CONSTRUCTION INDUSTRY COUNCIL
建造業議會

A COMPREHENSIVE HONG KONG BASED CARBON LABELLING SCHEME COVERING EMISSION INTENSIVE CONSTRUCTION MATERIALS

RESEARCH SUMMARY

Construction Industry Council A Comprehensive Hong Kong Based Carbon Labelling Scheme Covering Emission Intensive Construction Materials Research Summary

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FOREWORD

The significance of sustainability long be recognized. The whole world is endeavoring to reduce carbon emission, and the Government of the HKSAR has set a target to reduce the carbon intensity by 50-60 percent by 2020 compared with the level in 2005. The construction industry is a major contributor of carbon emission, and the manufacturing of construction materials alone contributes 15-40 percent of a building's life time energy consumption. Therefore, adoption of low carbon construction materials is of great significance to the sustainable development of Hong Kong and the world.

Since its establishment in 2007, the Construction Industry Council (CIC) has put much focus on sustainability in its work. The CIC launched the CIC's Carbon Labelling Scheme (CLS) in 2013, with an aim to reduce the carbon footprint generated from the construction industry by certifying low-carbon construction materials. The scheme is expected to steer the industry towards a sustainable construction practice. Meanwhile, the CIC engaged a research team from the University of Hong Kong, to establish the carbon assessment framework of commonly used construction materials to support the CLS.

The research team led by Professor Thomas NG has done a remarkable work. The international practice of carbon labelling has been extensively reviewed, and the assessment frameworks of commonly used construction materials at production level were successfully established. The developed frameworks were verified and improved following the semi-structured interviews with various industry stakeholders. Moreover, a quantification tool has been developed for each kind of material, which greatly facilitates the implementation of the scheme.

This project cannot succeed without the devotion of Professor Thomas NG and the research team, and their contributions are gratefully acknowledged. We also appeal all industry stakeholder to participate in the CLS.

Ir Albert CHENG
Executive Director
Construction Industry Council

PREFACE

More and more evidence shows that climate change is affecting the earth and the mankind. Therefore, proactive actions must be taken to revert the adverse impacts of climate change. In The University of Hong Kong, “environment” is identified as one of the five strategic research areas, and the Department of Civil Engineering has been actively involving in scientific research to help alleviate the environmental burden of the built environment. Examples of these include the feasibility of designing low carbon high-rise buildings, development of low carbon materials, devising carbon estimating models, formulating sustainable retrofit strategies, performing life cycle assessment, etc.

I am very thankful to the Construction Industry Council (CIC) for commissioning our Department to carry out a research on the development of a Carbon Labelling Scheme for construction products. Developing a Carbon Labelling Scheme for construction products is indeed very timely not only because infrastructure and construction facilities consume a large amount of construction products but also due to the fact that growing need for built facilities as a result of rapid urbanisation and economic growth around the world. Being able to differentiate the carbon footprint at the product level will enable clients, design team members and contractors select suitable low carbon materials to help minimise the embodied carbon of infrastructure and construction facilities.

It is encouraging to note that the research outcome of this study has paved way for the subsequent development of the CIC Carbon Labelling Scheme. The success of the CIC Carbon Labelling Scheme has demonstrated the importance of industry-academic collaboration in solving real world problems. Our Department will continue to work closely with CIC to reduce the carbon footprint of the built environment in Hong Kong.

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RESEARCH HIGHLIGHTS

1. Background

Excessive emission of greenhouse gas (GHG) is the fundamental cause of global warming. Since the Kyoto Protocol in 1997, a number of countries have put forward carbon emission reduction targets to help revert climate change. The Government of Hong Kong Special Administrative Region (HKSAR) has also set a target of reducing the carbon intensity by 50-60 percent by 2020 compared with the 2005 level so as to mitigate the impact of climate change.

While buildings are energy and emission intensive to construct and operate, the construction industry should play an indispensable role in GHG mitigation. Previous research indicated that the manufacturing of construction materials alone could contribute to 15-40 percent of a building's life time energy consumption. Minimising the carbon generated from the construction industry through prudent selection of "low carbon" construction materials is, therefore, highly desirable.

With an aim to steer the Hong Kong (HK) construction industry moving towards a sustainable construction practice, the Construction Industry Council (CIC) has commissioned a Research Team based at The University of Hong Kong (HKU) to develop a set of carbon assessment frameworks for six categories of construction materials in 2010, viz. cement, reinforcing bar and structural steel, aluminium, glass and ceramic tile. Subsequently, this CIC Carbon Labelling Scheme for Construction Products (the "Scheme") was launched in 2013, covering cement, reinforcing bar and structural steel products. However, due to a limited coverage of product categories in the previous study, a full scale implementation of carbon labelling and it subsequent application for decision making at the design, procurement, construction and operational stages may be hindered. Moreover, the developed carbon assessment frameworks in the previous study were based on PAS 2050 which has been replaced by the newly released standard, i.e. ISO/TS 14067. It is, therefore, necessary to extend the product categories under the Scheme.

2. Aim, Objectives and Methodology

In view of this, this Study aims to establish the carbon assessment frameworks of 10 additional categories of emission intensive construction materials / products in accordance with ISO/TS 14067 standard. Based on a quantitative analysis of the materials used for building projects in HK in terms of embodied carbon emissions, the 10 emission intensive materials covered in this Study are: (i) ready-mixed concrete; (ii) precast concrete; (iii) stainless steel; (iv) galvanised mild steel; (v) cast iron; (vi) brick; (vii) construction aggregate; (viii) asphalt pavement; (ix) sawn timber and plywood; and (x) gypsum board. Consequently, the materials / products included in the Scheme would cover the vast majority of embodied carbon in a construction project. The carbon label shall show the total amount of GHG emissions in terms of carbon dioxide equivalent (CO_2e) of a construction material from "cradle-to-site", covering the extraction of raw materials, manufacturing and transportation to the boundary of HK.

Specific objectives of this Study include: (i) reviewing the latest development of carbon footprint assessment and labelling schemes in construction both locally and internationally; (ii) enhancing the six previously developed carbon assessment frameworks based on ISO/TS 14067 and other relevant requirements raised by the industry after the validation conducted by the CIC; (iii) developing the carbon assessment frameworks including the carbon footprint of product (CFP) quantification tools of the 10 additionally selected construction materials / products; and (iv) compiling product-based guides for material suppliers / carbon auditors to assess the carbon footprint and apply for a carbon label.

To achieve the stipulated objectives, this Study was undertaken in three stages. Stage 1 attempted to review the recent development of carbon footprint assessment and carbon labelling schemes worldwide through an extensive desktop study. In the previous phase of the CIC study, more than 10 carbon labelling schemes from around the world have been reviewed including the Carbon Trust's Carbon Reduction Label in the United Kingdom (UK); CO_2Star Carbon Labelling Project in Europe, Carbonlabels.org and Carbon Label in the United States (US), and Carbon Reduction Label in Thailand. This Study began with a review of the recently developed carbon labelling schemes from 2012 to 2016, as well as a major update of the existing carbon labelling schemes. Four interviews with industry stakeholders were conducted in the initial stage to unveil the implications of the Scheme.

In Stage 2, the six carbon assessment frameworks established in the previous CIC study developed based on PAS 2050 were updated and enhanced in line with the newly released international standard, i.e. ISO/TS 14067. Given the assessment guides for cement and steel products had already been updated and as feedbacks were gathered from the industry stakeholders and material suppliers, the previously developed carbon assessment frameworks of aluminium, glass and ceramic tiles were updated according to the ISO/TS 14067. The guide booklets of the three material groups were also compiled correspondingly.

Stage 3 involved an extensive literature review and consultations with material manufacturers and suppliers to define the product scope and life cycle of the 10 selected product categories. The system boundary was then set to define the emission sources to be assessed. Based on the findings hitherto, a series of HK-based labelling frameworks and product-based guides for assessing the carbon footprint of the selected material groups were compiled. The developed carbon labelling frameworks were then verified and improved through 16 interviews involving relevant material manufacturers and suppliers.

3. Review of the Recent Development of Carbon Labelling Schemes

The first ever carbon labelling scheme, Carbon Trust's Carbon Reduction Label being launched in 2007, is still one of the most prevalent carbon labels worldwide and have been applied to products from various countries. As for the Carbon Reduction Label in Thailand, it now covers a series of building products including mixed cement, tile, carpet, paint, steel reinforcement, sanitary fitting, etc., despite the scheme only assesses the carbon footprint of a product during the production process.

Two new carbon-related schemes namely CarbonCare® Asia and Low-carbon Office Operation Programme (LOOP) have been launched locally during the research period. Both schemes aim to encourage and recognise the efforts of companies and organisations in their action to tackle climate change. Moreover, a Hong Kong Carbon Footprint Certification Scheme is being developed to help small and medium size manufacturers realise the life cycle carbon footprint of their production process.

In the US, a CarbonFree® Product Certification label has been developed. This is the first carbon neutral label in the US to recognise those companies which are not only aware of product emissions and but are also willing to compensate for their carbon footprint. Offsetting of the product's carbon footprint is performed quarterly based on the actual sale of the product.

4. Carbon Assessment Frameworks of 10 Additional Materials

The product category, process map, assessment system boundary, sources of emissions, and CFP quantification tool for the 10 additional construction materials were developed through an extensive literature review and consultations with material manufacturers and suppliers. The Scheme complies with the relevant international standards: (i) ISO 14040: Environmental Management – Life Cycle Assessment; (ii) ISO 14020: Environmental Labelling and Declaration; (iii) ISO 14024: Environmental Label and Declaration – Type III Environmental Declarations; and (iv) ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories.

The assessment framework classifies each material into a number of specific categories according to their performance properties, manufacturing methods and raw materials. The categorisation was established by referring to the available international standards including centralised product classification, British Standard and International Organization for Standardization. The system boundary for emissions assessment was set in accordance with ISO 14025 standard. Subsequently, the carbon emissions were allocated so as to partition between the product's life cycle and that of other products including those recycled materials. To assist material suppliers or carbon auditors to assess the carbon footprint and apply for the Scheme, product-based guides were compiled for each of the 10 construction materials.

