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Carbon audit: a literature review and an empirical study on a hotel

Structured abstract

Purpose
Worldwide many carbon audit guidelines have been developed, but comparative reviews of these guidelines and empirical findings of carbon emissions from hotels remain limited. The aim of the study reported here was to bridge these knowledge gaps.

Methodology/approach
A comparative review of the legislations and guidelines for carbon audits in Australia, the United Kingdom and Hong Kong was made. An empirical audit, which entailed a series of site visits and interviews for collecting the record data of a typical hotel in Hong Kong, was conducted to identify the sources and amounts of carbon emissions from the hotel.

Findings
Conduction of carbon audits for buildings in Hong Kong is entirely voluntary. Reporting of certain scopes of carbon emissions is at the sole discretion of the reporting party. Purchased electricity for the hotel is the dominant source of carbon emissions.

Research implications
Audits in future may follow the reported audit process to identify the carbon emissions from other hotels to enlarge the pool of empirical findings, which are prerequisite to developing carbon emission benchmarks and carbon footprint analyses.

Practical implications
The suggestions made for overcoming the obstacles found from the audit are crucial for performing smoother and more proper audits in future.

Originality/value
The review findings and the practical problems identified are useful information for the stakeholders of carbon audits, including the policy makers and the facilities management practitioners.

Paper type
Research paper

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Introduction

Nowadays, global warming is not only an environmental issue but also one of the biggest challenges to the international community. As the Intergovernmental Panel on Climate Change (IPCC) expected, the global temperatures would rise between 1 and 6ºC by the end of this century (Marsh et al., 2010). Central to this global warming problem is the emissions of greenhouse gases (GHGs), in particular the emissions of carbon dioxide due to energy generation.

Between 1984 and 2004, carbon dioxide emissions in the whole world have increased by 43%, with an average annual increase of 1.8% (Pérez-Lombard et al., 2008). In Hong Kong, the total amount of GHG emissions in 2007 was about 46,700 kilotonnes of CO_2-equivalent (CO_2-e), or 6.7 tonnes per capita (Environmental Protection Department, 2009), which is comparable to the statistic (6.26 tonnes per capita) announced by the International Energy Agency (International Energy Agency, 2009). Though being lower than those recorded in developed countries such as the United States (19.1), Australia (18.75), Singapore (9.8), Japan (9.68) and the United Kingdom (8.6), this level was still higher than that of the whole world (4.38).

Realizing the dominant energy consumption by buildings in developed and developing countries, IPCC recognized that the building sector has the greatest economic mitigation potential for reduction of GHG emissions (Intergovernmental Panel on Climate Change, 2007). Carbon audit, which can be used for revealing the major sources and amounts of

GHG emissions, is a life cycle assessment tool that can identify appropriate targets and opportunities for reducing the emissions from buildings (European Commission, 2009). Worldwide many guidelines have been developed for promoting carbon audits, but a comprehensive review of their key features is not available yet. Without understanding their bases and methodologies, it is not sure whether fair comparisons can be made between the results obtained from following these guidelines.

Lately, more and more efforts have been devoted to studying carbon emissions. Examples include: determination of carbon emissions based on simulated building energy consumptions (Kneifel, 2010); a modeling approach described by (Pękala et al., 2010) for optimal planning of energy systems subject to carbon and land footprint constraints; and a preliminary comparison of the carbon footprints of twelve metropolitan areas (Sovacool and Brown, 2010). Studies which investigate into carbon emissions based on in-depth field data of individual buildings, on the other hand, could not be found from the open literature.

In popular tourist destinations, e.g. Singapore and Hong Kong, hotels are among the energy-intensive building categories (Deng and Burnett, 2000; Lai and Yik, 2008; Priyadarsini et al., 2009). The predicted amount of carbon emissions due to energy use in the hotel industry is significant (Chan and Lam, 2002). Without performing empirical investigations into the hotels, however, their sources of carbon emissions and the actual extents to which they have contributed to such emissions remain unknown. Lacking such information, facilities managers could hardly determine if the carbon emissions from their facilities are acceptable or not.

Driven by the desire to filling the above knowledge gaps, a two-stage study was carried out.

