investigation	90% Coefficient substitution					
Full coefficient substitute	4.12	4.12	3.16			11.400	201%
Source	100% Coefficient substitution						

The results of the investigation, compared with the common supplier coefficient substituting, indicated a deviation of 201% in the carbon footprint calculation results. This highlights that even in the relatively straightforward manufacturing processes of metal products, which involve only a single material and 5 manufacturing procedures, there are significant discrepancies. This suggests that for other components, such as PCB and IC, which involve multiple materials and complex manufacturing processes, the deviation in carbon footprint calculations is likely to be even more pronounced. Furthermore, as we progressively replaced supplier investigation data with coefficient substitutes, the carbon footprint calculation results revealed that the errors tended to amplify as the completeness of the supply chain investigation decreased. Notably, when the information provided by suppliers accounted for less than 20% of the total carbon footprint, the resulting discrepancies could reach up to 100%.

In this investigation, the coefficients for steel rolling and steel ingots were sourced from suppliers within the same region, and both were published in 2013. Given that there have not been significant technological changes in steelmaking and related processes during this time frame, the use of these coefficients, due to their relevance in terms of time and geography, produced acceptable bias. However, in the cutting and stamping stages, the absence of coefficients from the same region in the database resulted in differences of 5 to 1,200 times in the coefficients used for these manufacturing stages. Therefore, this underscores that if coefficient have lower relevant with actual processes and backgrounds, the biases generated can be substantial.

Further exploration of the carbon emission hotspots throughout the entire manufacturing process of the SECC metal backplane reveals that, according to the results from the full investigation, the primary hotspots are sequentially identified as steel rolling, material extraction, steel ingot production, stamping, and cutting. However, when examining the emission hotspots by using substitute coefficients, the metal processing stages of stamping and cutting appear more significant. This discrepancy will influence subsequent supply chain management decisions.

Thus, if resources permit, it is recommended that each supplier's carbon emissions from processing and manufacturing be investigated and aggregated to reflect actual carbon emissions. However, in practice, it's challenging to systematically assess and calculate carbon emissions for each manufacturing and processing stage of individual components. In the next paragraph, this paper will propose a suitable logical framework for conducting supply chain assessments that balances information accuracy with investigation feasibility, establishing an effective investigation and management model.

5. Supply chain investigation and management discussion

To reduce the difficulty of collecting information from suppliers, we have streamlined the investigation process by referencing past assessments and hotspot analyses. By omitting less impactful data, to balance the quality of the data with the feasibility of the investigation, enhancing the overall integrity of carbon footprint information across the supply chain. The adjusted survey based on the cradle-to-gate framework, categorized into the materials, manufacturing, and transportation phases. In accordance with experiences, we have omitted inquiries related to carbon removal data, and only require suppliers to provide materials information that constitutes over 80% of the product's weight, which are typically hotspots, thereby alleviating the burden of collecting excessive upstream material data. And select appropriate coefficients to estimate materials phase carbon emissions. Furthermore, given the minimal contribution of transportation and in reality, suppliers are responsible for transporting products to customers, we do not collect upstream transportation information. Instead, we gather downstream transportation information to understand the carbon emissions associated with transportation. For the manufacturing phase, the increasing prevalence of organizational carbon footprint assessments in recent years means that most suppliers can provide third-party verified ISO 14064 information directly. Therefore, additional inquiries into emissions are not necessary; we only need to collect data pertaining to water usage, which is commonly involved in the electronics industry but not be covered by ISO 14064, and allocate organizational manufacturing carbon emissions logically to the products. The ideal approach is using the simplified investigation form to conduct inquiries with the each-tier suppliers of each components until reaching the raw material extraction suppliers, cumulatively incorporating the manufacturing and transportation emission data obtained in the responses to formulate the carbon footprint. However, in practice, the communication capabilities of the surveying entity with tier2 suppliers are typically not as strong as with tier1 suppliers, the associated costs tend to increase significantly. Therefore, it is essential to establish a suitable point at which to halt the investigation to balance the effectiveness of the data collected with the accessibility of communication.

Taking the SECC metal backplane as an example, with the Tier 1 stamping supplier information, the result is a material carbon emission contribution of 7.28 kg CO_2e/kg, and manufacturing emissions amount to 0.8001 kg CO_2e/kg. The total carbon emission aggregate to 8.0801 kg CO_2e/kg, with a deviation rate of 114%, and the materials and manufacturing phases accounting for 90% and 10%, respectively. In this context, it is advisable to investigate the Tier 2 suppliers to increase the proportion of supplier data collected, thereby reducing the bias introduced by secondary information. Upon completion of the Tier 2 supplier survey, the carbon footprint composition of the SECC metal backplane component can be delineated as follows: Tier 1 processing (stamping) contributes 0.8001 kg CO_2e/kg, Tier 2 processing (cutting) contributes 0.0034 kg CO_2e/kg, and the Tier 2 material amounts to 3.16 kg CO_2e/kg. At this stage, the data provided by suppliers account for 20% of the product's carbon footprint, resulting in an acceptable 5% deviation rate.

As discussed previously, if the coefficients have different background than the investigation target, the bias would likely be significantly greater. Therefore, while the experience gleaned from this analysis indicates that the proportion of supplier-provided data and manufacturing contributions to the product's carbon footprint can indeed converge the deviation ratio to 5% when they account for 20%, it is nevertheless advisable to assess the conditions of the coefficients and adapt the convergence mechanism appropriately to ensure that resources are allocated efficiently and assessments are accurate.

