Greenhouse gas emissions in building construction: a case study of One Peking in Hong Kong

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Abstract

The construction of buildings has a very important impact on the environment, and the process of manufacturing and transporting of building materials, and installing and constructing of buildings consumes great energy and emits large quantity of greenhouse gas (GHG). The present paper defines four sources of GHG emissions in building construction, which are: manufacture and transportation of building materials; energy consumption of construction equipment; energy consumption for processing resources; and disposal of construction waste, and then establishes the calculation method of GHG emissions. This paper presents a case study of GHG emissions in building construction in Hong Kong. The results show that 82-87% of the total GHG emissions are from the embodied GHG emissions of building materials, 6-8% are from the transportation of building materials, and 6-9% are due to the energy consumption of construction equipment. The results also indicate that embodied GHG emissions of concrete and reinforced steel account for 94-95% of those of all building materials, and thus the use of recycled building materials, especially reinforced steel, would decrease the GHG emissions by a considerable amount.

Keywords: Greenhouse gas (GHG); Emissions; CO_2-equivalent; Building construction; Embodied energy; Project case study

1. Introduction

The construction of buildings has a very important impact on the environment, and the construction industry is one of the greatest consumers of resources and raw materials [1]. According to data from the Worldwatch Institute, the construction of buildings annually consumes 40% of the stone, sand and gravel, 25% of the timber and 16% of the water in the world [2]. Manufacturing and transporting of building materials, and installing and constructing of buildings consume great quantities of energy and emit large amounts of greenhouse gases (GHG). In the member states of the European Union, buildings through their life cycle, including construction, operation and demolition, consume approximately 50% of the total energy demand and contribute almost 50% of the CO_2 emissions released to the atmosphere [1].

Although studies have been done on energy use and GHG emissions in the life cycle of buildings, very few have focused on the construction stage in particular and none comprehensively. For example, some literature, which studied the energy use or GHG emissions or CO_2 emission, only focused on manufacture of building materials, such as reference [1,6,10,11]; some focused on manufacture of building materials and energy consumption of construction equipment, such as reference [3,4,7,9]; some more focused on transportation for building materials or transportation for construction equipment or disposal of construction waste, such as reference [5,8,12,13]. Therefore, this paper aims to establish a calculation method for GHG emissions in building construction and to apply it to a practical case building in Hong Kong. The specific objectives are: (1) to define the scope and sources of GHG emissions in building construction, and form a suit of formulas for GHG emissions of each sources within the vested scope; (2) to calculate the GHG emissions in construction of the practical building, i.e. One Peking; and (3) to explain the outcomes of the results calculated by the above method, and make analysis of the results.

2. Review of relevant research works

2.1 Sources of GHG emissions

Searched by using terms "GHG or greenhouse gas or CO_2 or carbon dioxide" within title and "building or construction" within title, we found 17 papers at ASCE Research Library, 67 papers at Science Direct - Online Journals by Elsevier Science (1996+) and 73 articles at Science Citation Index Expanded (1970+). However, of these, there are only 20 which are related to the calculation of GHG or CO_2 emissions of buildings. Thereinto, 13 studies involved the construction stage of buildings. From these 13 studies, GHG emissions in building construction are mainly from six sources, which are summarized as follows: (1) manufacture of building materials; (2) transportation for building materials; (3) transportation for construction equipment; (4) energy consumption of construction equipment; (5) transportation for workers; (6) disposal of construction waste. Tab.1 shows the GHG emissions sources included in former studies.

2.2 Review of GHG emissions calculation method

For calculation for environmental impacts (also GHG emissions included) in previous studies, usually there are mainly two methods: process-based and economic input-output analysis-based.

Process-based method models different activities associated with a product or a service using process flow diagrams [8]. For every activity in the whole process, all materials and energy used in the process are identified. Thus, the environmental impacts and emissions can be measured accounting for production of the materials and consumption of the energy. Typical examples include: Gustavsson and Sathre [15] investigated the energy consumption of wood and concrete building materials and calculated the CO_2 emission due to different types of energy; Chen et al. [16] calculated the energy consumption by using the embodied energy intensities for manufacturing building materials, transporting building materials and installing different types of building component; González and Navarro [9] and Dimoudi and Tompa [1] calculated the CO_2 emission due to manufacturing building materials by using the CO_2 emission factors of kinds of building materials.