In Stage 1, the relevant legislations and carbon audit guidelines of Australia, the United Kingdom (UK) and Hong Kong were reviewed. In Stage 2, an empirical carbon audit was conducted based on the record data of a typical hotel in Hong Kong. The first of the following two parts will present the findings of the review, including the similarities and differences between the key features of the guidelines. The second part, which is drawn from the empirical audit, will report on its data collection process, how the collected data were processed, and the analyzed findings. Further to identifying the problems encountered during the audit, suggestions for how they may be overcome are also given.

Literature review

The 2009 RICS Global Zero Carbon Capacity Index (Royal Institution of Chartered Surveyors, 2010), which aimed at highlighting countries that are developing the capacity to make progress towards the goal of a zero-carbon built environment, showed that Australia and UK were the top two performing countries in terms of policy frameworks. As such, the following section will present a review of the legislations and guidelines in respect of carbon audits in these two countries. Then, a review of the local (Hong Kong) guidelines will be reported, followed by a comparison between the key features of the guidelines of these three places.

Australia

In Australia, the National Greenhouse and Energy Reporting Act 2007 (NGER Act) requires that all controlling corporations must apply for registration with the Greenhouse and Energy Data Officer if their corporate group emits greenhouse gases or produces or consumes energy at or above the specified thresholds for a financial (reporting) year. In order to help corporations understand their obligations under the Act, the Department of Climate Change of published the "National Greenhouse and Energy Reporting Guidelines" (NGERG) (Department of Climate Change 2008) and the "National Greenhouse and Energy Reporting (Measurement) Technical Guidelines" (NGER Technical Guidelines) (Department of Climate Change 2009a). Additionally, the same Department issued the "National Carbon Offset Standard" (NCOS), which has come into effect on 1 July 2010 (Department of Climate Change 2010). This Standard, established based on Australian Standard (AS) ISO 14064 series, International Standards ISO 14040 series and ISO 14065, the GHG Protocol and the NGER Act, provides guidance to businesses who wish to make their organization carbon neutral or develop carbon neutral products in a way that achieves emissions reductions.

According to NCOS, an organization should calculate the emissions of the six greenhouse gases covered by the Kyoto Protocol. The emissions are classified into three scopes (Table 1). Scope 1 covers all direct emissions and scope 2 the indirect emissions from the use of electricity, heating, cooling or steam attributable to sources within the chosen boundary. Other indirect emissions, which occur outside the boundary of a facility as a result of activities at a facility, are classified as scope 3. At a minimum, an organization should include scope 3 emissions from: business travel of its employees; disposal of waste generated by the organization; and use of paper in the course of its business.

Table 1 Classifications of GHG emissions-releasing activities

	Scope 1	Scope 2	Scope 3
Australia	• Combustion of fuel for energy • Extraction, production, flaring and distribution of fossil fuels • Industrial processes where a mineral, chemical or metal product is formed using a chemical reaction that generate greenhouse gases as a by-product • Waste disposal, either in landfill, as management of wastewater, or from waste incineration	• Emissions resulting from activities that generate electricity, heating, cooling or steam that is consumed by a facility, but do not form part of the facility	• Business travel of employees • Disposal of waste generated by the organization • Use of paper in the course of its business • Others
UK	• Combustion of fuels • Owned transport • Process emissions • Fugitive emissions	• Consumption of purchased electricity, heat, steam and cooling	• Purchased materials and fuels • Transport-released activities • Waste disposal • Leased assets, franchising and outsourcing • Sold goods and services
Hong Kong	• Combustion of fuels in stationary sources excluding electrical equipment to generate electricity, heat or steam • Combustion of fuels in mobile sources • Intentional or unintentional GHGs release from equipment and systems • Assimilation of CO_2 into biomass • Any other physical and chemical processing	• Consumption of purchased electricity • Consumption of purchased town gas	• Methane gas generation at landfill in Hong Kong due to disposal of paper waste • Electricity used for fresh water processing • Electricity used for sewage processing • Others

Furthermore, GHG emissions under scope 1 and scope 2 should be calculated in accordance with the methods and guidance provided in the NGER (Measurement) Determination, and the optional methods for calculating scope 1 emissions include: Method 1 – using default emissions factors derived from the latest version of the National Greenhouse Account Factors; Method 2 – a method using industry sampling and Australian or international standards listed in the NGER (Measurement) Determination or equivalent for analysis; Method 3 – a method using Australian or international standards listed in the Determination or equivalent standards for both sampling and analysis of fuels and raw materials; and Method 4 – direct measurement using continuous or periodic emissions monitoring. Rather than prescribing a reporting period, NCOS quoted a 12-month period as an example for calculation of GHG emissions. Audits of offset methodologies, projects and carbon footprint calculations required under the Standard should be undertaken by a suitably qualified auditor. When data of the three scopes are available, the amounts of GHG emissions can be calculated by following the guidance in NGERG and NCOS and applying the emissions factors derived from the National Greenhouse Accounts (NGA) Factors (Department of Climate Change, 2009b).

