Key Environmental Aspects of Sustainable Display and Labeling Mechanism

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Abstract
In today's era of environmental change, manufacturers must address their impact on society, particularly regarding electronic waste. Sustainable display panels should comply with regulations and focus on key criteria like recycled materials, energy efficiency, renewable energy, material reduction, and circular economy design. Our goal is to achieve closed-loop recycling and drive green transformation through collaborative efforts in the value chain.

Author Keywords
Sustainable products; Recycled material; Product Energy Efficiency; Renewable Energy; Circular Economy

1. Introduction
Under the ongoing development of research into the impact of products on the environment and human society, as well as the derivation of related regulations, the scope of concern regarding the environmental impacts of products is becoming increasingly broad. This has evolved from a focus on specific issues and regulations, such as toxic substances or harmful materials, to a more comprehensive understanding and research of complex environmental effects. In recent years, discussions surrounding climate change have intensified annually, and the foundational research related to carbon footprints has gradually become more comprehensive and quantifiable. This has led to a deeper understanding of the carbon emissions generated by operational activities and products and services, as well as their resultant environmental impacts, prompting the formulation of various mitigation and adaptation strategies. However, the climate change is just one factor among many influencing environmental impact. For example, under the ISO 14040 and ISO 14044 standards, the influence factors that define the environmental footprint of a product include 16 items.

In addition to the defined impact factors in product Life Cycle Assessment (LCA), major certification labels setters have also recognized other environmental impact factors, leading them to consider a multifaceted array of indicators during evaluations.

Common labels related to product environmental impacts include broader assessments like EPEAT, TCO, IEC, and ESPR, as well as specific items such as RoHS, Energy Star, EED, and WEEE. However, effectively communicating actual product conditions, including upstream and downstream communications, remains challenging due to the complexity of evaluation criteria and diverse assessment methods. One of the reason is that many recognition standards use a binary approach without comparative design, such as simply meeting Energy Star standards. We aim to improve information completeness in these design elements to facilitate more discerning evaluations of a product's environmental impacts and provide a basis for manufacturers or brands to assess these criteria.

This article focuses on the category of display products, presenting the aspects that require attention for current and future sustainable panel design, as well as the logic behind labeling design. We consolidate evaluation criteria for designable items within this product category that impact the environment, enhancing the discernibility of indicator items for products. Additionally, we propose a scoring design method in a simple and clear manner, aiming for greater transparency and visualization of information. This type of labeling design can facilitate more efficient communication along the supply chain, promoting an overall trend towards environment-friendly products and enabling upstream and downstream stakeholders to make reasonable assessments regarding environmental and financial choices. Furthermore, for manufacturers' internal management, it provides sufficient quantifiable basis, allowing them to effectively manage and review product designs to select options that are more environmentally friendly, resulting in positive overall environmental benefits.

2. Sustainable display characteristics and labeling management
For LCA, many aspects are less relevant to the product design itself. For instance, ecotoxicity (freshwater) is primarily related to the design and planning of panel manufacturing facilities, which results in a limited ability to distinguish the environmental impacts under different product designs. On the other hand, currently prevalent broad labeling systems often encompass a wide array of assessment criteria. For example, EPEAT includes four major areas: climate change mitigation, responsible supply chain, reduction of harmful chemicals, and sustainable resource management, with over a hundred assessment items. We believe that either the elements focused on by LCA or the various broad-scope certifications are indeed crucial to product environmental impact. However, for manufacturers in mature industries, such as the display panel manufacturing sector, the differentiation among these factors is minimal. Utilizing such aspects for assessing sustainable products could dilute the impact of design considerations. We argue that greater attention should be directed towards key design aspects related to the environmental impacts of different categories of components.

In addition, the concept of a circular economy is also crucial in the solutions to environmental degradation. The best way to reduce the environmental footprint of products is to ensure that each component can be reused until it must be remanufactured or discarded. By reducing the extraction and production at the source, as well as the final waste, we can prevent environmental damage. As illustrated by the "butterfly diagram" of the circular economy system published in 2012 by the Ellen MacArthur Foundation and McKinsey & Company [1], under the current linear economic model, we expend considerable resources on creating product uniqueness and high differentiation. However, if this mindset does not effectively enable a closed-loop cycle for resources, the impact of electronic waste will inevitably increase year by year. Liquid crystal panel products, as critical components of display product, are highly modular in nature. They include optical films, metal, and plastic parts within the backlight module, many of which have low usage wear and can potentially be reused. Materials such as glass and liquid crystals used in panel cells also have the potential for large-scale recycling and remanufacturing through closed-loop processes. If this economic model can be effectively assessed in the early stage of design, in collaboration with the value chain, and if it can lead to a redesign of the economic model, the concept can materialize. We believe

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that the characteristics of the circular economy, where applicable, should also hold a place in the scoring of sustainable panel evaluations.