Economic input-output analysis-based method considers not only the *direct* environmental impact of a product or a service, but also all *indirect* impacts involved in the supply chain. This approach is adopted by many researchers from USA and Japan, probably because the Input/Output Table of USA and Japan contains more than 400 sectors, which is elaborate enough to assess the environmental impacts in the construction industry. By using this method, Suzuki et al. [3], Suzuki and Oka [4] and Gerilla et al. [11] calculated CO_2 emission during building construction (also included manufacture of building materials); Seo and Hwang [7] calculated CO_2 emission from residential buildings; and Pacca and Horvath [17], Norman et al. [10] and Racoviceanu et al. [18] calculated GHG emissions in construction and operation of power plants, residential buildings and water treatment systems, respectively.

However, while economic input-output analysis-based method requires economic input-output data with resource input and environmental output, there is no such available data in Hong Kong. Therefore, this paper uses the process-based method for the calculation for GHG emissions.

3. Methodologies

3.1 Scope of the study

3.1.1 Definition of GHG

According to the definition in the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), GHG includes six types of gas [19-21], namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Since HFCs, PFCs and SF_6 are not commonly found in the construction of buildings in Hong Kong, this paper only focuses on three types of GHG, which are CO_2, CH_4 and N_2O.

3.1.2 System boundary

Processes embraced in the construction of buildings are: production of building materials (including acquisition of raw materials and manufacture of building materials); transportation of building materials to construction sites; and erection of buildings (also including disposal of waste and auxiliary materials incurred in the construction work). The system boundary of this study is limited to the above processes, and the GHG emission is due to energy consumption in these processes, as shown in Fig.1.

3.1.3 Sources of GHG emissions in this study

Within the system boundary as defined in Fig.1, we summarize four sources of GHG emissions in the construction of buildings, which are as follows:

- Manufacture and transportation of building materials;
- Energy consumption of construction equipment;
- Energy consumption for processing resources;
- Disposal of construction waste.

For calculation, they are divided into six parts as follows:

(i) Embodied GHG emissions of building materials, which are GHG emissions due to energy consumption for manufacture of building materials before transporting to construction sites;

(ii) GHG emissions from transportation for building materials, which are GHG emissions due to fuel and energy consumption for transporting building materials to construction sites;

(iii) GHG emissions from fuel combustion of construction equipment;

(iv) GHG emissions due to electricity used for construction equipment;

(v) GHG emissions due to electricity used for processing fresh water and sewage;

(vi) GHG emissions from fuel combustion of transportation for construction waste.

Fig.2 shows the sources of GHG emissions in the construction of buildings.

3.2 Calculation for GHG emissions in building construction

3.2.1 Embodied GHG emissions of building materials

We used formula (1) to calculate the embodied GHG emissions of all building materials.

$$E_i = \sum M_j^i \times f_j^i / 1000 \qquad (1)$$

where:

E_i is the total embodied GHG emissions of all building materials (in tons CO_2-e) (CO_2-e: CO_2-equivalent);

M_j^i is the amount of building material *j* (in kg); and

f_j^i is the GHG emission factor for building material *j* (in kg CO_2-e/kg). Based on CO_2 emission factors of building materials in former literature, GHG emission factors of building materials can be calculated by some method, such as the method in Tab.6. Tab.6 also shows the GHG emission factors of some building materials.

3.2.2 GHG emissions from transportation for building materials

We used formula (2) to calculate the GHG emissions from fuel combustion of transportation for building materials

$$E_{ii} = \sum M_j^{ii} \times (T_j^l \times f_l^{ii} + T_j^s \times f_s^{ii}) / 1000 \qquad (2)$$

where:

E_{ii} is the total GHG emissions from fuel combustion of transportation for all building materials (in tons CO_2-e);

M_j^{ii} is the amount of building material *j* (in tons);

T_j^l is the total distance of transportation for building materials *j* by land (in km), while T_j^s is the total distance of transportation for building materials *j* by sea (in km); and

f_l^{ii} is the GHG emission factor for transportation by land (in kg CO_2-e/ton·km), while f_s^{ii} is the

GHG emission factor for transportation by sea (in kg CO_2-e/ton·km). GHG emission factors for transportation by land and by sea are shown in Tab.2 for reference.

3.2.3 GHG emissions from fuel combustion of construction equipment

We used formula (3) to calculate the GHG emissions from fuel combustion of construction equipment.

$$E_{iii} = \sum F_j^{iii} \times f_j^{iii} / 1000 \qquad (3)$$

where:

E_{iii} is the total GHG emissions from fuel combustion of construction equipment (in tons CO_2-e);

F_j^{iii} is the amount of fuel *j* consumed by construction equipment (in litres); and

f_j^{iii} is the GHG emission factor for fuel *j* consumed by construction equipment (in kg CO_2-e/litre).