5. Perceptions of Local Industry Stakeholders on Carbon Labelling Scheme

Four semi-structured interviews with various industry stakeholders were conducted to unveil the implications and limitations of the existing green initiatives and legislations, perceptions of the Scheme, and key success factors for introducing the Scheme into the construction industry of HK. The interviewees were experienced local industry practitioners. The interviewees represent a broad spectrum of construction stakeholders including the government, consultants and contractors. With the launching of the Scheme for cement and steel, the interviewees provided valuable feedbacks on the assessment guides.

Findings from the expert interviews reveal that quality and cost are the governing factors when selecting construction materials. Some constructors and developers would, however, consider the environmental performance of materials chosen. There is an increasing interest in the carbon footprint in the local construction industry; the Scheme would encourage the use of low carbon materials. However, one interviewee pointed out that the quantification of CFP and the labelling procedure shall be as simplified as possible to facilitate data collection and verification. To increase the chance of success of the Scheme, the interviewees generally believed that the Scheme should be integrated into the existing building environmental assessment schemes, such as BEAM Plus. Besides, incentives should be provided to encourage stakeholders to participate in the Scheme.

CONTENTS

1 INTRODUCTION

1.1 Background

The problems given rise by climate change have called for drastic reduction in the level of greenhouse gas (GHG) emissions across the board (EPD, 2010). Scientists have proposed capping the atmospheric carbon dioxide (CO_2) concentrations (the most prominent GHG) to below 450 parts per million (ppm) with a desire to prevent an increase in the global temperature (Baer and Mastrandrea, 2006). This would require global GHG emissions to be cut back to 60-75% of the 1990 levels by 2020 (UNFCCC, 2007). In order to mitigate climate change and reduce GHG emissions in Hong Kong (HK), the HKSAR Government intends to reduce the carbon intensity by 50-60% by 2020 compared with the 2005 level (ENB, 2010).

The construction industry has a pivotal role to play in the reduction of GHG emissions due to its significant consumption of materials and energy for both new and existing construction facilities (González and Navarro, 2006). Around 40% of the total materials consumed by global economy are shared by the construction industry which consequently generates a significant amount of GHGs (California Integrated Waste Management Board, 2000).

During the life cycle of a building, the initial emissions mainly comprise of embodied GHG emissions of building materials (Nassen *et al.,* 2007). The energy consumption and GHG emissions involved in the extraction of raw materials, materials manufacturing processes, transportation of materials and other associated activities are defined as the materials' embodied energy and embodied GHG emissions respectively (Chen *et al.,* 2001). Fieldson *et al.* (2009) stressed the importance of making good decisions on the selection of materials in the early project stage which can effectively reduce the overall life cycle emissions. Minimising the output of GHGs in the construction field through prudent selection of "low carbon" construction materials is, therefore, highly desirable (Chau *et al.,* 2007).

A practical mechanism for reducing GHG emissions is through carbon labelling, which has undergone a rapid development in recent years (Vandenbergh *et al.,* 2011). This involves the measurement of the carbon footprints from the production of products or provision of services, to conveying the information to consumers or those who are making the sourcing decisions within a company (Carbon Trust, 2007). Well-designed schemes will create incentives for the production of different components along the supply chain to lower the overall emissions of construction materials. The Construction Industry Council (CIC) completed a pilot study on the development of the first set of carbon assessment frameworks for cement, reinforcing bar, structural steel, aluminium, glass and ceramic tiles.

The CIC carbon labelling initiative has been well-received by various industry stakeholders in HK and it is recognised as an effective measure to mitigate GHGs originated from the construction industry. As a result, the “Scheme” was launched in HK in January 2014.

However, due to the limited coverage of product categories in the initial study, a full scale implementation of carbon labelling and it subsequent application for decision making at the design, procurement, construction and operational stages may be hindered. It is, therefore, imperative and timely to expedite the development process of the Scheme by expanding the scope of the previous study to cover other emission intensive construction materials so as to ensure HK is at the forefront of carbon labelling development for construction materials. Besides, the Scheme for the first six materials were developed largely based on PAS 2050 (2011). With the release of the new international standard on product-based carbon footprint calculation (i.e. ISO/TS 14067), a review of the carbon assessment frameworks developed in the previous study becomes imminent to ensure they are in line with the latest trend. Moreover, feedbacks and suggestions on the developed carbon assessment frameworks were collected in the previous CIC study, thus enhancement should be made accordingly.

1.2 Aims and Objectives

The aim of this Study is to expand the recently developed Scheme to cover 10 additional construction materials / products known to have high carbon emissions by establishing relevant carbon assessment frameworks including, carbon footprint of product (CFP) quantification tools. Specific objectives to achieve the stipulated aim are:

Objective 1: To review the recent development of carbon footprint assessment and labelling schemes in construction both locally and internationally;

Objective 2: To enhance the six developed carbon assessment frameworks based on ISO/TS 14067 and relevant requirements raised by the industry;

Objective 3: To develop carbon assessment frameworks of 10 additional construction materials/ products known to have high level of carbon emissions; and

Objective 4: To compile product-based guides for material suppliers and carbon auditors to assess the carbon footprint of construction materials / products and application instructions for carbon labels.

1.3 Scope

This Study focuses on ready-mixed concrete, precast concrete, stainless steel, galvanised mild steel, cast iron, brick, construction aggregate, asphalt pavement, sawn timber and plywood, and gypsum board.

While environmental impacts can be expressed in various aspects including the toxicity of materials, this Study focuses on the GHGs [which is converted into carbon dioxide equivalent (CO_2e)] as covered by the Kyoto Protocol (United Nations, 1997). GHGs covered in this Study include the following six types of gases, namely CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) which have been found to have direct impact on global warming (United Nations, 1997). Other factors pertinent to environmental impacts may be added to the carbon label as supplementary data in future research studies if and when proven necessary.

While GHG emissions can be measured at the global, national, corporate or organisational, and product levels, the focus of this Study is at the product level, i.e. CFP. CFP examines the emissions associated with a specific good and service. This approach takes into account the impacts of processes, materials and decisions throughout the entire supply chain (Croft, 2010). With reference to the existing carbon inventories, the evaluation boundary adopted in this Study is set as “cradle-to-site”, covering the consecutive and interlinked stages of a product system, from raw material extraction or generation of natural resources to the point of use.

2 RESEARCH METHODOLOGY

To achieve the stipulated objectives, this Study was undertaken in three stages with the specifically designed research methods described below.

Stage 1: Review the Recent Development of Carbon Labelling Schemes in Construction and Other Industries

An extensive desktop study was conducted to examine local and international development of carbon footprint assessment and labelling. The review should not only cover the construction industry but also other sectors which have adopted the carbon labelling such as the food industry and fashion industry. In addition, four semi-structured interviews with various industry stakeholders were carried out to unveil the implications and limitations of the existing green initiatives and legislations, perceptions of the carbon labelling, and how to successfully introduce the Scheme to the construction industry of HK. Without a better understanding of the limitations and impacts of the carbon labelling scheme, it is difficult to ensure the Scheme is relevant for practical usage.

Stage 2: Enhance the Six Developed Carbon Assessment Frameworks and Compile Guide Booklets

The six carbon assessment frameworks developed in the previous CIC study were based on PAS 2050 – Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services (2011). However, the most up-to-date principles, requirements and guidelines for the quantification and communication of a product's carbon footprint should now be based on the newly released international standard, i.e. ISO/TS 14067. The difference between PAS 2050 and ISO/TS 14067 regarding the CFP quantification is minor and lies in the requirement of the reporting of the emissions arising from biogenic sources as ISO/TS 14067 requires the inclusion of emissions from biogenic sources in the final result while they shall be reported separately under PAS 2050. The previously developed assessment frameworks of two of the materials groups (i.e. cement and steel) have already been updated according to the new international standard as well as the concerns raised by industry stakeholders and material suppliers. Therefore, carbon assessment frameworks of the remaining three construction material groups developed in the previous phase (i.e. aluminium, glass, and ceramic tiles) should be adjusted and improved accordingly. Based on the enhanced carbon assessment frameworks, the assessment guides of the three material groups were revised accordingly.

Stage 3: Develop the Carbon Assessment Frameworks and Compile Guide Booklets for 10 Additional Materials

To define the product scope and life cycle of the selected material groups, an extensive literature review and consultation with material manufacturers / suppliers were carried out. Through these research tasks, the system boundary could be set to define which types of emissions should be included or excluded; and all attributable processes that shall be included in the boundary of the product's GHG inventory. Subsequently, the impacts of GHG emissions shall be allocated so as to differentiate between the product's life cycle and that of the other products including those recycled materials at the time of boundary setting. Carbon footprint quantification tools were then developed based on the identified boundary and sources of emissions. The Scheme shall comply with relevant international standards including (i) ISO 14040: Environmental Management – Life Cycle Assessment; (ii) ISO 14020: Environmental Labelling and Declaration; (iii) ISO 14024: Environmental Label and Declaration – Type III Environmental Declarations; and (iv) ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories.

It was imperative to obtain feedback and verify the developed carbon assessment frameworks of the 16 selected groups of construction materials (6 from the previous CIC study and 10 additional ones in this Study). Therefore, a cross-disciplinary study involving the associated material manufacturers / suppliers were conducted. Subsequently, the product-based carbon assessment guides were compiled for material suppliers or carbon auditors to assess the carbon footprint and apply for a carbon label from CIC respectively.

3 RESEARCH FINDINGS AND DISCUSSION

The previously developed carbon assessment frameworks of aluminium, ceramic tiles and glass have been updated and improved based on ISO/TS 14067 and other relevant requirements raised by the industry. The enhancements are related to the reporting of emissions associated with the combustion of biomass fuels and the expanded coverage of indirect emissions. Moreover, the product-based guide booklets for the three materials mentioned above have been compiled to allow material suppliers/ carbon auditors assessing the carbon footprint and applying for a carbon label under the Scheme.

Assessment frameworks were specifically designed for measuring the carbon footprint of the 10 selected construction materials in this stage namely ready-mixed concrete, precast concrete, stainless steel, galvanised mild steel, cast iron, brick, construction aggregate, asphalt pavement, sawn timber and plywood, and gypsum board. Each carbon assessment framework comprises the: (i) definition of the product category; (ii) delineation of the system boundary and development of process map for GHG emission assessment; (iii) identification of the sources of GHG emissions; and (iv) compilation of carbon assessment tools in Microsoft™ Excel format for users to prepare their product specific carbon inventories.

