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Challenges facing carbon dioxide labelling of construction materials

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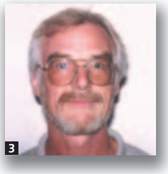

In the absence of a benchmarking mechanism specifically designed for local requirements and characteristics, a carbon dioxide footprint assessment and labelling scheme for construction materials is urgently needed to promote carbon dioxide reduction in the construction industry. This paper reports on a recent interview survey of 18 senior industry practitioners in Hong Kong to elicit their knowledge and opinions concerning the potential of such a carbon dioxide labelling scheme. The results of this research indicate the following. A well-designed carbon dioxide label could stimulate demand for low carbon dioxide construction materials. The assessment of carbon dioxide emissions should be extended to different stages of material lifecycles. The benchmarks for low carbon dioxide construction materials should be based on international standards but without sacrificing local integrity. Administration and monitoring of the carbon dioxide labelling scheme could be entrusted to an impartial and independent certification body. The implementation of any carbon dioxide labelling schemes should be on a voluntary basis. Cost, functionality, quality and durability are unlikely to be replaced by environmental considerations in the absence of any compelling incentives or penalties. There are difficulties in developing and operating a suitable scheme, particularly in view of the large data demands involved, reluctance in using low carbon dioxide materials and limited environmental awareness.

1. Introduction

Excessive greenhouse gas (GHG) emissions have been recognised as the root cause of anthropogenic climate change (IPCC, 2007). Scientists propose capping atmospheric carbon dioxide concentrations, the most prominent GHG, to below 450 parts per million with a desire to hold increases in global temperature to less than 2°C (Baer and Mastrandrea, 2006). This requires global emissions to be reduced to 60–75% of 1990 levels by 2020 (UNFCCC, 2007). Many countries around the world are adopting a variety of mandatory or voluntary measures to control GHG emissions and, to mitigate climate change and reduce GHG emissions, several developed countries have even committed to a long-term goal of reducing global GHG emissions by at least 50% by 2050 (G8 Summit, 2009). In 2009, the manufacturing and construction industries attributed approximately 13% of the total GHG emissions in the UK, US and European Union (UNFCCC, 2011). It is clear, therefore, that the construction industry has a major role to play if emission reduction targets are to be realised (González and Navarro, 2006).

Over the last decade, various building environmental assessment (BEA) methods and tools have been developed for appraising the environmental impact of buildings. These include Leadership in Energy and Environmental Design (LEED) in the USA, the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK, Green Star in Australia, Green Mark in Singapore and the Hong Kong Building Environmental Assessment Method in Hong Kong. While these tools have some useful attributes for the analysis of building designs (Veys, 2008), most construction industry energy considerations are made with respect to the post-occupancy phase (Dias and Pooliyadda, 2004). Although the energy used, and consequential carbon dioxide emitted, during the occupation of a building contributes to the majority of a building's lifetime 'carbon footprint', there are significant carbon dioxide consequences involved in the construction phase of a building (Monahan and Powell, 2011).

Previous studies have indicated that the manufacture of construction materials alone contributes as much as 70% of the GHG emissions in the construction stage (Smith *et al.*, 2005) and 15% of a building's lifetime energy consumption (Harris, 1999). The extraction, processing, manufacture, transportation and use of a product utilises energy and induces many environmental impacts, including the emission of GHGs. With the exception of the generally more evident energy in use, these impacts are regarded as hidden or embodied burdens. Fieldson *et al.* (2009) have stressed the importance of making the best decisions in the choice of materials in the early stages of projects to effectively reduce overall lifecycle emissions. Embodied energy and carbon dioxide are not, in current practice, generally taken into consideration when a building is designed, specified and constructed (Clarke, 2010; Monahan and Powell, 2011). Therefore, it is highly desirable to minimise the output of GHGs through the prudent selection of environmentally friendly or low carbon dioxide construction materials (Chau *et al.*, 2007; Hill and Bowen, 1997).

A practical mitigation mechanism for reducing carbon dioxide emissions that is undergoing rapid development is carbon dioxide labelling (Brenton *et al.*, 2008). However, unlike consumer products, a construction facility is unique, with its materials being chosen by the owner, design team and constructor on a project-by-project basis according to the time, cost, quality, safety and environmental requirements involved. While various materials of dissimilar properties may fulfil the same function, and as different construction techniques can be deployed by the contractor on site, devising a reliable carbon dioxide auditing and benchmarking mechanism for construction materials is a major challenge. This paper reports on a recent in-depth interview survey of informed opinions and concerns of stakeholders in the construction industry of Hong Kong on the potential and challenges for labelling the carbon footprint of construction materials. The paper begins by outlining the current efforts concerning the carbon footprint of construction materials. The essential considerations of a carbon dioxide label for construction materials as envisaged by the interviewees are then reported. Finally, the paper highlights the possible implications for a carbon dioxide labelling scheme in the construction industry.

