2011 2nd International Conference on Environmental Science and Technology
IPCBEE vol.6 (2011) © (2011) IACSIT Press, Singapore

Challenges and Emerging Solutions to the Development of a Product Carbon Labeling Methodology

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Abstract—**A product carbon labeling methodology has been under development to promote low-carbon production and consumption in Singapore. This paper discusses the challenges and emerging solutions to the development of the methodology. It reviews the major carbon labeling schemes worldwide and highlights a number of methodological issues. The existing and emerging standards for carbon footprint of product are examined to address some of the issues highlighted. Through analyzing the characteristics of the Singapore product systems, the specific challenges facing Singapore carbon footprinting and labeling are identified and potential solutions are explored. This helps remove some hurdles in the development and implementation of the carbon labeling methodology, thus to contribute to Singapore's transition to a recognized low-carbon economy.**

Keywords-Carbon labeling, carbon footprint of product; life cycle assessment; carbon emission reduction

I. INTRODUCTION

A. Carbon Labeling: Concepts and Terminologies

Product carbon labeling, as one of the climate mitigation instruments, is currently undergoing rapid development [1-4]. Carbon labeling aims at reducing greenhouse gas (GHG) emissions through more efficient production methods and more responsible consumption patterns promoted by labeled low-carbon products. It involves measuring the GHG emissions of products (including both goods and services) throughout their life cycle stages and communicating that emission information to the intended users through labels and certificates. As such, carbon labeling helps businesses, organizations and consumers reduce these emissions by making informed choice over the low-carbon products, processes and technologies.

The term *carbon footprint of products* (CFP) is used to describe the measurement result of GHG emissions that a particular product or service will cause during its lifetime. Other commonly used carbon terminologies are listed in Table 1.

B. Background of the Study

The aim of this carbon footprinting and labeling methodology is to promote GHG emissions reduction and energy efficiency in Singapore. By providing methods, tools and emission datasets for quantification and communication of product carbon footprint, the methodological system helps raise the public carbon consciousness for businesses and consumers to practice low carbon, energy efficient production and consumption. The methodology is based on the international CFP standards, including the PAS 2050 [6], the ISO standards for life cycle assessment (LCA) [8, 9] and for carbon footprint labeling [10, 14, 15]. It also references to the product carbon labeling practices in the UK, Japan and Korea.

TABLE I. CARBON TERMINOLOGY

Term	Description
Greenhouse gas (GHG)	GHGs covered in this paper are the six types of Kyoto Protocol gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).
Carbon	Shorthand for the six types of GHGs above.
Carbon footprint	Weighted sum of GHG emissions of a process or a product (that can be any goods or service), expressed in carbon dioxide equivalent (CO_2e).
Carbon dioxide equivalent (CO_2e)	A measurement unit that translates effects of all GHGs into the effect of carbon dioxide. CO_2e is the unit of carbon footprint.
Carbon labeling	Measurement and communication of the carbon footprint of products.
Product life cycle	Consecutive and interlinked stages of a product, from mining raw materials for the product, through its manufacturing and distribution, use and service, to recycling or final disposal of the product.
Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product throughout its entire life cycle.

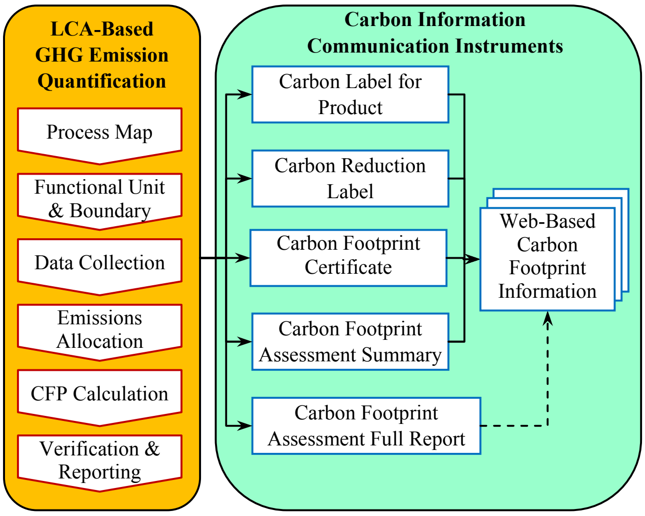

Figure 1. Methodological components for carbon footprinting and labeling of products.