3.1 Carbon Assessment Framework for Ready-mixed Concrete

This carbon assessment framework covers ready-mixed concrete from C30 to C70 in accordance with the cube test outlined in the "Code of Practice for Structural Use of Concrete 2013" (Buildings Department, 2013).

Ready-mixed concrete is essentially composed of Portland cement, sand, coarse aggregates (e.g. gravel, crushed stone) and water. Fly ash (FA) or ground granulated blast-furnace slag (GGBS) may be added to replace cement of a concrete product. The raw materials are often manufactured outside of the concrete batching plant and then transported to the plant by truck, barge or train. At most of the plants, cement is transferred pneumatically to storage silos by air blowers, while the aggregates are transferred to storage bins through conveyer belts, front-end loaders or bucket elevators. From the material storage silos, cement, aggregates and water are fed by gravity to a weigh hopper, where the raw materials are properly mixed and blended. Through the cement hydration process, the blended mixture starts to create a hard and porous substance known as ready-mixed concrete. The ready-mixed concrete is loaded to a mixer truck and then delivered to the construction sites or pre-cast plants.

The main emission sources during the manufacturing of ready-mixed concrete products are summarised in Table 1.

Table 1 Emission sources of ready-mixed concrete manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Fuels combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.2 Carbon Assessment Framework for Precast Concrete

This carbon assessment framework is applicable to all commonly used precast concrete products in HK such as block, slab, beam, staircase, façade, partition, as well as volumetric precast bathroom and kitchen. As suggested by the industry experts, the precast concrete products should be categorised into "standard products" and "project based products". Standard products refer to the precast concrete products produced from standardised steel moulds which are expected to be reused for unlimited times in a precast plant. Project based products, however, refer to the precast concrete products specifically designed for a project whereby the moulds cannot be reused in other projects implying that the used mould would either be discarded or reformed into new mould for new projects.

In most cases, precast concrete is composed of ready-mixed concrete, reinforcing bar and other finishing materials such as tiles, aluminium, glass, and mortar. Precast moulds or forms are normally made of either steel or plywood. To produce precast concrete, materials for concrete are transported to the batching plant, which is usually located within the precast yard. Reinforcements and other elements, such as isolation layers, are placed into the steel mould as designed. After that, raw materials of concrete are benched and mixed; release agent in the form of mineral oil is applied to the mould. Then, the concrete mixture is poured evenly into the mould by concrete spreader to form the precast elements. In some plant, air is removed and the concrete is compacted by an oscillation platform. This process guarantees the required strength concrete is achieved with a high quality finishing. Following that, the precast elements are sent to the curing furnace/ chamber. When the precast concrete component is hardened and developed to the desired strength, the mould is stripped. After that, finishing materials such as tiles, aluminium, glass, and mortar are installed as required. If mortar or more concreting material is applied, a second curing process might be required. The finished precast concrete products are lifted to the storage area and delivered to the construction site in HK.

The main emission sources during the manufacturing of precast concrete products are summarised in Table 2.

Table 2 Emission sources of precast concrete manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Fuels combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.3 Carbon Assessment Framework for Stainless Steel

The stainless steel family can be categorised by many ways, e.g. by metallurgical phases present in their microscopic structures, by their areas of application, or by the alloying elements used in their production. The most popular categorisation is to grade the stainless steels by the metallurgical phases present in their microscopic structures and chemical compositions, and there are a number of systems for grading stainless steel in such way including the Society of Automotive Engineers grading, unified numbering system grading, and EN-standard grading. However, this Study considers the stainless steel products for construction purposes only. After consulting local material suppliers, they suggested to categorised products according to their functions in construction, i.e. sheets, bars, wires, etc.

Stainless steel production process is similar to that of ordinary steel, except that higher portions of ferroalloys are added for the production of stainless steel. Chromium is the essential element to make the steel “stainless”, while nickel helps to develop the property to withstand extreme temperatures. The proportion of chromium is no less than 10% by weight, while nickel content usually ranges from less than 2% to as high as 25% by weight. Other minor alloying elements including molybdenum, copper and so on provide a wide range of mechanical and physical properties of stainless steel.

The raw material preparation usually consists of sintering and / or palletising of iron ore, coke making, iron making, steel making, and production of high-carbon ferrochromium and ferronickel.

High-carbon Ferrochromium Production

Chromium is added into the stainless steel manufacturing process in the form of chromium ferroalloys which is used most commonly in the high-carbon ferrochromium (Papp, 1995). In general, ferrochrome is produced by electric arc melting of chromite and chromium ore, thus the production of chromium ferroalloy is an electrical-power-intensive process. It is reported that the electricity intensity for produce high-carbon ferrochromium is between 5.5 and 10.5 MWh/t-FeCr in the old days (Udy, 1956), while it is 2 MWh/t-FeCr to 3.8 MWh/t-FeCr nowadays through energy-efficient processes (Papp, 1991).

Due to the large variety of manufacturing processes, ores, and practices of making high-carbon ferrochromium (Papp, 1995), it is hard to provide a standard list of processes and raw materials for high-carbon ferrochromium production. Thus, in this research the process map and major emission sources of high-carbon ferrochromium production are developed based on the most commonly adopted method provided in the literature. In most cases, the input materials for high-carbon ferrochromium production include chromium ore, limestone or dolomite, coke dust, coal, fixed carbon, quartz, bauxite and electrode paste (Papp, 1995). Among the above raw materials, the production of coke and limestone / dolomite ranks the top in both the quantity of usage and emission intensity (Papp, 1995).

Ferronickel Production

The alloying element nickel required in the stainless steel manufacturing is in the form of ferronickel. The production of nickel alloys in blast furnace and reverberatory furnace has been used in the past. Nowadays, efficient production of low cost ferronickel alloy is normally carried out in EAFs, e.g. submerged arc furnace, AC-arc furnace or DC-arc furnace (von Krüge *et al.*, 2010; Lagendijk and Jones, 1997).

Laterite ores, which represents 61% of nickel ore on earth, are the main raw material inputs to produce ferronickel (Ecobalance Inc., 2000). Before the ores are charged into EAF, they must be dried and heated in the calcination-reduction process to remove the crystalline water. After reacted with other feed materials (e.g. coal and slag), the ferronickel would be separated out under high temperature inside the EAF. If it is desired, the ferronickel might be refined into purer ferronickel product to meet the market specifications. The smelting process in the EAF consumes huge amount of electricity which is the main source of GHG emissions of ferronickel production.

Stainless Steel Manufacturing

Similar to other steel products, stainless steel is produced via two key routes: (i) integrated smelting involving BF iron-making followed by BOF; and (ii) EAF. In the BF-BOF route, the first step is to produce pig iron from iron ore. EAF is the alternative route in the steel production procedure. It uses scrap as its principal input. Production of primary steel is generally more energy intensive than the production of secondary steel via the EAF route due to the chemical energy required to reduce iron ore to iron using reducing agents.

The alloy element (e.g. Cr and Ni) is added into BOF or EAF. After the steel production, casting and shaping are the next steps. Casting can be a batch (i.e. ingots) or a continuous process (i.e. slabs blooms or billets). Finishing is the final production step, and may include different processes such as annealing, pickling, cutting and surface treatment.

The main emission sources during the manufacturing of stainless steel products are summarised in Table 3.

Table 3 Emission sources of stainless steel manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Furnace fuel combustion	Combustion of fuels used for heating of furnaces and power generation for EAF operation	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
	Non-kiln fuel combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
	Industrial processes	Coke making	• Raw materials consumed: measured at plant level • Production: measured at plant level • Emission factor: provided in the CFP quantification tool
		Sintering	
		Steel making	
		Limestone and dolomite production	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.4 Carbon Assessment Framework for Galvanised Mild Steel

According to the results of literature review and semi-structured interviews with industrial experts, this Study cover the galvanised mild steel defined by numbers of standards and practices (e.g. ASTM A123/A123M, 2013; ASTM A767/A767M, 2009; BS EN ISO 1461, 2009) which is mild steel products formed by rolling, pressing, forging and casting, and coated by zinc or zinc-alloy via hot-dip galvanisation including continuous hot-dip galvanisation.

In the continuous galvanisation process, rather than dipping in the zinc bath in batch by overhead crane or basket, steel coil or sheet is passed as a continuous ribbon through the cleaning tanks and zinc bath at a specified speed. After the cleaning process, the coil or sheet product is passed into a heating or annealing furnace to be softened and imparted the desired strength and formability. As the product exits the furnace, it enters into a vacuum chamber to prevent air from re-oxidising the heated steel product. The steel product is then sent around a submerged roll in the molten zinc bath to create the bonded coating and subsequently removed in a vertical direction. As the product is withdrawn from the bath, precisely regulated, high-pressure air is used to remove any excess zinc to create a closely controlled coating thickness. The steel coil or sheet is allowed to cool and solidify.

In preparing the zinc bath, zinc ingots are purchased and transferred to the galvanisation plant. The zinc bath is prepared by re-melting the zinc ingots at a temperature of around 450°C to keep it in liquid state. Electricity and natural gas is the most common heating methods of the zinc bath nowadays. Electrical heating is more popular because it is easier to control the temperature and the temperature is more stable than natural gas.

In the entire life cycle of a galvanised mild steel product, the manufacturing of mild steel product is the most emission-intensive process. In the boundary within the galvanisation plant, the heating of zinc bath should be the most energy and emission-intensive process.

The main emission sources during the manufacturing of galvanised mild steel products are summarised in Table 4.

Table 4 Emission sources of galvanised mild steel manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Furnace fuel combustion	Combustion of fuels used for heating of furnaces and power generation for EAF operation	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
	Non-kiln fuel combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
	Industrial processes	Coke making	• Raw materials consumed: measured at plant level • Production: measured at plant level • Emission factor: provided in the CFP quantification tool
		Sintering	
		Steel making	
		Limestone and dolomite production	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.5 Carbon Assessment Framework for Cast Iron

The cast iron family can be categorised by the alloying elements used in the production. The white cast iron which is hard but brittle has lower silicon content and low melting point. In white cast iron, substantially all of the carbon is in solution and in the combined form (ASTM A644-14, 2014). Grey cast iron is the most versatile and widely used cast iron which has a relatively large proportion of the graphitic carbon present in the form of flake graphite. Malleable cast iron is basically white iron that undergoes heat treatment to convert the carbide into graphite, and it has properties varying from both grey and white cast iron and behaves like low carbon steel. Ductile iron is a cast iron that has been treated in the liquid state so as that all of its graphitic carbon occurs as spheroids or nodules in the as-cast condition.