2. Carbon dioxide labelling of materials

According to the UK Carbon Trust (2007), carbon dioxide labelling involves measuring the carbon footprint from the production of products or provision of services to conveying the information to consumers or those who make sourcing decisions within companies. Well-designed schemes should create incentives for the production of different parts along the supply chain to lower material emissions. Thus, a carbon dioxide label is an instrument that enables construction professionals and policy makers to make appropriate choices of building materials. In addition, research has shown that carbon dioxide labelling is a valuable way for companies to demonstrate their carbon dioxide commitments to clients and thereby enhance their corporate image and reputation (Sullivan and Burke, 2009).

With the ever-increasing awareness of the strong links between the environment and the economy, clients have an undeniable obligation to ensure their projects are environmentally responsible by introducing measures into the construction process (Sterner, 2002; Suzuki *et al.*, 1995). Many governments have put forward various policy initiatives to reduce their country's carbon dioxide emissions. For instance, a study has been commissioned by the Hong Kong Housing Authority (HKHA, 2005) concerning the combined lifecycle assessment and lifecycle cost of building materials and components and an integrated decision support tool has been developed to compare and contrast material and design alternatives for public housing development based on their environmental impact. A similar study has also been conducted by the electrical and mechanical services department of the Hong Kong SAR government, which aimed to produce an assessment tool to facilitate designers appraising the lifecycle performance of commercial building developments in the city (EMSD, 2006). However, as secondary lifecycle inventory data were retrieved from proprietary databases, the embodied carbon dioxide for specific batches of materials (i.e. the primary data) was not assessed.

However, problems arise as there is no unanimous definition of low carbon dioxide materials nor an agreed method for evaluating the lifecycle GHG emissions of construction materials (Chau *et al.*, 2007). Existing carbon dioxide assessment methods, including the PAS 2050 and ISO 14060 series, are essentially a set of norms or guidance manuals rather than tools for calculating product or service carbon footprints, and hence they have to be supported by appropriate quantitative tools and datasets based on established guidelines. There are a number of footprint calculation tools available, but few of these apply lifecycle approaches suitable for the construction industry, primarily due to their diverse calculation methodologies and region-specific datasets (Fieldson *et al.*, 2009). Hence, a carbon dioxide labelling framework and labelling system tailored to the construction industry, which takes into account the embedded energy and GHG emissions of various types of construction products, and which constantly monitors and controls GHG emissions at the product level, would be indispensable.

In the absence of any established carbon dioxide labelling framework for construction materials, a series of semi-structured face-to-face interviews was conducted with experienced practitioners in Hong Kong. A total of 18 experts occupying senior management positions in various sectors, including the government, consultants, contractors, suppliers and non-government organisations (Table 1), agreed to share their views on the topic. As all the interviewees are at senior management level, a more flexible interviewing approach was considered to be more suitable so as to facilitate a free flow of ideas. Therefore, without being constrained by predetermined questions, the interviewees were encouraged to express their opinion on open-ended questions relating to

- the potential implications of a carbon dioxide labelling scheme for construction materials
- the envisaged carbon dioxide label for construction materials
- strategies for implementing a carbon dioxide labelling scheme.

The issues covered in the interviews were analogous to other similar research on energy-efficiency policy (Savacool, 2009) and carbon footprint standards and schemes (Bolwig and Gibbon, 2009). The questions used in the interviews are listed in the Appendix and the results are summarised and discussed in the following sections.

The findings reported in this paper rely on the fundamental concepts of the ‘content analysis’ research method in designing the survey component and analysing the interview dialogues. According to Weber (1990), content analysis can help classify textual materials and reduce them to more relevant and manageable items of data. The method is also widely applied to obtain the necessary information and understand the issues that are relevant to the general aims and specific questions of a research project (Gillham, 2000). In this research, the interviews were audio-recorded and then transcribed into written dialogues. A systematic account of the information obtained from the interviews was archived and analysed in a matrix table format using the content analysis method so as to establish similarities and differences of the interviewees’ opinions.

3. Current efforts concerning the carbon footprint of materials

The key findings of the interview survey are summarised in Table 2 and details are provided in the following sections.

3.1 Existing low carbon dioxide initiatives for construction materials

All the experts interviewed generally considered that a well-designed carbon dioxide label for construction materials would encourage the use of low carbon dioxide materials in constructing various building and civil engineering facilities. However, as commented by some interviewees, despite a growing awareness among developers, government and investors concerning the need for a low carbon dioxide environment, no carbon dioxide labelling scheme of any kind has been implemented that industry stakeholders can consult when choosing construction materials. In situations where environmental certification and recognition are needed for the construction industry, BEA schemes are usually adopted. Although BEA schemes incorporate the use of low carbon dioxide materials as one of their assessment criteria,

	Position	Background of organisation	Indicator
1	Deputy director	Government	G1
2	Assistant secretary	Government	G2
3	Chief architect	Government	G3
4	Senior architect	Government	G4
5	Architect	Government	G5
6	General manager	Developer	D1
7	Deputy general manager	Developer	D2
8	Product manager	Supplier	S1
9	Risk manager	Supplier	S2
10	Technical director	Supplier	S3
11	Director	Supplier	S4
12	Managing director	Contractor	Cr1
13	Environment manager	Contractor	Cr2
14	Deputy chairman	Consultant	Ct1
15	Director of building sustainability	Consultant	Ct2
16	Senior engineer	Consultant	Ct3
17	Senior team leader	Consultant	Ct4
18	Chief executive officer	Non-government organisation	NGO