Fig. 1 shows the major components of the methodological system. The quantification of GHG emissions of products is supported by an LCA-based calculation toolkit and a carbon emission database. The calculated carbon footprints are conveyed to the intended users by a set of communication instruments as shown in Fig. 1. Some components in the system have been applied to our pilot projects covering the carbon footprint assessment for food, furniture, packaging and manufactured products [13] since 2009.

II. Existing Schemes of Carbon Labeling

There is a strong momentum in both private-sectors and the public towards carbon labeling [5], which has propelled carbon label schemes/programs proliferating globally. In a recent study, Bolwig and Gibbon [11] identified 34 product or supply-chain carbon labeling schemes worldwide. Among them, 16 are the CFP schemes that are currently in operation. Most of the CFP schemes are from private-sectors owned by a mixture of voluntary bodies and private companies, including some large retailers [11].

The first public and the most widely implemented CFP scheme to date is the carbon labeling initiative of the Carbon Trust in the UK. This scheme consists of three major components to measure, reduce and communicate the life cycle GHG emissions of goods and services:

- A specification, PAS 2050 standard [6], to assess GHG emissions of products over their life cycles;
- A guide, code of good practice [7], to support the robust communication of CFP; and
- A carbon reduction label.

Its labeling methodology is aligned with the LCA framework specified in the ISO 14040 and 14044 standards [8, 9] and the type III environmental labeling principles in ISO 14025 [10]. Besides the UK, the scheme components have been adopted by Australia, Korea, Thailand, etc. By end of 2009, 2400 products and services had the Carbon Trust's labels worldwide [4].

France has adopted the most ambitious approach to product carbon footprinting of any country [11]. The French government is developing a national environmental labeling scheme to introduce *mandatory* carbon labeling for particular categories of products, which would be progressively taking effect by 1st January 2011. The aim is to provide consumers with environmental information to enable their purchase choices, for them to compare between products, and to harmonize environmental labeling communications across France. Pilot projects have been conducted with, for example, the supermarket chains and retailers. The scheme provides CFP guidelines and good practices repository to support the pilots. It also defines standard databases to host GHG emission data.

USA has three major carbon label schemes currently. The CarbonFree Label is developed based on the ISO LCA standards, the GHG Protocol [12] and the PAS 2050 methodology. Another scheme, the Carbon Labels, is designed for the organic food industry in North America. The third scheme for the Climate Conscious Carbon Label is based on hybrid ecoIO metrics to calculate carbon emissions of products. It uses a carbon rating approach to issue a Climate Conscious™ Silver, Gold or Platinum label to an assessed product depending on its carbon reduction percentage.

In Asia, Japan and Korea are forerunners in carbon footprint labeling for products. Japan launched its labeling scheme in 2008. With this scheme, the CO2e emissions produced throughout a product's life cycle is displayed on a carbon label on the package of the product. The labeling system enables customers to choose products with less impacts on the environment, at the same time, encourages businesses to make products with smaller footprints. Specifications [3] and product category rules (PCR) were established to facilitate a national pilot CFP project starting in 2009. By end of 2009, 42 PCRs were certified and 94 products issued with the CFP labels [18] in Japan.

Other existing carbon labeling schemes include: the CarbonCounted label in Canada, the Climatop label of Switzerland, the Product Carbon Footprint label in Germany, EU's Carbon Labels, Australia Carbon Reduction Label, the GHG Emission Certificate and Low Carbon Certificate in Korea, Thailand Carbon Reduction Label and Carbon Footprint Label, etc. Besides these, there are many new carbon labeling initiatives emerging, such as the China's Low-Carbon-Intensive Label, the Taiwan Carbon Label, and so on.