The raw materials used to produce cast iron include re-melting pig iron, often along with scrap iron, scrap steel, lime stone, coke and taking various steps to remove undesirable contaminants. The materials used to produce pig iron in a blast furnace are iron ore, sinter, coke and limestone. Sinter is made of finely divided iron ore which is roasted with coke and lime to remove a large amount of the impurities in the ore. Coke is use as both raw material input and energy source for heating in iron production. Coke is made by heating coal continuously until it becomes almost pure carbon and it can be either produced on-site or purchased. If coal, the main row materials for cokemaking, is well dried before used, the fuel consumption in the coke oven might be significantly reduced. Cokemaking is one of the main sources of GHG emissions in iron manufacturing.

The cupola furnace is filled with layers of coke and ignited; the raw materials are weighted and melted at an extremely high temperature in cupola furnace. The metal is alternated with additional layers of fresh coke, and limestone is added to act as a flux. During the melting process a thermodynamic reaction takes place between the fuel and the blast air. Carbon in the coke combines with the oxygen in the air to form carbon monoxide, and carbon monoxide further burns to form CO_2. Some of the carbon is picked up by the falling droplets of molten metal which raises the carbon content of the iron.

The main emission sources during the manufacturing of cast iron products are summarised in Table 5.

Table 5 Emission sources of cast iron manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Furnace fuel combustion	Combustion of fuels used for heating of furnaces and power generation for EAF operation	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
	Non-kiln fuel combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
	Industrial processes	Coke making	• Raw materials consumed: measured at plant level • Production: measured at plant level • Emission factor: provided in the CFP quantification tool
		Sintering	
		Steel making	
		Limestone and dolomite production	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.6 Carbon Assessment Framework for Brick

According to the results of literature review and semi-structured interviews with industrial experts, this Study focuses on unglazed bricks made from natural clay minerals through firing. Since common clay brick turns red after firing, it also refers to red brick.

The most common raw materials for producing brick are natural clay, e.g. kaolin and shale. Small amounts of manganese, barium, and other additives are blended with the clay to produce different shades, and barium carbonate is used to improve brick's chemical resistance to the elements. Many other additives are used in brick, and they include the by-products from papermaking, ammonium compounds, wetting agents, flocculents (which cause particles to form loose clusters) and deflocculents (which disperse such clusters). Some clay requires the addition of sand or grog (which is pre-ground, pre-fired material such as scrap brick).

To produce brick, the raw materials are first crushed and ground in a jaw crusher and mixed with liquid. Next, the mixture is shaped through different methods including extrusion, moulding, and pressing. Once the bricks are formed they are chamfered and cut into the desired standard. After that, they are dried in order to remove excess moisture to prevent causing cracks during the firing process. The firing process takes place in kiln where coal and gas are the major fuel sources. Firing hardens and strengthens the bricks. After cooling, the bricks are cooled and packaged.

The main emission sources during the manufacturing of brick products are summarised in Table 6.

Table 6 Emission sources of brick manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Kiln fuels combustion	Combustion of fuels used for all heating of kilns	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
	Non-kiln fuel combustion	Quarrying / mining raw materials On-site transportation Equipment Room heating and cooling On-site power generation	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.7 Carbon Assessment Framework for Construction Aggregate

This Study focuses on the aggregates for construction purpose in accordance with the Construction Standard CS3:2013 Aggregates for Concrete (CS3, 2013). Three aggregate product categories, namely: (i) coarse aggregates; (ii) fine natural aggregates class I; and (iii) fine natural aggregates class II are covered in this Study.

Construction aggregates are primarily obtained from quarries by blasting using explosives and drilling operations. The loosen hard rocks are loaded by power shovel or front-end loader to heavy weight vehicle, such as large haul trucks, that transport the material to processing facilities. After being transported to the processing facilities, the hard rocks are dumped into a storage bin. A scalping machine (e.g. grizzly feeder) separates finer rocks (i.e. undersized materials) from larger pieces (i.e. oversized materials). Normally, the large pieces from grizzly feeder require jaw crusher for initial size reduction. The oversized material after jaw crushing as well as the undersize materials are discharged onto a belt conveyor and delivered to a surge pile for temporary storage or are sold as coarse aggregates and fill materials for backfilling or land reclamation.

The crushed pieces and finer rocks stored in the surge piles can be delivered to downstream facilities for secondary size reduction to obtain fine aggregates. First, the materials should be conveyed to a cone crusher for secondary crushing. The size of aggregates can be reduced to about 2.5 to 10 cm. Some plants may produce manufactured sand which requires tertiary crushing of the bulk materials to 0.5 to 2.5 cm. The crushed products are conveyed or trucked directly to storage bins or to open area stockpiles. The smaller sized aggregates, such as manufactured sand, should be delivered to the washing and screening machines for cleaning and classification before they are delivered to the stockpiles. The final products, construction aggregates with various particle sizes, can be sold to concrete batching plant or other users in HK.

The main emission sources during the manufacturing of construction aggregates are summarised in Table 7.

Table 7 Emission sources of construction aggregates manufacturing

<table>
<tr><th colspan="3">Emission Components / Sources of Emissions</th><th>Sources of Parameters</th></tr>
<tr><td rowspan="6">Direct Emissions</td><td rowspan="5">Fuels combustion</td><td>Quarrying / mining raw materials</td><td rowspan="5">• Fuel consumption: measured at plant level
• Emission factors: IPCC defaults or measured</td></tr>
<tr><td>On-site transportation</td></tr>
<tr><td>Equipment</td></tr>
<tr><td>Room heating and cooling</td></tr>
<tr><td>On-site power generation</td></tr>
<tr><td>Industrial processes</td><td>Explosion / blasting of explosive</td><td>• Fuel consumption: measured at plant level
• Emission factor: default factor / input</td></tr>
<tr><td rowspan="4">Indirect Emissions</td><td colspan="2">External electricity production</td><td>• Power consumption: measured at plant level
• Emission factor: applicant-specific value or country grid factor</td></tr>
<tr><td colspan="2">Production of bought raw materials and energy wares</td><td>• Raw materials & energy wares purchased: measured at plant level
• Emission factor: default factor / input</td></tr>
<tr><td colspan="2">Off-site transportation</td><td>• Measured using WRI protocol / EPD / EMSD guidelines</td></tr>
<tr><td colspan="2">Land use change</td><td>• Measured in accordance with IPCC guidelines</td></tr>
</table>

3.8 Carbon Assessment Framework for Asphalt Pavement

This Study covers asphalt pavements, which can be divided into three different types of mix, namely asphalt concrete, hot rolled asphalt (HRA) and stone mastic asphalt (SMA), in accordance with "BS 594987:2007 Asphalt for Roads and Other Paved Areas – Specification for Transport, Laying and Compaction and Type Testing Protocols" and "BS EN 13108 Bituminous Mixtures – Material Specifications". Each category is sub-divided according to characteristics of the base and different courses in the pavement.

There are two typical types of plants conducting asphalt pavement manufacturing: drum mix plants and batch mix plants. In drum mix plants, the mixing process occurs directly in the dryer chamber, while in batch mix plants, the mixing of aggregates and asphalt cement takes place in a separate chamber called a pug mill. In general, asphalt pavement is produced through three main stages: (i) aggregates drying; (ii) aggregates heating; and (iii) mixing.

In batch mix plants, the aggregates are delivered from storage piles and placed in the hopper of cold feed unit. Then, aggregates are transported by conveyor belt into a rotary dryer for drying and heating. As the hot aggregates leave the dryer, they enter into a bucket elevator and go to vibrating screens to be separated into individual bins according to size. In order to control aggregate size distribution, a weigh hopper is equipped to weigh individual components and obtain the desired mix. The reclaimed asphalt pavement can be introduced at this point. Concurrent with the aggregates being weighed, the asphalt is heated into liquid form and pumped into an asphalt bucket for weighing to achieve the desired mix. After that, the prepared aggregates and asphalt cement with the operational reclaimed asphalt pavement are mixed in a separate mixer called pug mill. The resulting product of asphalt is later stored temporarily or delivered offsite for use.

In drum mix plants, the mixing is a continuous process which applies proportioning cold feed controls for the raw materials. In addition, the dryer is used not only to dry aggregates but also to mix the heated and dried aggregates with liquid bitumen. Aggregates, which have been proportioned by size gradations, are introduced to the drum at the burner end. As the drum rotates, the aggregates and the combustion products move in the drum. The bitumen is introduced into approximately the lower third of the drum. The aggregates are coated with bitumen as they reach the end of the drum. The recycled bitumen pavement is introduced at some point along the length of the drum, as far away from the combustion zone as possible (i.e. about the mid-point of the drum), but with enough drum length remaining to dry and heat the material adequately before it reaches the coating zone.

The main emission sources during the manufacturing of asphalt pavement products are summarised in Table 8.

Table 8 Emission sources of asphalt pavement manufacturing

Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Primary & secondary fuels combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.9 Carbon Assessment Framework for Sawn Timber and Plywood

According to BS EN 844-2:1995 "Round and Sawn Timber – Terminology – Part 3: General Terms related to Sawn Timber", sawn timber is defined as "timber section produced by the lengthwise sawing or chipping of logs or solid wood of large dimensions and possible crosscutting and / or further machining to obtain a certain accuracy". For plywood, it is in accordance to BS EN 636: 2012 "Plywood – Specification" which specifies the requirements for plywood for general purposes or structural application. Three classes under this standard, BS EN 636-1, BS EN 636-2, and BS EN 636-3, are based upon moisture resistance of the plywood applied in dry, humid and exterior condition, respectively. This Study covers the sawn timber and plywood products defined by the above standards.