Table 1. Summary of interviewees’ profiles

	G1	G2	G3	G4	G5	D1	D2	Ct1	Ct2	Ct3	Ct4	Cr1	Cr2	S1	S2	S3	S4	NGO	Total
Current efforts concerning the materials' carbon footprint																			
■ A well-designed carbon dioxide label for construction materials could encourage the use of low carbon dioxide materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	18
■ Despite growing environmental awareness, no carbon dioxide labelling scheme has been implemented in the local construction industry		✓				✓						✓	✓	✓	✓		✓		7
■ Some industry stakeholders have devoted much effort to reduce the carbon dioxide footprint of construction materials	✓	✓						✓		✓					✓				5
■ Cost, quality and durability are the major determinants in the choice of construction materials; consideration given to the environmental aspect is limited						✓	✓				✓	✓		✓			✓	✓	7
The envisaged carbon dioxide label for construction materials																			
■ Carbon dioxide label should indicate the lifecycle GHG emissions in terms of carbon dioxide equivalent (CO_2e), in addition to a benchmark rating of the material		✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓		13
■ A simple carbon dioxide label showing the carbon dioxide intensity with reference to the 'Carbon Reduction Label' developed by the Carbon Trust in the UK is appropriate					✓		✓	✓			✓			✓	✓				6
■ Apply the carbon dioxide label to the raw materials only		✓	✓		✓			✓			✓			✓			✓	✓	8
■ Apply the carbon dioxide label to a higher level (e.g. building components, entire building)				✓	✓						✓		✓	✓					6

Table 2. Summary of interview findings on carbon dioxide labelling for construction materials (continued on next page)

	G1	G2	G3	G4	G5	D1	D2	Ct1	Ct2	Ct3	Ct4	Cr1	Cr2	S1	S2	S3	S4	NGO	Total
■ Benchmark should be set using GHG emission level at the international standard, with proper adjustment to suit local industry capacity and technological level	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	14
Implementation strategies																			
■ Assign a certification body to implement the carbon dioxide labelling scheme and publish guidelines on how to conduct the carbon footprint assessment	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	16
■ Initiate the carbon dioxide labelling scheme on a voluntary basis	✓	✓		✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	15
■ Government participation is key to successful implementation of the carbon dioxide labelling scheme.		✓						✓				✓	✓	✓					5
■ Embed the carbon dioxide labelling mechanism into a building environmental assessment tool			✓	✓				✓	✓										4
■ Provide some incentives to private developers using low carbon dioxide materials	✓					✓		✓			✓					✓			5
Implications of carbon dioxide labelling																			
■ Carbon footprint assessments and labelling may involve extra start-up cost													✓				✓	✓	3
■ Developing a carbon dioxide label for each of these materials will involve a large amount of resources and effort (e.g. data acquisition and verification)	✓		✓	✓	✓	✓			✓	✓	✓	✓		✓			✓	✓	12
■ Deep-rooted local construction practices may override the selection of construction materials with carbon dioxide labels	✓	✓	✓					✓	✓	✓	✓		✓	✓	✓	✓			11
■ Limited environmental awareness is likely to be a barrier to the acceptance of carbon dioxide labelling in the local industry	✓			✓		✓			✓	✓		✓	✓	✓		✓	✓	✓	11

Table 2. Continued

they do not provide a clear mechanism for the measurement of the carbon footprint of construction materials. The use of low carbon dioxide emission materials merely serves as one of the many environmental criteria for overall certification.

Some of the interviewees pointed out that the public sector has taken some initiatives pertaining to environmental protection. One interviewee (G1) stated that some public authorities have devoted much effort to the selective use of construction materials in order to reduce the overall carbon footprint, for example 'eliminating plaster finishes and just applying paint on the fair face concrete wall surface can minimise the environmental impact without compromising building quality'. Furthermore, a series of research and pilot studies has been conducted by the government on the potential of novel and environmentally friendly materials that are available in the market.

Several initiatives have also occurred in the private sector. One of the construction material supplier interviewees (S2) has conducted an in-house carbon footprint audit of its own products as a result of the supplier's joint venture with a European company, providing exposure to overseas expertise in conducting carbon dioxide audits. Their carbon footprint audit is also seen as a means of improving the organisation's energy efficiency. The carbon footprint audit accords with the World Business Council for Sustainable Development's GHG accounting protocol and commenced in 2009. Subsequent GHG emission reduction measures were implemented and the outcome has brought about reductions in both carbon footprint and production costs. However, no benchmarking mechanism currently exists to further position themselves in terms of carbon dioxide emission levels in the industry and among all other business sectors. As S2 urged

> the implementation of a broader local carbon footprint mechanism and labelling scheme is imperative and timely in order to promote good practice in carbon reduction in addition to improving the energy efficiency of the construction industry as a whole.