GHG emission factor is calculated by: emission factor of CO_2 for fuel *j* + emission factor of CH_4 for fuel *j* × GWP of CH_4 + emission factor of N_2O for fuel *j* × GWP of N_2O (GWP: global warming potential). For diesel, GHG emission factor = 2.614+0.0239×21/1000+0.0074×310/1000 = 2.6168 (kg CO_2-e/litre), in which the emission factor of CO_2, emission factors and GWP of CH_4 and N_2O are referenced by EPD & EMSD [21].

3.2.4 GHG emissions due to electricity used for construction equipment

With reference to EPD & EMSD [21], we can calculate the GHG emissions due to electricity used for construction equipment by use of formula (4).

$$E_{iv} = \sum E_j \times f_j^{iv} / 1000 \qquad (4)$$

where:

E_{iv} is the total GHG emissions due to electricity used for construction equipment (in tons CO_2-e);

E_j is the quantity of purchased electricity from power company *j* (in kWh); and

f_j^{iv} is the emission factor for power company *j* (in kg CO_2-e/kWh). While it has a territory-wide default value of 0.7 kg/kWh in Hong Kong [21], f_j^{iv} also has specific emission factors provided by its respective provider of electricity. For reference, Tab.3 shows the emission factors for the power company China Light & Power (CLP) from year 2002 to 2007.

3.2.5 GHG emissions due to electricity used for processing fresh water and sewage

Also with reference to EPD & EMSD [21], we can calculate GHG emissions due to electricity used for processing fresh water and sewage by use of formula (5).

$$E_v = W^v \times (f_1^v + \alpha f_2^v)/1000 \quad (5)$$

where:

E_v is the GHG emissions due to electricity used for processing fresh water and sewage, which is measured by CO_2 equivalent (in tons CO_2-e);

W^v is the amount of water consumed (in m^3);

f_1^v and f_2^v are the emission factors due to electricity used for processing fresh water and sewage (in kg CO_2-e/m^3). f_1^v and f_2^v of year 2003 to 2007 in Hong Kong are shown in Tab.4 for reference; and

α is the assumed percentage of the fresh water consumed that will enter the sewage system.

3.2.6 GHG emissions from fuel combustion of transportation for construction waste

We used formula (6) to calculate the GHG emissions from fuel combustion of transportation for construction waste.

$$E_{vi} = \sum W_j^{vi} \times T_j \times f^{vi} / 1000 \qquad (6)$$

where:

E_{vi} is the total GHG emissions from fuel combustion of transportation for construction waste (in tons CO_2-e);

W_j^{vi} is the amount of waste transported to landfill *j* (in tons);

T_j is the double distance between construction site and landfill *j* (in km); and

f^{vi} is the GHG emission factor for transportation (in kg CO_2-e/ton·km), which can be evaluated as 0.159 (shown in Tab.2).

3.2.7 Total GHG emissions in the building construction

The total GHG emissions in the building construction can be calculated by formula (7).

$$E = \sum_{j=i}^{vi} E_j \qquad (7)$$

4. Case study: One Peking

4.1 Project description

The practical case, One Peking, is a commercial building in Hong Kong, of which the construction started in August 2001 and completed in April 2003, and this building achieved the highest HK-BEAM rating of *Excellent* upon building completion in 2003. More description of One Peking are shown in Tab.5, and the building materials used in the construction of One Peking are shown in Tab.6. In Tab.6, the distances from country of origin of the building materials to One Peking construction site are with reference to EMSD [24], except for the ready mix concrete which is assumed as 20 km. The quantity of ready mix concrete and reinforcement bars and the total quantity of all building materials are definite, which are in EMSD [24]. While the quantities of other building materials are not available according to reference [24], they may be calculated by the proportion of the building material (imported quantity of the material from the country of origin to Hong Kong in 2002 divided by total imported quantity of all the listed materials in Tab.6 in 2002) multiplying the total quantity of all building materials except ready mix concrete and reinforcement bars (which equals 21,547.8 tons). Taking glass, for example, the quantity of glass imported from China to Hong Kong in 2002 was 73,706,150 tons [25] and the total imported quantity of all the listed materials in Tab.6 in 2002 was 8,344,141,627 tons [25], so the proportion of glass is 0.88% (73,706,150/8,344,141,627); and then multiplying the total quantity of all building materials except ready mix concrete and reinforcement bars (21,547.8 tons), we can get the quantity of glass (190.3 tons). In Tab.6, CO_2 emission factor is referenced by Andrew [22] and González and Navarro [9], and GHG emission factor is adjusted by reckoning in CH_4 and N_2O, using the statistical data in EEA [23], wherein for 28 countries in Europe, for public power, production processes and road transport categories, CH_4 and N_2O account for 0.0144% and 0.0219% of CO_2, and the global warming potential of CH_4 and N_2O is 21 and 310 [21]. But for timber, because the proportion data of CO_2 emission from manufacture of timber and absorption during the wood growing to maturity are unknown, the GHG emission factor of timber is still valued as -1.141.