Sawn timber is produced through three main stages: (i) log sorting; (ii) main sawing; and (iii) post-treatment. After the forestry operation, the harvested logs are transported by trucks to the saw mill and weighed after arrival. Once loaded by a crane to the conveyor, simple trimming is done by a butt-reducer saw for uniform diameter. Then, the trimmed logs are delivered to the laser scanner to collect relevant information mainly the dimensional parameters such as diameter and length. According to the collected information, the logs go to the sorting system being kicked off the lines into different pockets after leaving the scanning system. Once the first stage of sorting is finished, the sorted logs are debarked and sometimes re-scanned and the generated bark is disposed as waste or used for other purposes such as garden use.

In order to make full use of wood and reduce waste generation, some plants apply computer programming to calculate the optimised sawing methods for optimum cuts. With precise calculation, logs are cut into required dimensional green timber in plain sawing, and the by-product sawdust can be used in paper making or as burning fuel for boilers according to the size by screening. Then, the green sawn timber is transferred for checking manually or mechanically. Based on the length and other characteristics, the timber is further sorted and the main sawing stage is over. Green sawn timber often has a high moisture content, which leads to negative impact in product quality. Therefore, season is needed after main sawing process to reduce the moisture content to a desirable level. In most cases, kiln drying is applied due to its high automaticity and controllability in temperature and pressure. After seasoning, the dried sawn timber is produced and graded into different classes according to its qualitative characteristics. The grading can provide a reference for timber selection in various applications.

The production of plywood can be divided into two stages: (i) veneer preparation; and (ii) veneer bonding. In the first stage, the debarked and cut logs are peeled in the lathe by rotary cutting in most applications to produce veneers. The generated veneers are then clipped to desirable size and delivered for drying. Hot steam is applied to control the moisture content of veneer at a level below 15% on the dry basis, while the target moisture content depends on the type of resin used in subsequent gluing process. The dried veneers are sorted and coated with resin for bonding by stacking veneers with the grain direction perpendicular to that on the next layer. The laid-up veneers are pressed under pressure and heated for resin curing. The pressed panels are sawed, sanded or coated to the appropriate dimensions and appearance.

The main emission sources during the manufacturing of sawn timber and plywood products are summarised in Table 9.

Table 9 Emission sources of sawn timber and plywood manufacturing

<table>
<tr><th colspan="3">Emission Components / Sources of Emissions</th><th>Sources of Parameters</th></tr>
<tr><td rowspan="5">Direct Emissions</td><td rowspan="5">Kiln and non-kiln fuels combustion</td><td>Quarrying / mining raw materials</td><td rowspan="5">• Fuel consumption: measured at plant level
• Emission factors: IPCC defaults or measured</td></tr>
<tr><td>On-site transportation</td></tr>
<tr><td>Equipment</td></tr>
<tr><td>Room heating and cooling</td></tr>
<tr><td>On-site power generation</td></tr>
<tr><td rowspan="4">Indirect Emissions</td><td colspan="2">External electricity production</td><td>• Power consumption: measured at plant level
• Emission factor: applicant-specific value or country grid factor</td></tr>
<tr><td colspan="2">Production of bought raw materials and energy wares</td><td>• Raw materials & energy wares purchased: measured at plant level
• Emission factor: default factor / input</td></tr>
<tr><td colspan="2">Off-site transportation</td><td>• Measured using WRI protocol / EPD / EMSD guidelines</td></tr>
<tr><td colspan="2">Land use change</td><td>• Measured in accordance with IPCC guidelines</td></tr>
</table>

3.10 Carbon Assessment Framework for Gypsum Board

This Study covers gypsum board products in accordance with "BS EN 520:2004 Gypsum Plasterboards – Definitions, Requirements and Test Methods". It is applicable to eight gypsum board product categories.

The manufacturing process of gypsum board production begins with the extraction of gypsum. There are three common methods for the gypsum extraction, namely: (i) natural gypsum extraction; (ii) synthetic gypsum extraction; and (iii) recycled gypsum extraction. In natural gypsum extraction, the mining process starts by crushing and stockpiling the gypsum ores from quarries or underground mines near the manufacturing plant (US EPA, 1993). The stockpiled gypsum ores are then dried in a rotary dryer and conveyed to a roller mill, where they are grinded to smaller sizes. The output is known as "mined gypsum". Synthetic gypsum is produced from the emissions cleaning technology known as flue gas desulphurisation (FGD), mostly at coal fired power station. Synthetic gypsum is a by-product through the reaction between limestone slurry and sulphur dioxide in the flue gas. The by-product gypsum is then delivered to a gypsum board manufacturing plant for further treatments. In recycled gypsum extraction, gypsum boards from building demolition are collected and transported to the recycling plant. The recycled gypsum separated from impurities (e.g. paper, metal and wood) is milled into smaller sizes. The resulting finely ground gypsum can be delivered to a gypsum board factory for secondary uses.

The finely ground gypsum from the extraction process is fed to a calcination kiln, where the gypsum is heated (at approximately 120-150°C) to form the dehydration product, which is known as stucco. The dehydration process occurs without emitting GHG, as follows:

$$\mathbf{CaSO_4{\cdot}2\ H_2O + heat \rightarrow CaSO_4{\cdot}1/2\ H_2O + 3/2\ H_2O}$$

After that, the stucco is firstly mixed with dry additives (e.g. perlite and fibre glass) and combined with water, soap foam, accelerator, and other supplementary materials in a pin mixer. The mixed slurry is then spread between two paper liners to form wet boards. As the wet board travels along the conveying line, the $CaSO_4{\cdot}1/2\ H_2O$ again combines with the water in the slurry to create $CaSO_4{\cdot}2\ H_2O$. The rehydration process results in a solid and strengthened gypsum board with a plaster core encased in two paper liners. Finally, the solid gypsum board is dried, trimmed and packaged for shipment.

The main emission sources during the manufacturing of gypsum board products are summarised in Table 10.

Table 10 Emission sources of gypsum board manufacturing

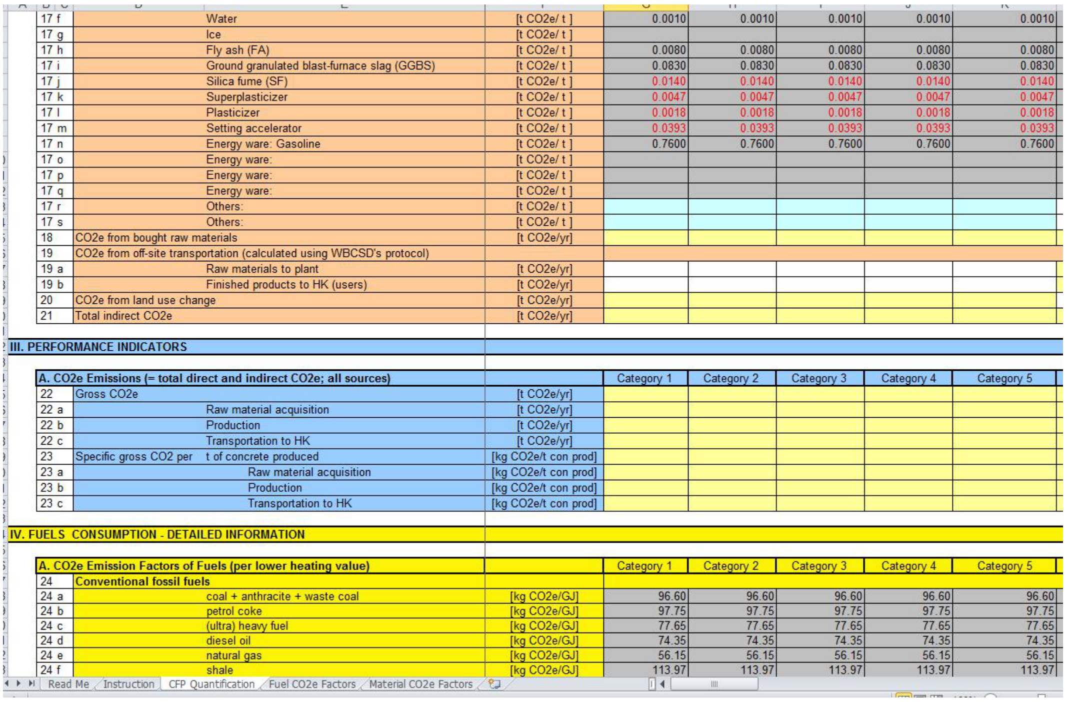
Emission Components / Sources of Emissions			Sources of Parameters
Direct Emissions	Kiln fuels combustion	Combustion of fuels used for all heating of kilns	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
	Non-kiln fuel combustion	Quarrying / mining raw materials	• Fuel consumption: measured at plant level • Emission factors: IPCC defaults or measured
		On-site transportation	
		Equipment	
		Room heating and cooling	
		On-site power generation	
Indirect Emissions	External electricity production		• Power consumption: measured at plant level • Emission factor: applicant-specific value or country grid factor
	Production of bought raw materials and energy wares		• Raw materials & energy wares purchased: measured at plant level • Emission factor: default factor / input
	Off-site transportation		• Measured using WRI protocol / EPD / EMSD guidelines
	Land use change		• Measured in accordance with IPCC guidelines

3.11 CFP Quantification Tool

A CFP quantification tool for each of the abovementioned product is presented in Microsoft™ Excel. Take ready-mixed concrete as an example, the layout of the user interface is shown in Figure 1. The tool consists of two instructional spreadsheets (i.e. “Read Me” and “Instructions”), a spreadsheet for data input (i.e. “CFP Quantification”), and two spreadsheets of default emission factors (i.e. “Fuel CO_2e Factors” and “Material CO_2e Factors”). The “CFP Quantification” sheet covers the calculation of all *Direct Emissions* and *Indirect Emissions* (Figure 1a). The data for computation of emissions from combustion of kiln fuels, combustion of non-kiln fuels, external electricity, production of bought raw materials and energy wares, off-site transportation, and land use change should be inputted here. The results of the calculation are displayed in performance indicators (refer to “III. PERFORMANCE INDICATORS” in the blue area in Figure 1b), which enable users to evaluate the environmental performance of their products directly.