Another material supplier interviewee (S1) commented that there is currently a high level of environmental awareness concerning indoor finishing materials, as these have a more direct contact with (and greater health impact on) end users. However, environmental certification schemes for indoor finishing materials focus on achieving an acceptable level of potentially harmful emissions, such as volatile organic compounds.

In short, most of the contractors and suppliers interviewed are generally not aware of any local carbon footprint schemes being applied to construction materials. Given their low profit margins, they are naturally far more concerned with the cost of the materials. Consequently, in order to contribute to the reduction of GHG emissions generated by construction materials, there will need to be either the provision of sufficient financial initiatives or an increase in demand by designers and developers for appropriate substitute materials.

3.2 Criteria for selecting construction materials

One practical issue is the availability of materials. In many cases, the government needs to provide many new infrastructure and construction facilities in the short and medium term, with a concomitant need for a considerable quantity of construction materials. In addition to basic functional requirements, they have to consider various criteria in their selection of these materials – not least their cost, quality, durability and environmental impact. As some of the government interviewees (G3 and G4) observed, although the public sector is keen to incorporate carbon footprint considerations into their material selection process, actual implementation will depend largely on the maturity of a local-based carbon dioxide labelling scheme and the availability of low carbon dioxide construction materials in the market – both of which are likely to need a lengthy development period.

Another issue is one of priority. As one of the consultant interviewees (Ct4) pointed out, smaller developers tend to leave the maintenance of finished buildings to end users and occupants, and therefore their primary concern is the financial return provided by the sale or rent of the building. One of the most important aspects is therefore the appearance of building materials in order to attract buyers or tenants. This perspective is different from the public sector as the government would select materials by considering their environmental impacts (G1 and G2). However, in cases where developers are responsible for the maintenance of completed projects such as commercial buildings, they do place more emphasis on the durability and quality of the materials than on their costs. As one developer interviewee (D1) admitted 'after basic requirements (including those concerning the environment) are met, we tend to choose the cheapest construction materials as much as possible'. This further reflects the importance of the public sector in driving and providing incentives for the use of low carbon dioxide materials in the construction industry.

As an indoor finishing material supplier (S1) stressed, suppliers face a similar situation – the preferences of their clients being the key consideration when choosing finishing materials, with environmental impacts of lesser importance – opining

> sometimes, both clients' needs or wants and environmental considerations do coincide. For example, odour is one of our clients' concerns as it affects indoor air quality. In this case, therefore, the environmental impact of the indoor finishing materials is taken into account indirectly in responding to the client's wishes.

One supplier interviewee (S4) also spoke from the contractors' perspective in acknowledging cost, quality and durability to be the major determinants in the choice of construction materials. Clients' requirements are crucial in the material selection process from the contractors' perspective and currently there is only very limited consideration given to their environmental impact.

4. The envisaged carbon dioxide label for construction materials

4.1 Carbon dioxide auditing

The expectation is that designers and specifiers will use carbon dioxide labels to select materials with relatively low carbon dioxide content for their buildings. The majority of the experts interviewed agreed that the carbon dioxide label should indicate the lifecycle GHG emissions in terms of carbon dioxide equivalent (CO_2e), in addition to a benchmark rating of the material. But, as one of the interviewees (Ct1) recognised, aiming at assessing the carbon dioxide footprint of construction materials 'up to the gate' (the construction site only) is more likely to succeed because assessing GHG emissions from cradle to grave is more difficult than just assessing the finished product. To overcome this, interviewee G2 suggested that

> for recycled construction materials, their carbon content can be audited in two possible ways: (i) the content of the recycled material among the construction materials and (ii) the proportion of construction materials that can be sent for recycling at the end of their product life.

The former is preferable for carbon dioxide labels as it would be difficult to predict the extent to which demolished construction materials will be recycled when using the latter approach.

One interviewee (G1) recommended adding lifecycle cost information to the label by elaborating GHG emissions according to several major lifecycle stages or activities (cf. Thomson *et al.*, 2011) such as those of production and transportation. Another interviewee (G2) suggested an alternative way would be to display only the total GHG emissions, while retaining GHG emission levels for different lifecycle stages in a database for further enquiry by users when needed, as this would help make the label as clear and simple as possible.

Further possibilities also exist for information provision. For example, in relating experiences to date with the carbon dioxide auditing process, one of the supplier interviewees (S2) noted that his organisation's internal carbon footprint auditing scheme now provides data on total GHG emissions, the intensity (per tonne of concrete or cement being produced), GHG emissions from administration procedures and GHG emissions per million dollars of the company's turnover. On the other hand, it was pointed out that some energy labels can be difficult to understand. As one interviewee (G5) intimated

> for the general public, a carbon label is easier to understand because the impact of the labelled product on climate change is expressed by a single GHG emissions value, while other eco-labels consider numerous environmental indicators.

What is needed, therefore, is a simple carbon dioxide label, with only the major carbon footprint values being shown. Several interviewees (D2, Ct1, Ct4 and S1) suggested adopting a form of the Carbon Reduction Label developed by the Carbon Trust in the UK for local-based carbon dioxide label as it is easier to recognise and understand.