Besides, an online tool called National Greenhouse and Energy Reporting System Calculator (NGER calculator) has been devised to assist corporations to self assess whether or not they should apply for registration under the NGER Act. Once registered, corporations will need to submit reports through the Online System for Comprehensive Activity Reporting (OSCAR), which is a web-based data tool enabling an organization to calculate greenhouse emissions based on its energy and emissions data.

United Kingdom

Pursuant to section 85 of the Climate Change Act 2008 of UK, the Government must, not later than 6 April 2012, make regulations under section 416(4) of the Companies Act 2006 requiring the directors' report of a company to contain such information as may be specified in the regulations about emissions of greenhouse gases from activities for which the company is responsible, or lay before Parliament a report explaining why no such regulations have been made. While further public consultation will be undertaken before a decision is made on whether or not reporting of carbon emissions should become mandatory, the Department for Environmental, Food and Rural Affairs (Defra) and the Department for Energy and Climate

Change (DECC) have published the "Guidance on how to measure and report your greenhouse gas emissions", which specifies the general principles and requirements for conducting carbon audits for all sizes of business and for public and voluntary sector organizations (Department for Environment Food and Rural Affairs, 2009a).

The guidance was formulated based on the GHG Protocol, and it aligns with several measuring and reporting schemes such as ISO 14064-1 and the Carbon Trust Standard. Being complementary to both PAS 2050 and ISO 14040, the guidance categorizes the emissions-releasing activities into three groups (Table 1), comprising direct (scope 1) and indirect emissions (scopes 2 and 3), which are determined by judging whether the sources of emissions are owned or controlled by the building owners. Scope 2 includes the indirect emissions that are a consequence of the organization's activities but which occur at sources the organization does not own or control. Scope 3 covers the organization's indirect emissions which are not classed as scope 2 emissions. Reporting of emissions under scopes 1 and 2 is recommended whereas reporting of those under scope 3 is discretionary.

The guidance recommends a reporting period of 12 months. All the six GHGs covered by the Kyoto Protocol have to be accounted for and reported according to the guidance. When calculating the GHG emissions, reference should be made to the emission factors contained in the Defra / DECC's GHG Conversion Factors (Department for Environment Food and Rural Affairs, 2009b). Besides using the Defra / DECC's spreadsheets, the online carbon calculator tool of the Carbon Trust may be used for calculating GHGs. Additionally, Defra has developed a domestic carbon footprint calculator for measuring household and individual footprints. This online tool, called Act on CO_2 Calculator, covers annual end-user (direct) CO_2 emissions whereas life-cycle (indirect) emissions are not currently included (Department of Energy and Climate Change, 2009).

With a view to informing low carbon design and influencing future policy and regulation, the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE) have co-organized an online benchmarking platform "CarbonBuzz", which allows practices to voluntarily share project data and best practice (Royal Institute of British Architects and Chartered Institution of Building Services Engineers, 2010). This platform makes use of CIBSE TM46, which contains energy consumption benchmarks for 29 building use categories. The electricity and fuel consumption (in kWh/m^2/yr) of a building project entered into the platform will be converted into a CO_2 emissions profile (in kgCO_2/m^2/yr), based on which the designed energy use of the project can be compared with its actual energy use.

Hong Kong

For raising the awareness of building users and mangers about GHG emissions and assisting them to measure the emissions, the Environmental Protection Department (EPD) and the Electrical and Mechanical Services Department (EMSD) jointly issued the first version of "Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes)" in 2008. The latest version of this set of guidelines (hereinafter referred to as "the Guidelines") was published in 2010, in which the emission factors for calculating GHG emissions have been updated but the format for reporting the emissions remains the same as that in the 2008 version.