1		CFP Quantification - Ready-mixed Concrete												
2														
3	Date of latest update		19/ Sep/ 2014											
4	Reporting Period													
5														
6	I. INFORMATION													
7														
8	A. General Plant Information													
9	1	Plant												
10	2	Company												
11	3	Country												
12	4	Description of concrete (e.g., product name, strength grade, SCM rate etc.)												
13	4 a	Category 1: C30s (30 MPa ≤ ƒcu < 40 MPa)												
14	4 b	Category 2: C40s (40 MPa ≤ ƒcu < 50 MPa)												
15	4 c	Category 3: C50s (50 MPa ≤ ƒcu < 60 MPa)												
16	4 d	Category 4: C60s (60 MPa ≤ ƒcu < 70 MPa)												
17	4 e	Category 5: C70s (70 MPa ≤ ƒcu < 80 MPa)												
18	4 f	Category 6: C80s (80 MPa ≤ ƒcu < 90 MPa)												
19	4 g	Category 7: C90s (90 MPa ≤ ƒcu < 100 MPa)												
20	4 h	Category 8: C100s (ƒcu ≥ 100 Mpa)												
21														
22	B. System Boundary													
23	5 a	Raw material preparation (bought raw materials, handling and storage)	[yes, no or n.a.]											
24	5 b	On-site transportation	[yes, no or n.a.]											
25	5 c	Equipment	[yes, no or n.a.]											
26	5 d	On-site power generation	[yes, no or n.a.]											
27	5 e	Room heating / cooling	[yes, no or n.a.]											
28	5 f	Off-site transportation	[yes, no or n.a.]											
29	5 g	(add other processes as appropriate)	[yes, no or n.a.]											
30														
31	C. Concrete Production			Category 1		Category 2		Category 3		Category 4		Category 5		
32				Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	P
33	6	Concrete production in volume	[m3/yr]											
34	7	Proportion	%											
35														
36	D. Raw Materials and Energy Used to Produce Concrete Products			Category 1		Category 2		Category 3		Category 4		Category 5		
37				Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	P
38	8 a	Ordinary portland cement, i.e. CEM I	[t/yr, dry weight]											
39	8 b	Fine aggregates (size < 4.75 mm), sand	[t/yr, dry weight]											
40	8 c	Fine aggregates (size < 4.75 mm), others:	[t/yr, dry weight]											
41	8 d	Coarse aggregates (size > 4.75 mm), e.g. gravel and crushed stone	[t/yr, dry weight]											
42	8 e	Recycled aggregates	[t/yr, dry weight]											
43	8 f	Water	[t/yr]											
44	8 g	Ice	[t/yr]											
45	8 h	Fly ash (FA)	[t/yr, dry weight]											
46	8 i	Ground granulated blast-furnace slag (GGBS)	[t/yr, dry weight]											
47	8 j	Silica fume (SF)	[t/yr, dry weight]											
48	8 k	Superplasticizer	[t/yr]											
49	8 l	Plasticizer	[t/yr]											
50	8 m	Setting accelerator	[t/yr]											

Figure 1 Spreadsheets of the ready-mixed concrete CFP quantification tool
CFP quantification



17 f	Water	[t CO2e/ t]	0.0010	0.0010	0.0010	0.0010	0.0010
17 g	Ice	[t CO2e/ t]					
17 h	Fly ash (FA)	[t CO2e/ t]	0.0080	0.0080	0.0080	0.0080	0.0080
17 i	Ground granulated blast-furnace slag (GGBS)	[t CO2e/ t]	0.0830	0.0830	0.0830	0.0830	0.0830
17 j	Silica fume (SF)	[t CO2e/ t]	0.0140	0.0140	0.0140	0.0140	0.0140
17 k	Superplasticizer	[t CO2e/ t]	0.0047	0.0047	0.0047	0.0047	0.0047
17 l	Plasticizer	[t CO2e/ t]	0.0018	0.0018	0.0018	0.0018	0.0018
17 m	Setting accelerator	[t CO2e/ t]	0.0393	0.0393	0.0393	0.0393	0.0393
17 n	Energy ware: Gasoline	[t CO2e/ t]	0.7600	0.7600	0.7600	0.7600	0.7600
17 o	Energy ware:	[t CO2e/ t]					
17 p	Energy ware:	[t CO2e/ t]					
17 q	Energy ware:	[t CO2e/ t]					
17 r	Others:	[t CO2e/ t]					
17 s	Others:	[t CO2e/ t]					
18	CO2e from bought raw materials	[t CO2e/yr]					
19	CO2e from off-site transportation (calculated using WBCSD's protocol)						
19 a	Raw materials to plant	[t CO2e/yr]					
19 b	Finished products to HK (users)	[t CO2e/yr]					
20	CO2e from land use change	[t CO2e/yr]					
21	Total indirect CO2e	[t CO2e/yr]					
III. PERFORMANCE INDICATORS							
A. CO2e Emissions (= total direct and indirect CO2e; all sources)			Category 1	Category 2	Category 3	Category 4	Category 5
22	Gross CO2e	[t CO2e/yr]					
22 a	Raw material acquisition	[t CO2e/yr]					
22 b	Production	[t CO2e/yr]					
22 c	Transportation to HK	[t CO2e/yr]					
23	Specific gross CO2 per t of concrete produced	[kg CO2e/t con prod]					
23 a	Raw material acquisition	[kg CO2e/t con prod]					
23 b	Production	[kg CO2e/t con prod]					
23 c	Transportation to HK	[kg CO2e/t con prod]					
IV. FUELS CONSUMPTION - DETAILED INFORMATION							
A. CO2e Emission Factors of Fuels (per lower heating value)			Category 1	Category 2	Category 3	Category 4	Category 5
24	**Conventional fossil fuels**						
24 a	coal + anthracite + waste coal	[kg CO2e/GJ]	96.60	96.60	96.60	96.60	96.60
24 b	petrol coke	[kg CO2e/GJ]	97.75	97.75	97.75	97.75	97.75
24 c	(ultra) heavy fuel	[kg CO2e/GJ]	77.65	77.65	77.65	77.65	77.65
24 d	diesel oil	[kg CO2e/GJ]	74.35	74.35	74.35	74.35	74.35
24 e	natural gas	[kg CO2e/GJ]	56.15	56.15	56.15	56.15	56.15
24 f	shale	[kg CO2e/GJ]	113.97	113.97	113.97	113.97	113.97

Figure 2 Spreadsheets of the ready-mixed concrete CFP quantification tool performance indicators

The developed assessment frameworks for the 10 construction materials have been verified through semi-structured interviews with material manufacturers, suppliers and local contractors. The assessment frameworks have addressed all the suggestions and comments collected from the semi-structured interviews. The carbon footprint assessment tools have then been developed based on the identified boundary and sources of emissions. For ready-mixed concrete, the CFP quantification tool has also been verified through a case study to ensure their completeness, consistency and accuracy. For the other nine construction materials, due to the very limited real data from manufactures and suppliers, it is impracticable to verify the CFP quantification tools using real cases. However, their completeness, consistency and accuracy have been confirmed during the semi-structured interviews and thus they should be ready for use in the next stage of Scheme implementation.

4 RECOMMENDATION AND DISCUSSION

4.1 Proposed Initial Benchmarks

To facilitate CIC delineating the carbon ratings of the 10 selected materials, an extensive literature review was carried out and the ranges as proposed in different standards have been made reference to.

The initial benchmarks of ready-mixed concrete are proposed based on the review of local and international databases of ready-mixed concrete available. This study adopts the ICE database as it has a comprehensive range of carbon emission factors of difference concrete grades (Table 11).

Table 11 Proposed benchmark for ready-mixed concrete

Concrete Grade	C30	C40	C50	C60	C70	C80
E_{da}	296	350	396	443	490	490
Carbon Rating			(kgCO_2e/m^3)			
A	<252	<298	<337	<377	<417	<417
B	252-281	298-333	337-376	377-421	417-466	417-466
C	281-311	333-368	376-416	421-465	466-515	466-515
D	311-340	368-403	416-455	465-509	515-564	515-564
E	>340	>403	>455	>509	>564	>564

Given the fact that the carbon emission factors of different construction materials would vary, the embodied carbon (per unit) of a prefabricated part largely depends on the design, i.e. amount of concrete and rebar used. Therefore, benchmarking the precast concrete product based on the total embodied carbon (per unit) is not feasible in this case. According to the opinions from the interviewed precast concrete manufacturers, the design details, e.g. reinforcement, of prefabricated parts are determined by the developer and architect and cannot be altered by precast concrete manufacturers. However, the source of raw materials, such as cement, aggregate, steel, aluminium, and the concrete design mix is within the control of precast concrete manufacturers. Therefore, the following benchmark regime (Table 12) for precast concrete is proposed.

Table 12 Proposed benchmark regime for precast concrete

Overall Carbon Rating for Precast Concrete*	Ready-mixed Concrete	Rebar	Wood Mould
A	A	A	A
B	B or above	B or above	B or above
C	C or above	C or above	C or above
D	D or above	D or above	D or above
E	E or above	E or above	E or above

The initial benchmarks of stainless steel are proposed based on the review of international databases of stainless steel available as a local database is currently absent. Two databases have been identified, i.e. ICE and ISSF life cycle inventory data (ISSF, 2015). As ISSF is more up-to-date and comprehensively reflecting the industry's situation, the ISSF 2015 data (2.92 $kgCO_2e/kg$) is proposed to be adopted as the initial benchmark in the Scheme. It is worthy to note that the data related to stainless steel in the ICE database was also sourced from the previous ISSF data (Tables 13 and 14).

Table 13 Available carbon database of stainless steel

Data sources	ICE (2011)	ISSF (2015)
	Unit ($kgCO_2e/kg$ of stainless steel)	
Emissions Factors	6.15 (Grade 304 stainless steel; not separate primary and recycled materials production routes; sourced from ISSF data)	4.2 (virgin steel) 2.0(50 % of stainless steel scrap) 2.92 (Average)

Table 14 Proposed benchmark for stainless steel	
Carbon Rating	**Carbon Emission ($kgCO_2e/kg$)**
A	≤ 1.61
B	1.61 ~ 2.19
C	2.19 ~ 3.65
D	3.65 ~ 4.23
E	≥ 4.23

For galvanised mild steel, one database has been identified, i.e. ICE. However, the database only provides carbon emission factor for one type of galvanised steel product, i.e. coil / sheet. The emission factor of 100% primary galvanised steel coil / sheet is 3.01 $kgCO_2e/kg$; the emission factor of EU (with typical recycle content of 59%) is 1.54 $kgCO_2e/kg$; the emission factor of non-EU countries (with typical recycle content of 35.5%) is 2.12 $kgCO_2e/kg$; the emission factor of world typical value (with typical recycle content of 39%) is 2.03 $kgCO_2e/kg$. The proposed benchmark of galvanised mild steel is established based on the world typical value (39% recycle content), which is 2.03 $kgCO_2e/kg$ (Table 15).