An additional problem concerning the lifecycle issue is that the GHG emissions of construction materials arising from repair and maintenance works are difficult to measure during the operational stage. As one of the suppliers (S3) pointed out:

> an alternative is for the expected service life of the material to be stated on the label, as this should help differentiate different project types – such as those for residential and commercial buildings – so that a fair comparison can be made between projects.

Another theme concerns the classification of construction materials for labelling. For example, the classification adopted at the interviews was: L1, raw materials (e.g. cement); L2, building materials (e.g. concrete); L3, building components (e.g. façade). Opinions of industry stakeholders on these are quite diverse, however – even among the government interviewees, the views were quite different. One (G3) would prefer the carbon dioxide label to be applied to raw materials only, as finished construction materials may change in composition and form with advancements in technology. Another (G4) considered that the building component level (i.e. the top level), in terms of the functional unit, would be a more convenient way for decision makers and designers to deliver a low carbon footprint design. One supplier interviewee (S1) thought carbon dioxide labels should be provided on both raw materials and functional units, with a consultant interviewee (Ct4) further advocating that the label cover all three levels (L1, L2 and L3). An interviewee from a government department (G5) suggested that 'computer software such as building information modelling (BIM) should be developed to assist the complicated process of estimating the overall carbon footprint of the finished structure'. Further investigations are clearly needed to determine the practicality and effectiveness of these opinions before a solution is reached to ensure an adequate trade-off is made between fulfilling the desired functions of the carbon dioxide label and the effort involved in generating the label.

One interviewee (Ct2) further suggested having an overall carbon dioxide label to certify a completed building's GHG emission performance as a guide for designers and developers in selecting low carbon dioxide materials. At the same time 'this would allow the general public and end users to appreciate the overall performance of the building and let those investing in building construction gain some recognition for their social commitment'.

4.2 Benchmarking mechanisms

Benchmarking is one of the basic features of carbon dioxide labelling. For example, it should be possible to categorise construction materials or building components into, for example, gold, silver or bronze standards by means of careful benchmarking exercises. One suggestion made by interviewee G1 was to set a benchmark for a material by using its average GHG emission level from as many producers as possible around the world. It was also considered that adopting international standards as benchmarks for the carbon dioxide label would help ensure the standards set for a country are aligned with international standards so that international clients would have a better incentive to include the label in their development requirements (D2 and S2). On the other hand, most interviewees stressed that the benchmark should be adjusted to local industry capacity and technological level to ensure it is practical and achievable. However, as supplier interviewee (S2) insisted, 'the benchmarking should be based solely on local construction materials, as using overseas data may be inappropriate for the local situation'. Therefore, data acquisition is a critical challenge when setting up benchmarks for a carbon dioxide labelling scheme.

5. Implementation strategies

Most interviewees agreed that a certification body would be needed to implement the carbon dioxide labelling scheme and publish guidelines on how to conduct carbon footprint assessments; it was suggested that allocating the auditing task to such a body would be the most effective way for government to promote the initiative. An alternative is for academic bodies and private entities to form such an organisation.

All interviewees were convinced that, in order to avoid any conflict of interest, acquisition of the necessary GHG emission data throughout the lifecycle of construction materials should be the responsibility of an impartial and independent agency or expert. One view (G2) was that the activities of a certification body could also be extended beyond sourcing GHG emissions data to the regular maintenance and verification of an emissions database. Either way, the need was voiced for the carbon dioxide auditors and assessment experts to be suitably qualified in a similar way to the existing BEA (e.g. Leed or Breeam) certification mechanism (interviewee D1).

Most interviewees agreed that the carbon dioxide labelling scheme should be carried out on a voluntary basis during its initial implementation phase. A voluntary scheme would allow the industry to familiarise itself with the scheme and its related procedures, and also create a buffer for the training of experts in carbon footprint assessment and certification. An early launching of the scheme was urged to prevent it losing impetus and that, when it is launched, government should support the scheme by applying the carbon dioxide labelling concept for its own construction projects. By doing this, private sector organisations should also learn how to adapt to the carbon dioxide labelling scheme when they bid for government projects. A number of interviewees (G2, S1, Ct1, Cr1 and Cr2) also insisted that government participation would be the key to successful implementation of such a scheme.

Once established in this way, it was felt that regulations, codes of practice and even legislation would need to be enacted in order for the framework and procedures to be more widely acceptable to the industry. Again, embedding the scheme into a BEA was recommended (by interviewees G3, G4, Ct1 and Ct2) and referring to similar carbon footprint assessment and green building schemes in other countries would help obtain wider recognition for the scheme.

Another suggestion concerning implementation was to provide some incentives to private developers using low carbon dioxide materials (G1, D1, Ct1 and Ct4). One supplier (S3) further recommended introducing a reward and penalty mechanism for material suppliers by comparing the GHG emissions of the materials they supply against a set benchmark.

6. Implications of carbon dioxide labelling

6.1 Potential benefits

Of course, successfully implemented carbon dioxide labelling would generate a greater market potential for those construction materials that are labelled, responding to the need for companies to differentiate themselves by increasing their competitive edge. Taking such green initiatives is a possible way of enabling companies to establish a good business brand name and, through carbon footprint assessment of their construction products, exert an influence on raw material suppliers to reduce the upstream GHG emissions of the product lifecycle.