Designed with reference to the GHG Protocol and ISO 14064-1, the Guidelines are applicable to buildings which are entirely used for commercial (e.g. offices, retails, hotels, etc.), residential or institutional purposes such as schools and universities. Among the six GHGs covered by the Kyoto Protocol, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), the Guidelines cover only the first five because SF_6 is not commonly found in normal operations of the building types covered by the present Guidelines.

Under the Guidelines, GHG emissions and removals in buildings are broadly classified into three scopes (Table 1), i.e. direct (scope 1) and indirect emissions (scopes 2 and 3), by judging whether or not the sources of emissions and removals are within the physical boundary of the building concerned. Scope 2 includes the indirect emissions that are emitted due to the generation of purchased energy outside the building boundary; scope 3 covers the indirect emissions which are not included in scope 2.

The GHG emissions and removals in scopes 1 and 2 have to be reported on a gas-by-gas basis. Reporting of GHG emissions from scope 3 activities is optional. The activities to be accounted for are not limited to those listed in Table 1 as some other activities such as business travel by employees and uses of sold products and services can be included under an "Others" category. Nevertheless, no quantification methodology has been defined for calculating these emissions.

While the GHG Protocol and the IPCC Guidelines for National Greenhouse Gas Inventories have provided internationally agreed methodologies for estimating GHGs inventories (Intergovernmental Panel on Climate Change, 2006), the emission factors stated in the Guidelines make reference not only to these two sources, but also to the information published in the annual reports of the two local power companies, the local town gas company, and two government departments - the Water Supplies Department and the Drainage Services Department.

The data required for calculating GHG emissions within the three scopes include: type and quantity of fuel consumed; number of trees planted; quantities of electricity consumed, paper purchased, town gas consumed, paper recycled and water consumed; and type and quantity of refrigerants released. These data can be converted into GHG emissions or removals by applying the equations and the corresponding emission or removal factors as shown in Appendix A, which was prepared under this study by consolidating the information of the relevant publications (Drainage Services Department, 2008; Hong Kong and China Gas Company Limited, 2008; China Light and Power Holdings, 2009; Water Supplies Department, 2009; Environmental Protection Department and Electrical and Mechanical Services Department, 2010).

Intended to help small and medium enterprises assess their carbon footprints due to products manufactured and services provided, a booklet entitled "Carbon Audit Toolkit for Small and Medium Enterprises in Hong Kong" has been published (University of Hong Kong, 2010). Accompanying this set of guidelines is a CD containing a carbon calculator software that can be used for electronic calculation of carbon emissions.

Besides, the Hong Kong Awards for Environmental Excellence has introduced the Carbon"Less" Certificates scheme. Implemented by the Hong Kong Productivity Council, the aim of this scheme is to recognize buildings or organizations that have achieved a verified absolute reduction of overall carbon emissions (Hong Kong Awards for Environmental

Excellence, 2009). For new participants, a Carbon"Less" N% Certificate will be awarded if they have achieved at least 3% reduction in overall carbon footprint against their baseline total emissions, where N% denotes the actual amount of carbon footprint reduction. For existing Carbon"Less" Certificate holders who wish to get a further Certificate, they must at least maintain their pervious year's carbon footprint and achieved at least another 3% reduction in overall carbon footprint against their baseline within three consecutive years.

Table 2 Key features of the carbon audit guidelines in Australia, UK and Hong Kong

Feature	Australia	UK	Hong Kong
Reporting of carbon emissions	Mandatory (governed by National Greenhouse and Energy Reporting Act)	Will become mandatory (governed by Climate Change Act; Companies Act)	Voluntary (not governed by law)
Standards that the guidelines are based on	AS ISO 14064, ISO 14040, GHG Protocol, NGER Act 2007	GHG Protocol (also aligns with ISO 14064-1 and Carbon Trust Standard; complements PAS 2050 and ISO 14040)	GHG Protocol, ISO 14064
GHGs quantified	All six Kyoto Protocol recognized gases	All six Kyoto Protocol recognized gases	Five Kyoto Protocol recognized gases (i.e. CO_2, CH_4, N_2O, HFCs, PFCs)
Emissions classified into scopes 1, 2 and 3	Yes	Yes	Yes
Optional reporting for scope 3	No	Yes	Yes
Separate guidelines for emission factors	National Greenhouse Account Factors	Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting	None (see Appendix A for the emission factors consolidated under this study)