Table 15 Proposed benchmark for galvanised mild steel (coil / sheet)	
Carbon Rating	**Carbon Emission ($kgCO_2e/kg$)**
A	≤ 1.12
B	1.12 ~ 1.52
C	1.52 ~ 2.54
D	2.54 ~ 2.94
E	≥ 2.94

For the cast iron, one database has been identified, i.e. ICE. However, the database only provides the embodied carbon of general cast iron (2.03 CO_2e/kg). This value is a very roughly estimated figure as pointed out by ICE because the amount and quality of data collected in ICE is limited (ICE, 2011). The proposed benchmark of cast iron is then established based on this value (Table 16).

Table 16 Proposed benchmark for cast iron

Carbon Rating	Carbon Emission ($kgCO_2e/kg$)
A	≤ 1.28
B	1.28 ~ 1.75
C	1.75 ~ 2.91
D	2.91 ~ 3.37
E	≥ 3.37

For the clay brick products, two data sources have been identified, i.e. ICE and Brick Development Association in the UK. The carbon emission data (for general clay bricks) they provided are 0.24 $kgCO_2e/kg$ and 0.252 $kgCO_2e/kg$ respectively. Therefore, the proposed benchmark of clay bricks is established based on the average of the above two data: 0.246 $kgCO_2e/kg$ (Table 17).

Table 17 Proposed benchmark for clay brick

Carbon Rating	Carbon Emission ($kgCO_2e/kg$)
A	≤ 0.21
B	0.21 ~ 0.23
C	0.23 ~ 0.26
D	0.26 ~ 0.28
E	≥ 0.28

For the construction aggregate products, four data sources have been identified, i.e. ICE, European Reference Life Cycle Database, Chinese Life Cycle Database, and Gan *et al.* (2016). The carbon emission data for gravel / crushed rock and sand is shown in Table 18, and the proposed benchmarks for gravel / crushed rock and sand are shown in Table 19.

Table 18 Available carbon data sources of gravel / crush rock and sand

Data Source	Gravel / crushed rock	Sand
Bath ICE, 2011	0.0052	0.0051
European Reference Life Cycle Database (ELCD), 2012	0.0032	0.0023
Chinese Life Cycle Database (CLCD), 2013	0.0022	0.0026
Gan *et al.*, 2016	0.0044	0.0044
Range	0.0022 - 0.0052	0.0023 - 0.0051
Average carbon emission value, E_{da}	0.0038	0.0036

Table 19 Proposed benchmark for construction aggregate

Data sources	Carbon Emission ($kgCO_2e/kg$)	
	Gravel / Crushed Rock	Sand
A	≤ 0.0032	≤ 0.0031
B	0.0032 ~ 0.0036	0.0031 ~ 0.0034
C	0.0036 ~ 0.0039	0.0034 ~ 0.0038
D	0.0039 ~ 0.0043	0.0038 ~ 0.0041
E	≥ 0.0043	≥ 0.0041

For the asphalt pavement products, two data sources have been identified, i.e. ICE and White *et al.* (2010); and the carbon emission data as identified are 0.076 $kgCO_2e/kg$ and 0.09 $kgCO_2e/kg$ respectively. Therefore, the proposed benchmark of asphalt pavement is established based on the average of the above two data: 0.083 $kgCO_2e/kg$ (Table 20).

Table 20 Proposed benchmark for asphalt pavement

Carbon Rating	Carbon Emission ($kgCO_2e/kg$)
A	≤ 0.071
B	0.071 ~ 0.079
C	0.079 ~ 0.087
D	0.087 ~ 0.096
E	≥ 0.096

For the sawn timber and plywood products, one data source has been identified, i.e. ICE; and the carbon emission data is 0.87 $kgCO_2e/kg$ for sawn hardwood, 0.59 $kgCO_2e/kg$ for sawn softwood and 1.1 $kgCO_2e/kg$ for plywood. Therefore, the proposed benchmarks of sawn timber and plywood are established based on these figures (Table 21).

Table 21 Proposed benchmark for sawn timber and plywood

Data sources	Carbon Emission ($kgCO_2e/kg$)		
	Sawn Hardwood	Sawn Softwood	Plywood
A	≤ 0.74	≤ 0.50	≤ 0.94
B	0.74 ~ 0.83	0.50 ~ 0.56	0.94 ~ 1.05
C	0.83 ~ 0.91	0.56 ~ 0.62	1.05 ~ 1.16
D	0.91 ~ 1.00	0.62 ~ 0.68	1.16 ~ 1.27
E	≥ 1.00	≥ 0.68	≥ 1.27

For the gypsum board products, two data sources have been identified, i.e. ICE and the European Reference Life Cycle Database; whereby the carbon emission data found are 0.39 $kgCO_2e/kg$ and 0.202 $kgCO_2e/kg$ respectively. Therefore, the proposed benchmark of gypsum board is established based on the average of the above two data: 0.296 $kgCO_2e/kg$ (Table 22).

Table 22 Proposed benchmark for gypsum board

Carbon Rating	Carbon Emission ($kgCO_2e/kg$)
A	≤ 0.25
B	0.25 ~ 0.28
C	0.28 ~ 0.31
D	0.31 ~ 0.34
E	≥ 0.34

4.2 Perceptions of Local Industry Stakeholders on Carbon Labelling of Construction Materials

In order to capture the opinions and concerns of stakeholders in the HK construction industry, interviews were carried out with four local industry practitioners. The interviewees represented a broad spectrum of construction stakeholders from government bureaux/ departments, material manufacturers, consultants and contractors. The interviewees were asked to provide their opinions on the following aspects, i.e. the: (i) implications and limitations of the existing green initiatives and legislations; (ii) aspirations and perceptions of carbon labelling in HK; and (iii) strategies and measures needed to successfully implement the Scheme of construction materials in HK.

Criteria Adopted by Industry Stakeholders in Selecting Construction Materials in HK

An interviewee from the government believed that the contractors in HK would definitely consider the cost of materials as the primary factor. He further pointed out that some client bodies in HK especially those from the public sector would consider the environmental impacts of building materials in their project as well. However, many private developers would only consider lowering the environmental impacts of their projects if there are incentives, e.g. gross floor area (GFA) concession or for the sake of establishing a better reputation.

The representatives from a local contractor concluded that the contract requirement was the most critical issue. During the procurement procedure, they will consider the cost, quality of supply as well as other factors such as safety of product, i.e. whether the product contains hazardous materials that will harm construction workers or whether the products contain recycled materials. If the price of a product is similar, they would tend to choose products having better green performance. They also mentioned that their company had been very supportive to the sustainable development initiatives in HK, and had been trying to procure green construction materials even though this requirement was not included in the contract. For example, they required the timber being used in a construction project be certified under the Forest Stewardship Council (FSC). He also used steel as another example and pointed out that although the Hong Kong Building Environmental Assessment Method Plus (BEAM Plus) did not offer extra points for the usage of green steel products, their company would still aim to procure steel produced in a greener manner. Despite that, they pointed out that carbon / green labels for construction materials were still not widely adopted in HK and around the world.

From the perspective of a building services consultant, an interviewee believed that the two main factors to be considered when selecting building services equipment are energy efficiency and quality (durability and reliability). This interviewee stressed that a building services consultant would design and specify equipment / components based on its energy efficiency and performance in technical specifications, and the contractors shall select appropriate equipment and submit detailed specifications and catalogues to their office for review and approval.

Current Situation of Green Initiatives and Legislations in HK Construction Industry

According to all the interviewees, the most popular and commonly adopted green initiatives in HK are BEAM Plus, Leadership in Energy and Environmental Design (LEED), Mandatory Energy Efficiency Labelling Scheme (MEEL), and Buildings Energy Efficiency Ordinance. All the interviewees agreed that BEAM Plus and LEED were playing their intended roles in propelling HK towards the goal of sustainable development. If the government or clients request greater adoption of building products with low carbon and / or green certification, it will definitely send a strong message to the industry.

One interviewee commented that government departments had been actively participating in the BEAM Plus scheme and most of their projects had achieved the gold or even platinum level in BEAM Plus. This view is also shared by the other two interviewees. In contrast, local private developers are more profit-orientated, and not all would be actively advocating the adoption of voluntary green initiatives such as BEAM Plus and LEED according another interviewee. This is primarily because the application of the above mentioned green initiatives would increase the cost of their projects.

An interviewee from the contractor group elaborated that sustainable development did not necessarily equal to follow green criteria blindly. Stakeholders in the construction industry should be aware of the environmental impacts of the products all through the supply chain. For example, it is quite unreasonable to import low carbon or green construction materials all the way from Europe to HK since the transportation of such materials would significantly increase the amount of transportation emissions.

Aspirations and Perceptions of the CIC Carbon Labelling Scheme

A government official interviewed believed that the management of many local developers, consultants, contractors, etc. were aware of the importance of reducing the carbon footprint of buildings. However, their decisions were still predominantly affected by the quality and cost of materials. Therefore, developers could play a critical role in promoting the use of low carbon materials. If developers encourage or require the labelled materials be used in their projects, the entire supply chain including the consultants, contractors and suppliers would follow.

A contractor representative, however, pointed out that carbon labelling was not widely adopted in HK at the moment. Nevertheless, he is supportive to the Scheme and his organisation is willing to purchase construction materials which are carbon labelled. Recently, their organisation has formed a team to calculate the carbon emissions of their buildings and this includes collecting relevant data and information from manufacturers and hiring a third-party organisation to audit the data. They have directed significant efforts in exploring more about the certification systems from around the world, as well as monitoring the green developments of construction materials/ products available in the market. They believe that the Scheme could save them considerable effort in soliciting the information related to low carbon construction materials/ products.