Green initiatives such as carbon footprint assessments and labelling may involve extra start-up costs and, according to some interviewees (Cr2, S4 and NGO), construction companies often see them as a burden on their operations. However, as one contractor (Cr1) pointed out, high competition in the supply market should reduce the long-term cost of low carbon footprint materials. Even in the short-term, one developer (D2) had found that the final costs involved in realising environmental/energy savings may not be as high as expected if certain targets are set for a project at the outset. Also, one interviewee's (D1) organisation even considers a carbon footprint assessment to be a both a tangible benefit on energy efficiency and an intangible benefit in terms of a better brand name. Similarly, another interviewee (S2) found that cost savings can be induced as a result of the identification of processes that involve greater energy and waste reduction in in-house carbon dioxide audits for carbon footprint assessment. Therefore, their organisation has a strong incentive to conduct carbon footprint assessments despite the start-up costs involved, with the interviewee adding that 'we wish to differentiate from others, so green initiative may be a factor for them to sustain their business, not a burden'.

6.2 Challenges

One of the major difficulties mentioned by most interviewees is the proliferation of building materials in the market. Developing a carbon dioxide label for each of these materials will involve a large amount of resources and effort. Therefore, it is necessary to carefully categorise construction materials with similar properties and GHG emissions for the scheme to operate efficiently.

Many interviewees (G1, G3, G4, G5, Ct4, NGO, S1 and S4) commented on the problem of data acquisition and verification. One issue is the scale involved. Cement is one example – there can be more than 100 activities involved in its manufacture, with every activity emitting some GHGs and making it very difficult to collect all the emissions data required. Here, the hope is to begin with few production activities that produce the greatest intensity of GHG emissions to capture at least 80–90% of the entire lifecycle GHG emissions involved. Another issue is that the data for GHG emissions assessment are difficult to obtain as this often involves the collection and release of sensitive business information concerning stakeholders along the material supply chain (interviewees G3 and S3). Supplier S2 stated that overseas carbon footprint data may also need to be modified to take into account differences in transportation mode, waste treatment and power generation efficiency. Likewise, it is difficult to verify the data as many building materials are imported from elsewhere, where geographical diversity makes the verification process very complicated (interviewees G2 and G3).

As different construction materials are used in different types of projects, most interviewees felt that a few commonly consumed construction materials (e.g. cement, reinforcing bars, structural steel, tiles and glass) should be chosen for initial development of the carbon dioxide labelling mechanism. However, it is likely to be difficult to further expand the list of construction materials in a country. For example, one government interviewee (G1) had tried to identify the largest lifecycle environmental impact and establish possible remedial actions for 10–20 construction materials by conducting material selection forums with 200 competing participants. The results were found to be very different depending upon the background of participants and the organisations involved. For instance, organisations specialising in domestic buildings proposed construction materials very different from those used in commercial buildings. As a result, it was concluded that a satisfactory solution would only be possible with the collection of some additional statistical data.

Many interviewees also believed that deep-rooted local construction practices may override the selection of construction materials with carbon dioxide labels. As the engineering design and construction process for a particular type of structure is well established and highly efficient, even if an alternative material or design with a lower carbon footprint is identified, the developer may not be willing to switch as it could reduce the efficiency of the construction processes involved. It was also asserted that the level of general environmental awareness is quite low, which is likely to be a barrier to the acceptance of carbon dioxide labelling in the local industry. One solution appears to be better public education concerning the environmental impact of construction materials.

A final comment from a government interviewee (G2) concerning construction material supply was that, as the construction market is relatively small in most countries, the implementation of any carbon dioxide labelling scheme may deter some material suppliers from meeting the local carbon footprint standard. Instead, they might choose to focus on other emerging markets with less environmental restrictions – to the obvious detriment of the local market.

From the above findings, interviewees across the industry spectrum had a consistent stance on the following views.

(*a*) A well-designed carbon dioxide label could stimulate demand for low carbon dioxide construction materials.
(*b*) The carbon dioxide labelling framework should strive to assess GHG emissions during different stages of the lifecycle of construction materials.
(*c*) Adopting international standards while retaining sufficient local integrity when setting benchmarks for the local-based carbon dioxide labelling scheme would enhance the credibility of the scheme.
(*d*) The roles of administering and monitoring the carbon dioxide labelling scheme should rest with an independent certification body.
(*e*) It would be prudent to implement the carbon dioxide labelling scheme on a voluntary basis.
(*f*) Developing such a labelling scheme would necessitate a huge amount of resources.

(*g*) There may be reluctance in the use of the labelled materials.
(*h*) Low environmental awareness is a barrier to the uptake of any carbon dioxide labelling schemes for construction materials.