In the simplified survey form for supplier investigations, the manufacturing phase reflects first-hand information from the supplier, while the materials phase, although based on first-hand usage information from the supplier, is calculated using coefficients from the database. This reliance on substitute coefficients is a source of deviation. Therefore, if the results from the simplified supplier investigations indicate that the carbon emission contribution from the manufacturing phase is lower than that from the materials phase, it suggests that the uncertainty in this investigations result constitutes more than half of the data composition. In such situations, to enhance the reliability of the supplier coefficients, it is advisable to collaborate with the Tier 1 supplier to conduct investigations and gather information from the upstream Tier 2 suppliers. Conversely, if the manufacturing phase contribution exceeds that of the materials phase, it indicates that the contribution primarily derives from the operational emissions of the investigated supplier. In this case, the potential for improving accuracy through upstream investigations is limited, and the priority for upstream traceability investigations could be lower. The overall investigation and carbon reduction strategy process recommendations are shown in Figure 3.

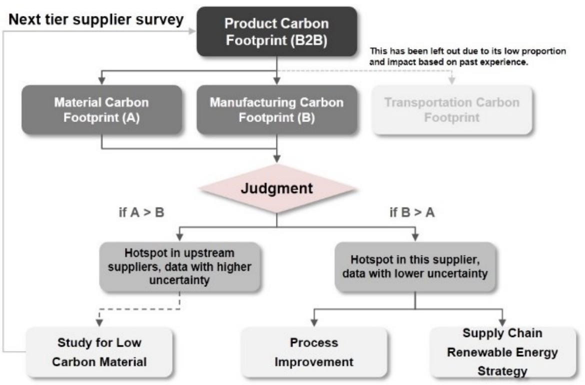

Figure 3. Supply Chain investigation and management strategy process recommendations

6. Supply Chain carbon reduction management strategies

Product carbon emission hotspot analysis can assist in formulating product carbon reduction strategies. For electronic products primarily focus on the main carbon emission hotspots: the manufacturing and material phase. The most mainstream and effective approaches in these areas include improving energy efficiency and increasing the use of renewable energy in the manufacturing phase, as well as implementing design reductions, material substitutions, and the use of recycled materials in the material phase. Given the current state in which renewable energy and recycled materials are not yet widely adopted, it is crucial to maximize the effectiveness of low-carbon strategies by implementing differentiated requirements based on the specific carbon emission characteristics of each supplier. This tailored approach can better align strategies with the unique profiles and capabilities of suppliers, ultimately enhancing the overall effectiveness of carbon reduction efforts within the supply chain.

Continuing with the example of the SECC metal backplane, the carbon emissions from the materials and manufacturing phases account for 90% and 10% of the total product carbon footprint, respectively. This indicates that even in the most ideal scenario where the supplier uses 100% renewable energy for manufacturing, the carbon footprint of this component could only be reduced by at most 10%. Thus, when the manufacturing phase contributes a higher percentage to the overall carbon emissions, collaborating with the supplier to implement renewable energy usage would likely yield substantial contributions to reducing the overall carbon footprint of that component. Conversely, when the carbon emissions from materials exceed those from the manufacturing phase, the carbon reduction strategy should focus on upstream suppliers' carbon management. This would involve conducting advanced investigations with the immediate upstream suppliers, while also exploring opportunities for collaboration to assess low-carbon alternatives, the use of recycled materials, or optimizing product design to reduce the amount of materials used.

Using recycled materials, which replace virgin materials with waste products, can help avoid the carbon emissions associated with the extraction and mining of virgin materials, and can also reduce upstream processing emissions. For instance, with current technology, steel with a recycled content of 20% (RC20) can have a carbon footprint that is 0.275 metric tons lower per ton of steel compared to standard galvanized steel [4], which can translate to a 7% reduction in the carbon footprint of the SECC metal backplane component. If further advancements allow for the use of recycled scrap steel instead of original steel ingots, the carbon footprint of the SECC metal backplane could potentially be reduced by over 50%.

7. Conclusion

The investigation results for the SECC metal backplane demonstrate that even in relatively straightforward supply chain scenarios, discrepancies between comprehensive supply chain investigation data and coefficient substitution can still reach up to two times. Additionally, when using coefficients that are geographically and technically aligned with actual industry practices, the estimation bias is only 5%. However, when constrained by the sources available in the coefficient database, and forced to use coefficients from similar technologies but different regions, the bias can soar to thousands of times. This highlights the critical necessity of conducting thorough supply chain traceability investigations to ensure the accuracy and reliability of carbon footprint assessments. Until a complete framework for carbon footprint information exchange is in place, individual enterprises can manage their supply chains based on the carbon footprint structure of electronic products, simplifying the investigation information and framework according to the carbon emission proportions of component manufacturing and materials to enhance the coverage of carbon footprint information.

Based on the analysis of the differences between the supply chain investigation results for the SECC metal backplane and those obtained through coefficient substitution, it is recommended that in supplier investigations, if the carbon footprint proportion from manufacturing is higher, investigations into the upstream supply chain can be deferred, and engage with the supplier on energy efficiency improvements and introduce renewable energy. Conversely, if the investigation results indicate a higher carbon footprint proportion from materials, it becomes essential to conduct inquiries into the upstream supply chain to enhance the accuracy of data related to that component. Additionally, discussions should be held with the supplier regarding low-carbon practices, the use of recycled materials, and product design optimization.

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