Fuel, electricity and water use and solid waste generated in the construction site over the construction period of One Peking are shown in Tab.7. The data will be used for calculation of GHG emissions later.

4.2 GHG emissions calculation

4.2.1 Total GHG emissions

Using formula (1)-(7) above, we can get the six parts GHG emissions and the total GHG emissions in the building construction of One Peking (shown in Tab.8).

Embodied GHG emissions of building materials by specific element in the construction of One Peking are shown in Tab.9.

4.2.2 Monthly GHG emissions

By the calculation method and assumed values in Tab.8, we can get the monthly GHG emissions in the construction of One Peking for E_{iii}-E_{vi} (as unavailable monthly data for E_i and E_{ii}), which is shown in Fig.3.

4.3 Evaluation of the method used

From Tab.11, we can find that, GHG emission intensity from residential buildings is larger than that from office buildings, and that from buildings with SRC structure is much lager than that from buildings with RC structure, and that calculated by EIO analysis-based method is much larger than that calculated by process-based method. Thus, the GHG emission intensity in the construction of the case building-One Peking that is an office building with RC structure, which is calculated by process-based method, must be smaller than 715 kg CO_2-e/m^2 (No. 1 Building), and probably be around 266 to 386 kg CO_2-e/m^2 (No. 6 Building and No.7 Building). Besides, from Tab.12, we can find that, GHG emission intensity from office buildings must be small than 81.99 kg CO_2-e/HK$1000, because industrial buildings emits more GHG, and probably be around 35.7 CO_2-e/HK$1000. So, based on the above analysis and the GHG emission intensity in the construction of One Peking in Tab.10, we can say that the result calculated by the proposed method is reasonable.

4.4 Analysis of the emissions in this case

4.4.1 Analysis of total GHG emissions

The percentage of six parts of the total GHG emissions of One Peking is shown in Fig.4. From Fig.4, we can see that, for using recycled reinforced steel and aluminum, 90.0% of the total GHG emissions are due to manufacture and transportation of building materials, wherein 81.6% are from the embodied GHG emissions, and 8.4% are from the transportation; 8.6% of the total GHG emissions are due to the energy consumption of construction equipment; about 1.3% are due to disposal of construction waste; and only 0.1% are due to energy consumption for processing resources. Whereas for using virgin reinforced steel and aluminum, 92.8% of the total GHG emissions are due to manufacture and transportation of building materials, wherein 86.7% are from the embodied GHG emissions, and 6.1% are from the transportation; 6.2% of the total GHG emissions are due to the energy consuming of construction equipment; about 0.9% are due to disposing construction waste; and only less than 0.1% are due to energy consuming for processing resources;

The result indicates that, whatever for using recycled materials or virgin materials, manufacture and transportation of building materials and energy consumption of construction equipment contribute the most of GHG emissions in building construction. Furthermore, using recycled materials reduces 5.1% of GHG emissions due to manufacture of materials than using virgin ones. Thus, we can conclude that, by using recyclable building materials, transporting building materials by sea, and adopting energy-saving construction technology, we can make lower GHG emissions in building construction.

4.4.2 Analysis of embodied GHG emissions of building materials

From Tab.9 we can see that, manufacture of virgin reinforced steel and aluminum in One Peking releases 6,329.75 tons GHG emissions more than that of recycled reinforced steel and aluminum. While embodied GHG emissions of concrete account for 77.89% by using recycled reinforced steel, GHG emissions from manufacture of reinforced steel account for 41.19% by using virgin reinforced steel. Moreover, embodied GHG emissions of concrete and reinforced steel account for 93.99% - 95.11% of those of all building materials. This result indicates that using recycled building materials, especially reinforced steel, can decrease the GHG emissions by a considerable amount.

4.4.3 Analysis of monthly GHG emissions

From Fig.3, we can see that GHG emissions both in the beginning and in the ending several months of the project can be regarded much smaller than those in the middle months. The result confirms our expectations and is not surprising.

5. Conclusions

We conducted this study to identify the scope and sources of GHG emissions in building construction, which are manufacture and transportation of building materials, energy consuming of construction equipment, energy consuming for processing resources and disposing construction waste. For calculation, we divided these four sources into six parts, and then established the calculation method of each part.