Table 2 summarizes the comparisons between the key features of the carbon audit guidelines in Australia, UK and Hong Kong. Common to all these guidelines, the GHG Protocol is central to the bases of their formulations. Among their differences, it is of particular importance to note that reporting of carbon emissions has already been made mandatory in Australia and will become mandatory in UK (subject to confirmation after public consultation), but there has been no plan defining when it will be made mandatory in Hong Kong. Only five of the six Kyoto Protocol recognized gases have to be reported in Hong

Kong. Reporting of scope 3 emissions is compulsory in Australia but is optional in both UK and Hong Kong. Under the three guidelines, different sets of emissions factors are used for calculating carbon emissions or removals. Given these differences, adopting a particular guideline to perform a carbon audit for a building would give a result which is different from one obtained based on another guideline.

Empirical audit

The hotel selected for this in-depth empirical study was a typical 4-star hotel in Hong Kong. With a gross floor area of about 40,700m^2, the hotel was 19-storey high, accommodating over 600 guestrooms, four restaurants, one bar, and some retail shops. The monthly average occupancy rate of the hotel exceeded 87% and the daily average number of its direct staff was about 400.

A questionnaire, which contained a data template designed according to the Guidelines and a series of questions devised for identifying the characteristics of the hotel's facilities, was prepared for use in interviewing the responsible staff. Since this was the first ever carbon audit for the hotel, a kick-off briefing was held to explain to the staff about the purpose of the study, its methodology, the tasks to be carried out and the data to be collected. Afterwards, the study team walked through the main areas of the hotel to comprehend the natures and operations of its major facilities.

With the support given by the senior management including the Director of Engineering of the hotel, the relevant staff was asked to fill in the data template. But because no such audits had been conducted before, most of the required data were not readily available. As a result, the study team re-visited the hotel in an attempt to collect the relevant data records. Through three more visits, the documentary records collected include the electricity bills, water bills, operation and maintenance (O&M) log sheets of the facilities, and orders placed for purchase of paper and collection of paper for recycling over a period of one year. After entering the data retrieved from these documentations into the template, a final meeting was held with the responsible staff to clarify the queries found during the retrieval process.

In accordance with the Guidelines and the equations summarized in Appendix A, a GHG emissions calculator was developed under this study. The calculator, in the form of an electronic spreadsheet, is applicable to commercial, residential or institutional buildings in Hong Kong. The collected data were inputted to this calculator and the computed results, which are in tonnes of CO_2 equivalent, are shown in Table 3.

Table 3 Summary of the audit results

Emissions / Removals	CO_2	CH_4	N_2O	HFCs	PFCs
Scope 1 Direct Emissions					
Stationary sources combustion	0	0	0	N	N
Mobile sources combustion	0	0	0	N	N
Fugitive emissions	N	N	N	0	0
Scope 1 GHG Removals					
Assimilation of CO_2	0	N	N	N	N
Scope 2 Energy Indirect Emissions					
Purchased electricity	6867.7 (8584.6)	N	N	N	N
Purchased town gas	154.0	N	N	N	N
Scope 3 Other Indirect Emissions					
Disposal of paper waste	N	-20.3	N	N	N
Consumption of fresh water	72.15	N	N	N	N
Treatment of waste water	25.84	N	N	N	N
Other GHG Removals					
GHG reductions and removals project	0	0	0	0	0
Sub-total / overall					
Sub-total of scope 1 emissions	0				
Sub-total of scope 1 removals	0				
Sub-total of scope 2 emissions	7021.7 (8738.6)				
Sub-total of scope 3 emissions	77.69				
Overall emissions	7099.4 (8816.3)				

Note: The values in parentheses were calculated based on a territory-wide default emission factor. Those without parentheses were based on the specific emission factor given by the power company. "N" denotes "not applicable".

Direct emissions and removals by sinks

The only stationary source of combustion was an emergency power generator in the hotel. Diesel oil was consumed in the monthly tests for this generator but, according to the hotel staff, no records had been kept for such consumptions. In the past, there were two boilers consuming diesel oil to produce hot water. But before the reporting period, these boilers had been replaced by a heat pump system and a back-up hot water heater, with both of them consuming electricity instead of diesel oil. Hence, no GHG emissions from combustion of fuels in stationary sources were reported.