III. Methodological Issues and Standard-Based Solutions

The scientific foundation of CFP calculation is life cycle assessment (LCA) based on the ISO 14040 [8] and 14044 standards [9]. The LCA framework in these standards specifies guidelines, requirements and procedures for: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, results interpretation, critical review and limitations of LCA, conditions for use of value choices, etc.

However, when these LCA principles are applied to carbon footprint assessment, several methodological issues are emerging. They are mainly related to: 1) the lack of standardized LCA calculation methods for CFP assessment; and 2) the needs for additional methods/techniques to address essential aspects of carbon footprinting and labeling of products. These are elaborated as follows.

A. Issues with LCA Calculation Methods for CFP

There is no single LCA method that is universally agreed upon [11]. Different calculation methods interpret and implement the LCA standard principles in different ways. Many of theses LCA-based calculation methods have focused more on impact assessment in LCA, but left unsolved challenges on the inventory and interpretation phases of LCA. Consequently, when such methods are used for product-based LCA in carbon footprinting, they may potentially bring in the following methodological issues.

- Boundary issue: how to define a system for LCA. This includes the coverage over which types of GHG emissions from what emission sources and which life cycle stages to be include in the system boundaries, especially how to handle the use-stage emissions and the Scope 3 emissions [16].
- Data issue: how to deal with the inventory data. It is very difficult to get the consistent, location-specific, and up-to-date inventories for CFP. The data quality, data sharability, and data sources accessibility are also big concerns.
- Allocation issue: how to treat emissions allocation. This is related to two aspects: 1) the lack of specific allocation rules and procedures, and 2) how to analyze and compare the results from different allocation methods, such as system expansion, physical cause-effect allocation, or economic allocation.
- Cut-off issue: how to deal with inclusion/exclusion of emissions in CFP and what cut-off criteria to use, by materiality threshold, GHG emission threshold or any other rules.

B. Issues with Additional Methodological Needs in CFP

Besides the LCA calculation methods, additional mechanisms are needed to present the LCA-based CFP information in simple, clear and understandable carbon label numbers to facilitate consumers' purchase choice. The requirement of labeling products with carbon values can pose new challenges. This is mainly related to the communication, validation and comparison of the calculated carbon footprints.

- Communication issue: how to convey the CFP results in a clear, robust and consistent way to businesses and consumers and what content and format to use for B2B and B2C communications of CFP.
- Verification issue: How and who to verify the labeling methods, GHG inventories, calculation procedures and rules, and CFP results.
- Comparison issue: How to compare CFP labels meaningfully, between the similar products or across the different types of products. The challenge of comparability also involves the disclosure of system boundary assumptions, data sources used, supporting information, and interpretations of the CFP calculation method used.

Substantial efforts have been made to address the CFP challenges, such as those examined in the non-exclusive list above. Included are the standard-based solutions that are detailed below.

C. Standard-Based Solutions

A number of national/international standards have been (are being) developed for carbon footprinting and labeling of products. The most established methodologies include: PAS 2050 [6] for product life cycle GHG emissions assessment, the environmental declaration methodology from ISO [10], the forthcoming ISO methodology for CFP quantification [14] and communication [15], and the GHG Protocol for product life cycle accounting and reporting [12].

PAS 2050 has defined a consistent and comprehensive approach to complex issues in CFP assessment. It provides detailed methods and techniques to identify system boundaries and boundary exclusions, functional unit, emission sources, embedded carbon in products, cut-off rules, data collection requirements, data quality rules, calculation procedures, allocation criteria, and verification of results. The CFP assessment with this methodology covers the entire life cycle stages of a product. The assessment results will produce a single CO2e figure per functional unit as the carbon footprint of the product under assessment.