Based on the concepts summarized above, along with our comprehensive understanding of the environmental impacts of panels, the focus on product environmental footprints or appropriate certification categories, and the consideration of quantifiable and comparable design differences, we have identified five distinct indicators for evaluating sustainable panel products, as shown in Figure 1. These five indicators are: (1) Recycled Materials Use, (2) Product Energy Efficiency Improvement, (3) Renewable Energy Use (in panel manufacturing), (4) Material Reduction and Manufacture Simplification, and (5) Design for Circular Economy.

In the following chapter, we will elaborate on these topics in greater detail and propose methods for applying the scoring system. Through attention to these aspects and the transparent and visualized information, we can facilitate continuous improvement of product environmental impacts. In practical terms, during communication within the supply chain, we can move beyond merely exchanging financial information to encompassing comprehensive comparisons and discussions of quantifiable environmental impact factors.

Figure 1. There are the indicator items can be categorized into five aspects: the use of recycled materials, energy consumption caused by product use, use of renewable energy, reduction of material usage and simplification of processes, and design for a circular economy.

3. Quantification and Application of the Five Key Aspects

As discussed above, we have selected five aspects of information to establish indicators for sustainable display products. For each aspect, we will create five levels of classification for the sub-items, and we will calculate a cumulative score using a weighting method. The five aspects will yield five score values, each being a positive integer between 0 and 5, with one decimal place. In the following sections, we will disclose the sub-items covered under each aspect and the criteria for the scoring methodology.

(a) Recycled Materials Use: The categories of recycled materials are divided into two types: Post-Industrial Recycled (PIR) materials and Post-Consumer Recycled (PCR) materials. Due to the requirement of optical-grade materials in panel products and the proprietary compositions of various suppliers, the use of PCR is relatively challenging under the current economic model. Therefore, we will still incorporate PIR to mitigate the environmental impacts associated with manufacturing waste. As technology continues to develop and the model of a circular economy is established in the future, we can adjust the weightings to reflect the importance and distinctiveness of PCR materials. The main score definitions are outlined as Table 1.

Table 1. Score definition of Recycled Material Use.

Sub-items	Score definitions	Total Score for Aspects
The proportion of PIR materials in the weight of the panel module.	Adjust the score to a scale of 0, 1, 2, 3, 4, and 5 based on the proportion. (where 0 points represent 0%, 5 points represent 100%, and the intermediate values are designed as equally interpolated values)	Based on the PIR score A and the PCR score B, the final score for this aspect is calculated as the weighted sum (αA +βB) , where α and β represent the respective weights.
The weight proportion of PCR materials in the panel module.		

(b) Product Energy Efficiency Improvement: The sub-item for energy consumption during product use is a single item, and we will refer published energy consumption specifications to derive applicable values for panel modules, and subsequently classify the distinguishability based on the energy consumption values of different products. Since panel module products are not the final goods to end consumers, it is challenging to apply existing energy efficiency labels or regulations, such as Energy Star or ErP, which usually only certify whether the type of product meets specific criteria and do not provide a means to distinguish the degree to which the product surpasses or falls short of those specifications. Therefore, we will develop the potential for distinguishability in this regard. As illustrated in Figure 2, we first need to select reference standard criteria and then publicly indicate the logic behind the designation of the proportion "P%" of the panel module's share of the final product's energy consumption. Subsequently, we will obtain the energy consumption value "R"(watt) based on the specifications for that product. This value will then be used to define the energy consumption level for the product. The main score definitions are outlined as Table 2.

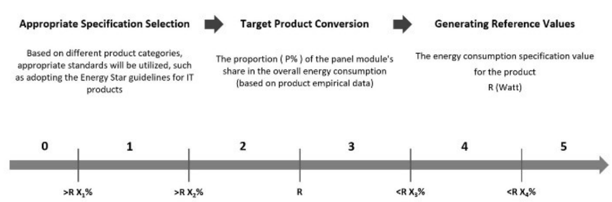

Figure 2. Logic for defining energy consumption scores.

Table 2. Score definition of Product Energy Efficiency Improvement.

Sub-items	Score definitions	Total Score for Aspects
The relationship between product energy consumption and the reference value "R"	Define the proportions X_1 and X_2 for values greater than R, and the proportions X_3 and X_4 for values less than R. Based on these values, determine the score range to which the product specifications belong.	Equal to the score of the sub-items.