Dedicated transport services were not provided by the hotel for its guests or staff members. Although taxi or vans were called for the guests upon their requests, these transport services were not controlled by the hotel and so the corresponding fuel consumptions were not included in calculating the GHG emissions. As a result, there were no GHG emissions due to combustion of fuels in mobile sources.

Refrigerant R22 was used in the chillers of the hotel while the refrigerants used in the refrigerators serving its restaurants were R134a and R404a. From the O&M log sheets, there were no records showing that refrigerant refill works had been undertaken for this group of equipments during the reporting period. As such, there were no emissions of Fugitive Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs).

Planting of trees, through assimilating CO_2 in their plant tissues, can help reduce GHG emissions. Removal of trees, on the other hand, will reduce potentials of GHG removals. Throughout the reporting period, there were no planting or removals of trees in the hotel.

Therefore, no additions or reductions in CO_2 emission were recorded in this respect.

Energy indirect emissions

The annual electricity consumption of the hotel was over 12,263 MWh, leading to 6,867.7 tonnes of CO_2-e emission when the emission was quantified based on the specific emission factor from the power company (i.e. 0.56 kgCO_2-e/kWh). This amount of emissions would rise to 8584.6 tonnes of CO_2-e if the emissions were quantified based on the territory-wide default emission factor (i.e. 0.7 kgCO_2-e/kWh). While these two quantification methods are both applicable, the former method should better reflect the actual emission because the power company's emission factor was derived based on the GHG emissions resulted from electricity production in the power plant.

Cooking appliances in the kitchens of the restaurants consumed town gas. From the town gas bills, the total consumption of town gas was 259,646 units. This was equivalent to emission of 154 tonnes of CO_2-e per year. Counting in this part of emission, the total amount of GHG emissions reported in scope 2 was 7,021.7 tonnes of CO_2-e when the emissions were quantified based on the power company's specific emission factor, or 8,738.6 tonnes of CO_2-e when they were quantified based on the territory-wide emission factor.

Other indirect emissions

From the available purchase orders, 1,125 reams of 80 grams per square meter A4-size paper were used in the hotel. This amount was equivalent to 2,806.6 kg of paper. Meanwhile, 7,032 kg of paper was collected for recycling. Based on these data, a negative value of indirect emissions due to disposal of paper waste (-20.3 tonnes of CO_2-e) was obtained. This result, which seems to be strange, was due to the fact that the available record of paper consumption was confined to A4-size paper while the consumptions of other sizes (e.g. B3, A3) of paper and other paper types such as those used as invoices, receipts, packaging paper, cartons for goods, newspapers and magazines provided for the guests, etc. were not recorded. In contrast, the amount of all kinds of paper collected for recycling, which can be readily quantified by their weights measured during the daily collections, was properly recorded.

Electricity is needed for processing fresh water and sewage by the Water Supplies Department and the Drainage Services Department, respectively (Environmental Protection Department and Electrical and Mechanical Services Department, 2010). Referring to the water bills, 175,302 m^3 fresh water was consumed, accounting for 72.15 tonnes of CO_2-e indirect emissions. As 83,552 m^3 fresh water was used by the restaurants and 91,750 m^3 fresh water was used for other commercial purposes, the sewage from the former accounted for 10.06 tonnes of CO_2-e indirect emissions and that from the latter contributed to 15.78 tonnes of CO_2-e indirect emissions, giving a total of 25.84 tonnes of CO_2-e indirect emissions due to the use of electricity for processing sewage.

Overall emissions

The overall GHG emissions were 7,099.4 tonnes of CO_2-e when the emissions due to purchased electricity were quantified based on the power company's emission factor. Averaged on a daily basis and normalized with respect to the number of guestrooms (i.e. scale of the hotel), this amount of emissions became: 31.07 kg CO_2-e per room-day, or 38.59 kg CO_2-e per room-day when the quantification was based on the territory-wide emission factor.

Whether this emission level is on the high or low side is uncertain because carbon emission benchmarks for hotels in Hong Kong are not available. Yet, a search from the open literature found some benchmarks in the United States (Carbonfund.org, 2010): 29.53 kg CO_2-e per room-day for average hotels and 33.38 kg CO_2-e per room-day for upscale hotels, which are comparable to the emission level of the present hotel.