Having attended the CIC training course, two interviewees representing contractors found that it would take a long time and it was a tedious task to fully understand the labelling procedures and the CFP quantification tools. Besides, it is difficult to collect and verify the data since most material manufacturers are not based in HK. There was also a lack of universally recognised data collection method for the Scheme.

Material Coverage of the CIC Carbon Labelling Scheme

When reviewing the coverage of the Scheme, an interviewee from the government pointed out there were still many materials to be embraced. Apart from those materials being used for major building structures, building services components, such as copper for cable, polyvinylchloride conduit, stone tile, and dry wall panel should also be covered by the Scheme in future. The contractor interviewed suggested that the Scheme should include more materials used in civil engineering projects, including those for the construction of tunnel, highway and bridge. This interviewee felt that the materials of some building services components, such as pipe and duct should not be overlooked as considerable quantities of these materials are consumed in a construction project. The most common ones are steel, copper and unplasticised polyvinylchloride for pipe, steel for duct, and copper for cable.

Barriers in Implementing the CIC Carbon Labelling Scheme in HK

According to the government official, the costs for manufacturers to apply for the Scheme is one of the key barriers for implementation. He believed that majority of the stakeholders were willing to participate in the Scheme if the overall cost of certification was reasonable.

Some interviewees worried that the collection of the necessary data would create a problem since the construction materials used in HK are imported from all over the world. Therefore, it could be difficult to trace back to the manufacturing processes and verify the data source reliably. It was essential to ensure that the report on the manufacturing processes and the corresponding data were accurate. A contractor representative suggested that the involvement of import associations in HK may help verify the data. These associations should have more accurate data related to the imported products and they may also have more intelligence about the manufacturers. All these comments point to a simplified CFP assessment method to successfully promote the Scheme.

An interviewee also concerned about the possible overlapping of the Scheme and BEAM Plus, and he questioned whether it would be a waste of resources to apply for both. He pointed out that BEAM Plus had advantages in promoting the development of green buildings in the construction industry. Besides, BEAM Plus is quite practical and more mature. On the other hand, the Scheme is an environmental assessment scheme with a rather different concept. Because of that, the industry may be confused by the existence of two different schemes.

Implementation Strategies for Carbon Labelling Scheme in HK

One interviewee from the contractor group emphasised the importance of the supply chain. As every sector in the construction supply chain is closely linked, any green initiatives should percolate through the entire supply chain. The success of sustainable development in the construction industry depends very much on the joint efforts of the whole supply chain. For example, in some construction projects, subcontractors would purchase the necessary materials directly. These subcontractors should also be regarded as the key stakeholders and they should be aware of the Scheme. The certification system should bring benefits to the entire supply chain in order to motivate them participating in the Scheme.

All interviewees agreed that the Scheme should be implemented voluntarily in the beginning. Lessons can be drawn from the Electrical and Mechanical Services Department's (EMSD) Energy Efficiency Registration Scheme, which was a voluntary scheme when first introduced in 1998, and subsequently became mandatory through the Buildings Energy Efficiency Ordinance in 2012. Likewise, the Scheme can be implemented voluntarily at first and made mandatory when substantial attention is received. Moreover, interviewees suggested that the performance standards could be easier in the beginning before being tightened up gradually.

It was also noted by a government official that the best way to encourage stakeholders to participate the Scheme is to provide incentives. All interviewees advocated that the Scheme should be integrated with BEAM Plus so that developers may gain benefits from the relevant incentives like GFA concession to commensurate their extra effort in selecting and ordering low carbon materials.

4.3 Future Work

Establishing a Local Carbon Emissions Database

While one of the core components of the developed carbon assessment framework is the CFP quantification, the absence of a local database of embodied carbon for construction materials at present could hinder industry professionals from assessing the actual carbon footprint of construction materials. The carbon footprint of construction materials as recorded in overseas databases may not totally reflect the HK situation, primarily due to the fact that they employ different materials classification regimes. Therefore, a carbon labelling scheme specifically designed for HK is desirable so as to enable the embodied carbon of a construction product be compared with other comparable materials being used in the local industry and / or those manufactured or used in other developed countries. The HK-based carbon emission database for construction materials would also facilitate the development of localised benchmarks.

Low Carbon Design

The Scheme could substantially reduce the embodied carbon of building to some extent. However, if low carbon design is adopted in the early planning stage, the carbon emissions of the embodied and other life cycle stages of building would be further reduced. Take concrete as an example. A low carbon design mix of concrete could reduce a reinforced concrete structure building's embodied carbon by 5% at most, whilst a design adopt steel structure could safe more than 20% of the embodied emissions because of the less use of concrete and rebar. Besides, low carbon design has considerable impact on the life cycle carbon emissions of building especially in the operation stage.

Extending the Range of the Construction Materials / Products

The proposed Scheme is now extended to the 15 construction materials which cover the major portion of the entire building embodied carbon emissions sources. However, it can be further extended to cover other types of materials in the future which may account for significant GHG emissions in the HK construction industry. Moreover, given that a building's operational phase accounts for 80-85% of GHG emissions throughout its life cycle, building services installations/ systems are recommended to be covered in the labelling scheme.

Establishing an Online Platform for Low Carbon Construction Materials/ Products

An Online Platform for the low carbon construction materials/ products under the Scheme would be established to disseminate and promote the Scheme. Three overseas online platforms namely SGLS, GECA, and MAT have been reviewed, and their strengths and weaknesses have been revealed. The proposed online platform would be built based on learning from the strength of the three online platforms. It would enable manufacturers and suppliers to showcase their low carbon products and allow potential clients, design team members and contractors to identify low carbon construction materials more easily and effectively.

5 REFERENCES

ASTM A123/A123M (2013) *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

ASTM A644 - 14 (2014) *Standard Terminology Relating to Iron Castings*

ASTM A767 / A767M (2009) *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*

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.

BS EN 520:2004 (2004) *Gypsum plasterboards - Definitions, requirements and test methods*

BS EN 636-1 (2012) *Plywood - Specification - Part 1: Requirements for plywood for use in dry conditions*

BS EN 636-1 (2012) *Plywood - Specification - Part 2: Requirements for plywood for use in humid conditions*

BS EN 636-1 (2012) *Plywood - Specification - Part 3: Requirements for plywood for use in exterior conditions*

BS EN 844-2 (1995) *Round and sawn timber - Terminology - Part 3: General terms related to sawn timber*

BS EN 13108 (2006) *Bituminous Mixtures - Material Specifications*

BS EN ISO 1461 (2009) *Hot dip galvanized coatings on fabricated iron and steel articles. Specifications and test methods*

Buildings Department (2013) Code of Practice for Structural Use of Concrete 2013. Available in http://www.bd.gov.hk/english/documents/code/CoP_SUC2013e.pdf

California Integrated Waste Management Board (2000) Designing With Vision: A Technical Manual for Material Choices in Sustainable Construction. California Environmental Protection Agency: California, CA, USA.

Carbon Trust (2007) Carbon Footprint Measurement Methodology. *The Carbon Trust*, 670 London, UK.

Chau, C.K., Yik, F.W.H., Hui, W.K., Liu, H.C. and Yu, H.K. (2007) Environmental impacts of building materials and building services components for commercial buildings in Hong Kong, *Journal of Cleaner Production*, 15(18), 1840-1851.

Chen, T.Y., Burnett, J. and Chau, C.K. (2001) Analysis of embodied energy use in the residential building of Hong Kong, *Energy*, 26(4), 323-340.

CLCD (2013) Chinese Life Cycle Database (CLCD), Sichuan University, China and IKE Environmental Technology CO., Ltd, China.

CS3 (2013) Construction Standard CS3:2013 Aggregates for Concrete

Croft, N.H. (2010) Product carbon footprint ("PCF") – Focus on the consumer, Vision, 37, 5-7, *Hong Kong Quality Assurance Agency*, Hong Kong.

Ecobalance Inc. (2000) Life Cycle Assessment of Nickel Products: Final Report. Prepared for Nickel Industry LCA Group.

ELCD (2012) European Reference Life Cycle Database (ELCD), European Commission – Joint Research Centre.

EPD (2010) Greenhouse Gas Emissions in Hong Kong by Sector, Environmental Protection Department, Government of the HKSAR, Hong Kong.

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

Gan, V.J.L., Cheng, J.C.P. and Lo, I.M.C. (2016) Integrating life cycle assessment and multi-objective optimization for economical and environmentally sustainable supply of aggregate, *Journal of Cleaner Production*, 113, 76-85.

González, M.J. and Navarro, J.G. (2006) Assessment of the decrease of CO2 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.

Lagendijk, H. and Jones, R.T. (1997) Production of Ferronickel from Nickel Laterites in a DC-arc Furnace. *36th Annual Conference of Metallurgists*, Sudbury, Canada, August 1997.

Nassen, J., Holmberg, J., Wadeskog, A. and Nyman, M. (2007) Direct and indirect energy use and carbon emissions in the production phase of buildings: An input-output analysis. *Energy*. Vol. 32, pp1593–1602

Papp, J.F. (1991) Chromium 1990. USBM Annu. Rep. p. 9.

Papp, J.F. (1995) Chromium Life Cycle Study. United States Department of the Interior, Bureau of Mines. *Information Circular 1994*

PAS 2050 (2011) Specification for the assessment of life cycle greenhouse gas emissions of goods and services, PAS 2050, *British Standard Institute, UK.*

United Nations (1997) The Kyoto Protocol. New York: United Nations.

UNFCCC (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, United Nations Framework Convention on Climate Change, Bonn, Germany.

US EPA (1993) Gypsum Manufacturing. Environmental Protection Department (EPA), US.

Vandenbergh M.P., Dietz, T. and Stern, P.C. (2011) Time to try carbon labelling, *Nature Climate Change*, 1, 4-6.

von Krüger, P., Silva, C.A., Batista Vieira, C., Araújo, F.G.S., Seshadri, V. (2010) Relevant Aspects Related to Production of Iron Nickel Alloys (Pig Iron Containing Nickel) in Mini Blast Furnaces. *The Twelfth International Ferroalloys Congress Sustainable Future*. June 6 – 9, 2010, Helsinki, Finland

White, P., Golden, J.S., Biligiri, K.P. and Kaloush, K. (2010) Modeling climate change impacts of pavement production and construction. *Resources, Conservation and Recycling*, 54 (11), 776-782.

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