(c) Renewable Energy Use (in panel manufacturing): In response to the global trend toward net-zero carbon emissions, the carbon footprint hotspots of panel products still encompass the challenges posed by carbon emissions generated during manufacturing. However, since panel modules are highly electrified products, the ability to utilize renewable energy during manufacturing will significantly impact their environmental effects on climate change. We also recognize that obtaining renewable energy may not be easy, making this aspect of product strategy extremely important. To determine the use of renewable energy in manufacturing, we can establish criteria based on the renewable energy certificates used by the factory to produce the product, and subsequently derive a score. The main score definitions are outlined as Table 3.

Table 3. Score definition of Renewable Energy Use

Sub-items	Score definitions	Total Score for Aspects
The proportion of renewable energy used in product manufacturing.	Adjust the score to a scale of 0, 1, 2, 3, 4, and 5 based on the proportion. (where 0 points represent 0%, 5 points represent 100%, and the intermediate values are designed as equally interpolated values)	Equal to the score of the sub-items.

(d) Material Reduction and Manufacture Simplification: The manufacturing of panel modules is positioned in the downstream segments of the electronics industry. Therefore, we understand that the materials used in the products contribute significantly to the overall environmental impact. For this aspect, we have chosen to assign scores based on quantifiable carbon footprint data. By quantifying impacts in terms of carbon footprint, we can establish a common scoring basis between material factors and manufacturing factors.

Materials in panel manufacturing can be further categorized into two types: (1) required during the manufacturing process and (2) existing in the final product. While we typically consider the materials present in the finished product to have a greater impact, we cannot overlook the materials used during manufacturing processes, as these reflect issues related to chemical usage and process gas emissions stemming from multiple processing steps. Thus, we will include this as one of our points of concern.

Similarly, the challenges arising from multiple processing steps, in addition to those previously mentioned, also lead to increased electricity demand, which should be discussed as well. However, we also recognize that carbon footprint data can vary significantly under different scenario assumptions. Given that panel processing has developed over many years, products that minimize resource use have already been well established. Therefore, we will utilize verifiable data from the in-house carbon management system to define the upper and lower boundaries for the scoring calculation, as shown in Figure 3. The main score definitions are outlined as Table 4.

Table 4. Score definition of Material Reduction and Manufacture Simplification.

Sub-items	Score definitions	Total Score for Aspects
Carbon emissions from materials required during the manufacturing process (A)	Score is assigned based on the respective group, with 0, 1, 2, 3, 4, and 5 points.	Based on the score A, B, and C, the final score for this aspect is calculated as the weighted sum (αA +βB +γC) , where α, β, and γ represent the respective weights.
Carbon emissions from materials Existing in the final product (B)		
Carbon emissions from manufacturing energy (C)	Based on the use of manufacturing energy, with the amount of resources utilized as the calculation basis, score are assigned based on the respective group, with 0, 1, 2, 3, 4, and 5 points.	

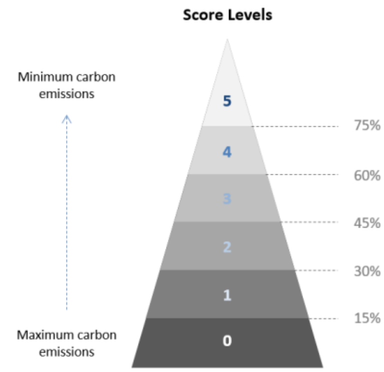

Figure 3. Using carbon emissions as the basis for score calculation.

(e) Design for Circular Economy: The circular economy is one of the best solutions for reducing the environmental impact of final products. However, this aspect cannot be achieved independently by electronic component manufacturers. This is primarily because achieving a fully closed-loop system for a product involves not only decisions within the value chain but also interrelated factors such as consumer habits, the development of business models, and the establishment of recycling chains.

Specifications designed for circularity, investments by manufacturers in remanufacturing processes, the establishment of recycling chains, and investments in product classification capabilities, along with considerations of logistics, information transmission, and economic models, all require collaboration among the various roles in the entire circular chain. Therefore, the scoring in this aspect will primarily be based on a cumulative sum of sub-item scores.

These items will include whether agreements for recycling and remanufacturing have been established with brand customers, thereby promoting a shift towards circular product design and management for both brand customers and manufacturers. We have designed a total of five scoring conditions, primarily focusing on the potential for high circularity in product differentiation. These include whether closed-loop materials are used and whether these materials can re-enter the cycle, whether circular procurement agreements with customers have been established, and actions such as refurbishing or upgrading. Additionally, we will further assess whether the scale of circularity is expanding and whether resource consumption for circularity has been effectively reduced through design. The main score definitions are outlined as Table 5.