The emissions calculated by both quantification methods show that the majority of the GHG emissions (about 99%) came from the energy indirect emissions in scope 2. The GHG emissions due to other indirect emissions categorized under scope 3 were minimal. There were no scope 1 direct emissions or removals from the hotel. Nevertheless, it should be noted that the accuracy and completeness of these results are limited by the following problems.

Problems and suggestions

For complying with the statutory fire services requirements (Fire Services Department, 2005), the emergency power generator must be tested to run for a period of not less than 30 minutes in each month. Even though the amount of diesel oil so consumed may be small, it should be recorded for the purpose of carbon audit. Moreover, the generator might have consumed additional diesel oil during the reporting period if there were emergency situations where the generator was activated. Without a proper record of the diesel oil consumption, the corresponding amount of GHG emission could not be identified.

Under the Guidelines, the reporting party may choose to report GHG emissions associated with mobile combustion sources (e.g. transport provided for the hotel's guests) under scope 3.

While the transport services (i.e. calling for taxi and vans) were arranged but not controlled by the hotel and so their emissions were not taken into account in the preceding calculation, this unaccounted element should be noted especially when the audit result of this hotel is compared with that of another whose emissions due to provision of guest shuttle bus service has been accounted.

The record kept by the hotel on the amounts of paper consumed and paper collected for recycling was not complete. While the data required for completing such a record spread over different departments (e.g. administration, engineering, etc.) of the hotel, cooperation among these departments is essential in order to maintain a proper record for use in carbon audits.

Data pertaining to the shop tenants of the hotel could not be made available for this study. Without such data including utilities consumptions and amounts of paper used and collected for recycling, the corresponding carbon emissions and removals were not included in the audit. When carbon audits become commonplace, hopefully, the culture may change and the shop tenants would provide the required data. Alternatively, consideration should be made to incorporate an appropriate contract term into the future leases, making it an obligation for the tenants to provide the relevant data for carbon audit purpose.

Reporting of GHG emissions in scope 3 is optional. Even though the Guidelines have listed out some examples of emissions (e.g. emissions from outsourced activities, waste disposal other than those covered in the prescribed scopes) that the reporting party may consider to include in a carbon audit, which of them would be included is at the sole discretion of that party. This flexibility leads to some potential problems. Firstly, the total GHG emissions of the building may be underestimated if the audit does not cover the scope 3 emissions.

Secondly, the sources and the extents of the unreported scope 3 emissions could not be unveiled, which is not in line with the aim of the Guidelines. Thirdly, the scope 3 emissions from different buildings may be reported to different extents, meaning that their audit results are obtained on different bases. When interpreting the carbon audit results of different buildings, therefore, care should be exercised to observe any difference in the bases or scopes of their audits.

Conclusions

Hong Kong is behind Australia and UK in that no legislations have been in place or in the pipeline requiring mandatory reporting of carbon emissions from corporations or buildings. The current setting of its carbon audit guidelines is similar to those overseas but reporting of scope 3 emissions is entirely optional. The problems that may arise from this flexibility should be observed especially when making comparisons between audit results which are obtained from adopting different degrees of the flexibility.

The empirical audit on the hotel, covering in-depth investigations into the carbon emissions over a period of one year, is a pilot demonstration for the hotel industry in Hong Kong. Despite the difficulties encountered during the data collection process, the result of this audit showed that the purchased electricity was the dominant source of carbon emissions. Among the problems identified, the lack of complete record data was a major obstacle to the audit.

The experience gained from the audit and the suggestions given on how the problems may be overcome can help conduct smoother and more proper audits in future. When more audit results are made available, a database of carbon emission benchmarks can be established.

Carbon emissions from buildings, which can serve as a key performance indicator of facilities management, can be compared against the benchmarks. This will enable facilities managers to identify which areas of carbon emissions should be minimized in order to make their buildings green and sustainable.