ISO is currently developing a new CFP quantification methodology in the draft ISO 14067-1 standard [14], as the base for the measurement, reporting and verification of product life cycle GHG emissions. The proposed methodological framework covers the goal and scope definition of the quantification for CFP, inventory analysis for CFP, environmental impact analysis of GHG emissions, interpretation of CFP, and reporting. The GHG emissions arising from all the life cycle stages of a product will be considered. Besides the full CFP assessment, the methodology also allows the partial carbon footprint calculations to cover selected life cycle stages, if relevant rules are followed to enable the partial CFP modules' integration into the full life cycle CFP. The ISO quantification methodology prefers to use product category rules (PCRs) to specify product system boundary, unit, allocation, data, and calculation rules. This would ensure better transparency and comparability of carbon footprints of different products.

Another major quantification methodology is under development by WRI/WBCSD. The unique feature of the methodology is that it covers the GHG accounting and reporting not only for product [12] but also for supply chain [16]. At the product level, by integrating LCA and GHG accounting, the new methodology enables the quantification and aggregation of life cycle GHG emissions into product carbon footprints. At the supply chain level, it provides guidelines to enable businesses to quantify GHG effects throughout the whole product chain beyond their own operating boundaries, thus to allow them to reduce the GHG effects over the whole chain.

The ISO standard on environmental labels and declarations [10] provides a comprehensive methodology for communication of LCA results. It is also applicable to CFP communications. Instead of using the mass- or volume-based methods, this methodology adopts a functional unit based approach to communications of LCA. Principles are specified to ensure the comparability, flexibility, verifiability and transparency in both business-to-business (B2B) and business-to-consumer (B2C) communications. The requirements on environmental declaration content, updating, verification are also provided. Specifically, the procedures for PCR development and review are defined. The methodology has been used in the type III environmental declarations to present LCA-based product environmental information to intended users and to enable PCR-based environmental performance comparison between products.

The CFP-specific communication methodology is being defined in the draft ISO 14067-2 standard [15]. It recommends the use of PCR as the reference to the communicated CFP information. Especially, when a carbon footprint communication is intended for B2C, a carbon footprint PCR should be used. This will allow consumers to integrate footprint information as one of the purchase decision criteria for products comparison. The method emphasizes that "comparison of CFP is only possible if the CFP is quantified in accordance with the same PCR" [15]. Other communication requirements are also defined, such as on interpretation of CFP, content and format for CFP communication, confidentiality of product-specific data during communication, full or partial life cycle GHG emission communication, verification of communication to consumers, etc.

Our carbon footprint assessment projects [13] heavily depend on the above standards. The results showed that with the standard-based solutions and methodologies, most of the challenges identified in Sections 3.1 and 3.2 for CFP quantification and communication can be properly handled. On the other hand, the pilot projects have also revealed some new challenges specifically related to carbon labeling for Singapore products (see next section for details).

IV. Challenges Facing Singapore Product Carbon Labeling and Emerging Solutions

A. Characteristics of Singapore Product Systems

Singapore-made products tend to have characteristics that make it more challengeable to introduce carbon footprinting and labeling at the product-level. These characteristics include:

1) Complex product supply chains

Many Singapore goods and services are involved in long and complex supply chains. For example, the manufactured products can comprise high numbers of components/parts sourced in different locations globally, then channeled back to Singapore for assembly through dense product supply networks. Or, it can be the other way, parts and components made here go through individual product supply chains and long distance transportations to somewhere for making the final products. Though Singapore does not have agriculture, our food industry heavily depends on foreign supplies. The food chains are subject to frequent changes, because of seasons, price fluctuations, currency exchange rates, etc. The GHG LCA for such products with complex supply chain relations would be a very challenging, time-intensive and costly task.

2) Diverse product usage situations and end-of-life options

Singapore is a country surviving on exports. The usage and end-of-life processing of the exported products happen in various locations with diverse use patterns and conditions, or with different end-of-life treatments (recycling, disposal, or remanufacturing, etc). This makes it very difficult to collect/compile emission data at the use phase and end-of-life phase for calculating carbon footprints over the whole product life cycle.