Through the scoring of the five aspects mentioned above, we can effectively obtain information on the distribution of the status radar chart and the total score, as shown in Figure 4. Under conditions of sufficient and transparent information disclosure, we can effectively compare the differences between products and identify improvement strategies for each product. Additionally, by applying the concept of graded labels to assign levels to the total scores, the goal is to manage and control the environmental friendliness of multiple products. With this information, electronic component manufacturers can more effectively provide customers with key items regarding product environmental impact and optimized carbon reduction pathways. For the manufacturers themselves, the process of information management can also be used to review product portfolios and effectively propose incentives for establishing circular economy business models, thereby enabling the environmental impact of display products to potentially decrease year by year.

Table 5. Score definition of Design for Circular Economy.

Sub-items	Score definitions	Total Score for Aspects
Whether closed-loop materials are used and if those materials can re-enter the cycle.	If the statement is met, 1 point will be awarded.	The total score obtained for this aspect.
An agreement is reached with brand customers for the recycling of discarded modules, wherein damaged items are replaced or upgraded and returned to the brand customers for resale.	If the statement is met, 1 point will be awarded.	
An agreement is reached with brand customers for the recycling of discarded modules. This includes shared designs among multiple products, such as backlight modules and circuit board components, which are designed for easy disassembly. Damaged items are repaired or upgraded through mutual exchange and returned to the brand customers for resale.	If the statement is met, 1 point will be awarded.	
An agreement is reached with brand customers for the recycling of discarded modules. This includes shared designs among multiple products, such as display components, which are designed for easy disassembly. Damaged items are repaired or upgraded through mutual exchange and returned to the brand customers for resale.	If the statement is met, 1 point will be awarded.	
An agreement is reached with brand customers for the recycling of discarded modules. This includes shared designs for materials among multiple products, which feature easy separability. Damaged items are repaired or upgraded through mutual exchange and returned to the brand customers for resale.	If the statement is met, 1 point will be awarded.	

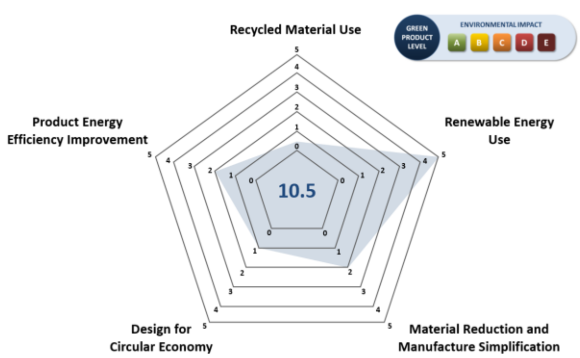

Figure 4. The environmental-friendly radar chart of the product.

4. Conclusion

The environmental impacts of human activities have triggered serious issues, such as resource depletion and climate change, which require urgent attention. Recently, however, many countries and entrepreneurs have committed to achieving net-zero emissions, offering hope for change. As product manufacturers, we must focus on reducing our products' environmental impact by leveraging technology and improving energy efficiency to mitigate waste associated with the traditional linear economy.

This paper highlights the importance of every role in the value chain, stressing that manufacturers must also assume responsibility for environmental improvement. We present a communication framework and practical evaluation methods to identify key sustainability considerations for display panel products, facilitating informed decision-making throughout the value chain.

Additionally, a crucial aspect of data communication is credibility. However, establishing third-party verification can be challenging for manufacturers with a high diversity of products. Moreover, this assessment tool is typically used during the value chain communication phase in product design, rather than after the product sales activities have occurred and the product has been produced, which makes it unsuitable for third-party verification. In this context, we also propose an appropriate practice. We can support the credibility of the database used for calculations by employing third-party audits of data quality. By referring these database resources, we can calculate the data for the five key aspects' sub-item scores and ensure the accuracy and security of the information. Furthermore, the primary purpose of such tools is not to obtain public certification rather to facilitate value chain communication, the need for verification is relatively less pressing. Nonetheless, demonstrating the reliability of information through data quality audits remains essential.

Ultimately, our goal is not only to assess the environmental impacts of products for better management but also to advance circular economy objectives. We have designed indicators that evaluate the implementation of circular economy practices and look forward to promoting circular procurement and utilization in the future.

5. Acknowledgements

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6. References

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