7. Conclusions

Although the use of low carbon dioxide construction materials is one of the assessment criteria of the commonly adopted BEA schemes, they fail to provide a clear mechanism concerning measurement of carbon footprints. In the absence of a benchmarking mechanism that is particularly designed to cater for local requirements and characteristics, a carbon footprint assessment and labelling scheme for construction materials is urgently needed to promote carbon dioxide reductions in the industry. This paper reports on a recent interview survey of 18 senior and experienced industry practitioners to elicit their knowledge and opinions on the potential of such a carbon dioxide labelling scheme. The interviewees represent a broad spectrum of construction stakeholders, including the government, consultants, contractors, suppliers and non-government organisations.

The results of the survey indicate that a locally based carbon dioxide labelling framework should assess the GHG emissions of different stages of construction materials' lifecycle. However, cost, functionality, quality and durability are still the most important considerations when selecting materials for construction projects. At present, the industry will only consider the environmental impact of materials when these criteria are fulfilled. However, the interviewees expected that selection of low carbon dioxide materials would be driven by clients once a local carbon dioxide labelling scheme was fully implemented.

The problem is aggravated by a lack of agreement on the level at which to label products. One view is that an overall carbon dioxide label for the finished building or structure is needed to demonstrate environmental awareness to the general public and clients. An alternative is that the carbon dioxide label should be applied only at the raw materials level as the composition and form of the finished construction materials may eventually change. On the other hand, there is some support for labelling at the building component level as it would be more convenient for decision makers and designers to deliver low carbon footprint designs this way.

A general consensus exists that benchmarking is one of the basic features of carbon dioxide labelling. Adopting international standards as benchmarks for a locally based carbon dioxide label was seen as beneficial to ensure that the standards of a country are aligned and international clients have a stronger incentive to include the material labelling requirements in their developments. On the other hand, the benchmarks also need to be adjusted to the local industry's capacity and technological level to ensure they are achievable and practical. Nevertheless, introducing and implementing a carbon dioxide labelling scheme is not without difficulties, especially as there are numerous building materials on the market. The resources and effort required to develop and maintain a carbon dioxide label for each construction material would be substantial, in addition to the challenges in soliciting and verifying overseas GHG emissions data. Technically, the most effective way to implement a carbon dioxide labelling scheme is to seek a certification body to conduct the auditing task. Given the sensitivity of the data, this will need to be impartial and independent to avoid any conflict of interest when acquiring data related to the lifecycle GHG emissions of construction materials.

Initial future research, therefore, needs to be aimed at finding solutions to the following problems identified in this research

(*a*) the level at which to label products
(*b*) the assessment of emissions at different lifecycle stages
(*c*) the impact of cost, functionality, quality and durability
(*d*) the form of benchmarking needed
(*e*) the collection and maintenance of a suitable database.

In addition, further work is needed to clarify general principles and international standards for incorporation into the carbon footprint assessment method. Past experiences in implementing carbon dioxide labelling schemes worldwide and the perception towards carbon dioxide labelling schemes by industry practitioners also need to be consolidated to formulate pragmatic strategies and implementation plans. Finally, it is felt that the construction community would benefit considerably from a series of pilot studies aimed at identifying any unforeseen practical issues that might arise prior to full implementation.

APPENDIX: INTERVIEW QUESTIONS

Potential implications of the proposed carbon dioxide labelling scheme for construction materials

1. What is the industry's (clients, design consultants, contractors and suppliers) current level of awareness and implementation towards lifecycle carbon dioxide emissions of construction materials?
2. What are the current common criteria for selecting construction materials (cost, quality, durability, environmental impact, etc.)? Will the carbon dioxide label influence the behaviour of decision makers (i.e. clients, design consultants and contractors)?
3. What are the potential pros and cons of implementing a carbon dioxide labelling scheme for construction materials? Which group of construction stakeholders will benefit from or be affected by the carbon dioxide labelling scheme?

4. What are the major barriers (e.g. economic, legal, technical) of initiating such scheme?

The envisaged carbon dioxide label for construction materials

5. Do you think a carbon dioxide label for construction materials should reflect carbon dioxide emissions throughout the entire supply chain process as shown below (extract from PAS 2050 standard)? And how?
6. Among various emission stages, which are the major ones that require extra attention? Which are the most insignificant emissions? Is there any anticipated difficulty in obtaining such measurements/data at different stages?
7. At which level should numerous construction materials be labelled (L1, raw materials, e.g. cement; L2, building material, e.g. concrete; or L3, building component, e.g. façade), such that decision makers can effectively utilise the label during various project design phases?
8. How to benchmark the lifecycle greenhouse gas emissions of construction materials for the labelling scheme?
9. What information should be presented in the carbon dioxide label with reference to the energy label as shown below? Which party should compile and verify the emission information on the label respectively?

Formulate strategies to implement a carbon dioxide labelling scheme for construction materials

10. How should the proposed carbon dioxide labelling scheme for construction materials be realised (voluntary or mandatory)? Will there be incentives for various stakeholders to adopt the carbon dioxide labelling scheme? What are the success factors of launching the carbon dioxide labelling scheme?
11. Is there any experience to be learnt from the implementation of energy efficiency labelling schemes to the carbon dioxide labelling scheme for construction materials? As a starting point, which material(s) should first be labelled?
12. Which party should manage the scheme and serve as the certifying body? Which party in the construction industry should drive the adoption of low carbon dioxide construction materials? And how?
13. How do you see the development of such a labelling scheme in the construction industry in the next 5–10 years?