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Appendix A Equations for calculating carbon emissions (in tonnes of CO_2-e)

Scope 1 - Direct Emissions / Removals	
Stationary Sources Combustion	**CO_2 emissions = Σ Fuel consumed (litre) x Emission factor of CO_2 / 1000 Eq. (A.1)** **CH_4 or N_2O emissions = Σ Fuel consumed (litre) x Emission factor of CH_4 or N_2O / (1000 x 1000) x GWP Eq. (A.2)** where emission factor of CO_2 = 2.614 (kg/litre) for diesel oil, emission factor of CH_4 = 0.0239 (g/litre) for diesel oil, emission factor of N_2O = 0.0074 (g/litre) for diesel oil, Global Warming Potential (GWP) of CH_4 is 21 while it is 310 for N_2O
Mobile Sources Combustion	**CO_2 emissions = Σ Fuel consumed (litre) x Emission factor of CO_2 / 1000 Eq. (A.3)** **CH_4 or N_2O emissions = Σ Fuel consumed (litre) x Emission factor of CH_4 or N_2O / (1000 x 1000) x GWP Eq. (A.4)** where emission factor of CO_2 = 2.360 (kg/litre) for unlead petrol (ULP), emission factor of CH_4 = 0.645 (g/litre) for gas oil for ship, emission factor of N_2O = 0.429 (g/litre) for jet kerosene, emission factor of CH_4 = 0.253 (g/litre) for ULP for passenger car, emission factor of CH_4 = 0.146 (g/litre) for gas oil for ship, emission factor of CH_4 = 0.069 (g/litre) for jet kerosene, emission factor of N_2O = 1.105 (g/litre) for ULP for passenger car, emission factor of N_2O = 1.095 (g/litre) for gas oil for ship, emission factor of N_2O = 0.000 (g/litre) for jet kerosene, Global Warming Potential (GWP) of CH_4 is 21 while it is 310 for N_2O
Fugitive Emissions	**$OE = \Sigma (C_s + C_i - C_d - C_e)_j \times GWP_j / 1000$ Eq. (A.5)** where OE = SF_6 or HFC or PFC emissions from operation of equipment due to release of refrigerant j (in tonnes of CO_2-e), C_s = Refrigerant inventory at beginning of the reporting period (in storage, not equipment) (kg), C_i = Refrigerant added to the inventory during the reporting period (kg), C_d = Refrigerant disposed of through environmentally responsible means during the reporting period (kg), C_e = Refrigerant inventory at end of the reporting period (in storage, not equipment) (kg), GWP = 100-year global warming potential of refrigerant j (1300 for HFC-134a; 3260 for R-404A; 0 for R22 (not covered in Kyoto protocol))
Assimilation of CO_2 into biomass through planting of trees	**CO_2 removed by trees = Net number of additional trees (at least 5m in height) x Removal factor (23kg / tree / year) / 1000 x Length of reporting period in years Eq. (A.6)**
Scope 2 - Energy Indirect Emissions	
Consumption of purchased electricity	**GHG emissions = Purchased electricity (kWh) x Emission factor / 1000 Eq. (A.7)** where emission factor based on China Light Power = 0.56kg CO_2-e/kWh, emission factor based on territory-wide default value = 0.7kg CO_2-e/kWh
Consumption of Town gas	**GHG emissions = Purchased town gas (unit) x Emission factor / 1000 Eq. (A.8)** where town gas is charged in unit (1 unit registered by the gas meter = 48 mega joules (MJ) consumed), emission factor for town gas = 0.593kg CO_2-e/unit
Scope 3 - Other Indirect Emissions	
Methane gas generation at landfill due to disposal of paper waste	**GHG emissions = (Ps + Pi – Pr – Pe) x Emission factor (4.8 kg CO_2-e /kg) /1000 Eq. (A.9)** where Ps = Paper inventory at beginning of the reporting period (in storage) (kg), Pi = Paper added to the inventory during the reporting period (kg), Pr = Paper collected for recycling purpose (kg), Pe = Paper inventory at end of the reporting period (in storage) (kg), emission factor = 4.8 kg CO_2-e/kg of waste
Consumption of fresh water	**GHG emissions = Fresh water consumed (m^3) x Emission factor / 1000 Eq. (A.10)** where emission factor = unit electricity consumption of fresh water x territory-wide default value (i.e. 0.7kg CO_2-e /kWh) of purchased electricity = 0.4116kg CO_2-e /m^3
Treatment of waste water	**GHG emissions = Fresh water consumed (m^3) x Default emission factor / 1000 Eq. (A.11)** where default emission factor (kg/m^3) for restaurants and catering services = (0.7 x emission factor), default emission factor (kg/m^3) for other commercial, residential and institutional purposes = (1.0 x emission factor), emission factor = unit electricity consumption for processing sewage x territory-wide default value (i.e. 0.7kg/kWh) of purchased electricity = 0.172kg CO_2-e/m^3