B. Challenges and Potential Solutions to Carbon Labeling for Singapore Products

Some of the LCA-based calculation issues and CFP communication problems have been discussed in previous sections. In particular, the issues of defining boundaries, collecting inventory data, and making CFP comparable have attracted great attentions. To those issues discussed earlier can be added the specific challenges featured out from the characteristics of Singapore product systems. They are mainly associated with the three aspects in: product chain complexity; low-cost footprinting and labeling; and effective conveying of more disaggregated carbon information at the product-level to businesses and consumers.

1) Product chain complexity challenge and solution

Product chain complexity can be an issue in the implementation of the current methodology, because the complex chain makes it very difficult to derive a carbon footprint, with sufficient accuracy within reasonable resources, for a product tracing out across the chain. In this situation, the CFP calculation may need suppliers to provide emission data. It may also require certain emission knowledge of the foreign product systems.

With this methodology, the challenge is addressed by encourage supply chain partners to provide CFP certificates or life cycle emission data of their products. On the other hand, carbon emission databases for supply chains need to be developed. They would keep and track the relevant supply chain emission data for the use in CFP calculations.

2) Challenge and solution to low-cost CFP

Another challenge with the implementation of the labeling methodology is the cost and effort required for product carbon labeling and certification. A detailed product-level GHG LCA is usually costly and time consuming, which may prevent rapid and widespread adoption of carbon labels. When a product is exported overseas, the data collection for its use phase and end-of-life phase tends to be high-cost and low-accuracy.

In our pilot projects [13], a low-cost approach was used to perform simplified LCA calculations with satisfactory accuracy for some manufactured or food products. To further improve the cost efficiency for CFP assessment, the current labeling system is developing a comprehensive emission factor database and a carbon footprinting toolkit with the standardized calculation procedures and reporting formats. With such a database and toolkit, it is expected to reduce GHG LCA calculation effort and time, and to improve the assessment quality, thus to make the carbon footprinting and labeling more cost effective.

3) Challenge and solution to communication of specific carbon information

Sufficient release of the calculated CFP information would benefit businesses and consumers for their informed action on carbon reduction, and the disaggregated emission data at different levels would cater for their different information needs. However, this requirement would pose another challenge. The confidentiality of product-specific information may raise concerns from the data owners.

To address this issue, the approach taken in our methodology is through design of different communication instruments with different levels of information release. The designed communication instruments include: the carbon labels for products, carbon reduction labels, carbon footprint certificates, carbon footprint assessment summaries, and full reports for CFP assessment (refer to Fig. 1). Web-based representations are also defined for posting of these CFP documents, except the full reports (on request). As such, this approach will help remove the data confidentiality concerns of companies and encourage them to fully disclose their product footprints.

V. CONCLUSION

Carbon footprinting and labeling for products is a new instrument to promote GHG emission reduction and energy efficiency in Singapore. It may also improve the competitiveness of Singapore's exports through differentiating Singapore goods and services with certified low carbon footprints. Our experiences with the carbon assessment projects have demonstrated the potentials for labeling footprints of products to stimulate reduction in carbon emissions by both businesses and customers. However, the full-scale implementation of the labeling methodology and its success require innovative solutions to proper handling of product chain complexity for CFP; provision of low-cost inventories and calculation tools; effective conveying of the disaggregated carbon information to intended users; and so on.

There is clearly a need for more studies on carbon labeling methodologies and practices. Our next focus will be on carbon footprint analysis: 1) to identify carbon hot-spots for production process improvement; and 2) to understand the effect of consumption pattern changes on GHG emission reduction. The findings will be used to enhance our software toolkit, emission databases, and the carbon footprinting and labeling methodology.

ACKNOWLEDGMENT

The authors wish to thank the STA members of SIMTech and the NTU attachment students, Mr. X. Hu and Mr. Y. Sheng, for their support and literature collection in this study.

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