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REFERENCES

Baer P and Mastrandrea M (2006) *High Stakes: Designing Emissions Pathways to Reduce the Risk of Dangerous Climate Change*. Institute for Public Policy Research, London, UK.

Bolwig S and Gibbon P (2009) *Emerging Product Carbon Footprint Standards and Schemes and their Possible Trade Impacts*. Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Denmark.

Brenton P, Edwards-Jones G and Jensen M (2008) *Carbon Labelling and Low Income Country Exports: An Issues Papers*. Munich Personal RePEc Archive, MPRA paper No. 8971, pp. 1–36.

Carbon Trust (2007) *Carbon Footprint Measurement Methodology*. Carbon Trust, London, UK.

Chau CK, Yik FWH, Hui WK, Liu HC and Yu HK (2007) Environmental impacts of building materials and building services components for commercial buildings in Hong Kong. *Journal of Cleaner Production* **15(8)**: 1840–1851.

Clarke B (2010) Briefing: carbon critical design. *Proceedings of the Institution of Civil Engineers – Engineering Sustainability* **163(2)**: 57–59.

Dias WPS and Pooliyadda SP (2004) Quality based energy contents and carbon coefficients for building materials: A systematic approach. *Energy* **29(4)**: 561–580.

EMSD (Electrical and Mechanical Service Department) (2006) *Life Cycle Energy Assessment of Building Construction – An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments*. EMSD, Hong Kong Government, Hong Kong. Consultancy study report submitted by Ove Arup and Partners, Consultancy agreement no. CAO L013.

Fieldson R, Rai D and Sodagar B (2009) Towards a framework for early estimation of lifecycle carbon foot printing of buildings in the UK. *Construction Information Quarterly* **11(2)**: 66–75.

G8 Summit (2009) *Chair's Summary*. See http://www.g8italia2009.it/G8/Home/News/G8-G8_Layout_locale-1199882116809_1199902080214.htm (accessed 30/01/2011).

Gillham W (2000) *The Research Interview*. Real World Research, London, UK.

González MJ and Navarro JG (2006) Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact. *Building and Environment* **41(7)**: 902–909.

Harris DJ (1999) A quantitative approach to the assessment of the environmental impact of building materials. *Building and Environment* **34(6)**: 751–758.

Hill RC and Bowen PA (1997) Sustainable construction principles and a framework for attainment. *Construction Management and Economics* **15(3)**: 22–29.

HKHA (Hong Kong Housing Authority) (2005) *Life Cycle*

Assessment (LCA) and Life Cycle Costing (LCC) Study of Building Materials and Components. HKHA, Hong Kong.

IPCC (Intergovernmental Panel on Climate Change) (2007) *Climate Change 2007: The Physical Science Basis*, Cambridge University Press, Cambridge, UK.

Monahan J and Powell JC (2011) An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings* **43(1)**: 179–188.

Savacool BK (2009) The importance of comprehensiveness in renewable electricity and energy-efficiency policy. *Energy Policy* **37(4)**: 1529–1541.

Smith A, Watkiss P, Tweddle G *et al*. (2005) *The Validity of Food Miles as an Indicator of Sustainable Development*. Department for Environment, Food and Rural Affairs, London, UK.

Sterner E (2002) 'Green procurement' of buildings: a study of Swedish client's considerations. *Construction Management and Economics* **20(1)**: 21–30.

Sullivan R and Burke P (2009) *Managing Greenhouse Gas Emissions across the Value Chain: The New Agenda*. Insight Investment Management (Global) Limited and Acona Limited, London, UK.

Suzuki M, Oka T and Okada K (1995) The estimation of energy consumption and CO_2 emission due to housing construction in Japan. *Energy and Buildings* **22(2)**: 165–169.

Thomson CS, El-Haram MA and Emmanuel R (2011) Mapping sustainability assessment with the project life cycle. *Proceedings of the Institution of Civil Engineers – Engineering Sustainability* **164(2)**: 143–157.

UNFCCC (United Nations Framework Convention on Climate Change) (2007) *Analysis of Mitigation Potentials and Identification of Ranges of Emission Reduction Objectives of Annex I Parties – Draft Conclusion Proposed by the Chair*. Ad hoc working group on further commitments for Annex I Parties under the Kyoto Protocol fourth session, August 27–31, Vienna, FCCC/ KP/AWG/2007/L.4. UNFCCC, Bonn, Germany.

UNFCCC (United Nations Framework Convention on Climate Change) (2011) *Greenhouse Gas Inventory Database: GHG data of Annex I Parties*. See http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php (accessed 25/06/2012).

Veys A (2008) *A Financial Accounting Based Model of Carbon Foot printing using an Example in the Built Environment*. Thesis for partial fulfilment for the requirements of Masters in sustainable energy futures and for the Diploma of Imperial College, London, UK.

Weber RP (1990) *Basic Content Analysis*. Saga Publications, California, USA.

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