By analyzing of the results of GHG emissions in construction of the practical case, One Peking, we found that almost 98.6% - 99.2% of the total GHG emissions in building construction come from manufacture and transportation of building materials and energy consumption of construction equipment, wherein 81.6% - 86.7% are from the embodied GHG emissions of building materials, 6.1% - 8.4% are from the transportation for building materials, and 6.4% - 8.6% are due to the energy consumption of construction equipment. The result indicates that, by using recyclable building materials, transporting building materials by sea, and adopting energy-saving construction technology, we can reduce GHG emissions in building construction to a significant degree.

Furthermore, by comparing of GHG emissions from manufacture of virgin reinforced steel and aluminum and those from manufacture of recycled reinforced steel and aluminum in One Peking, we found that, embodied GHG emissions of concrete and reinforced steel account for 93.99% - 95.11% of those of all building materials; and using recycled building materials, especially reinforced steel, would decrease the GHG emissions by a considerable amount.

Finally, from the result of monthly GHG emissions in the construction of One Peking, we found that GHG emissions both in the beginning and in the ending several months are much smaller than that in the middle months, which confirms our expectations.

Additionally, further research would be conducted on the GHG emissions calculation for other stages of the case building-One Peking, such as operation, maintenance and demolition, which could be a meaningful comparison with the results in this paper.

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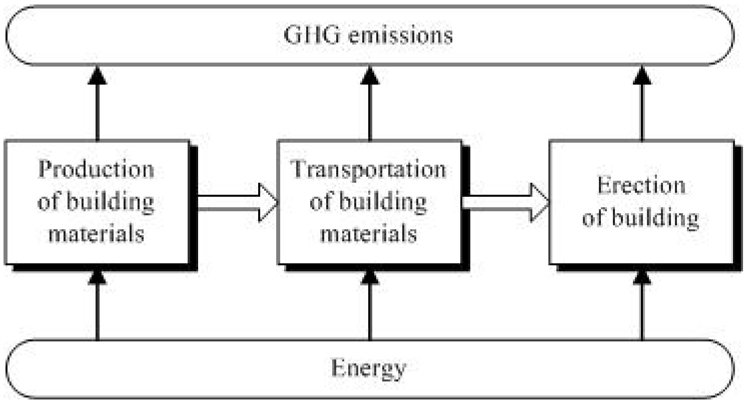

Fig.1: System boundary of GHG emissions in the construction of buildings

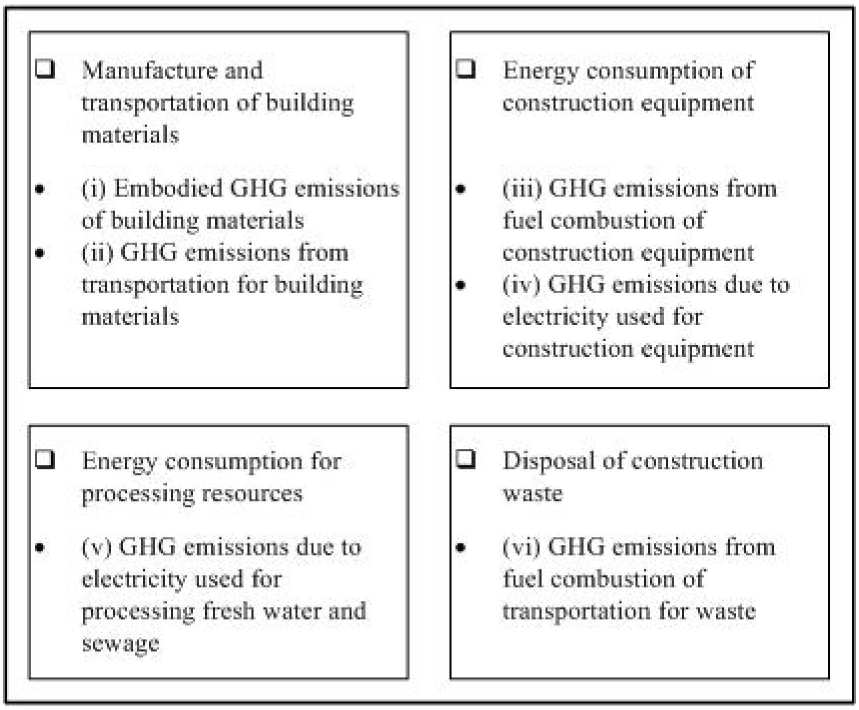

Fig.2: Sources of GHG emissions in the construction of buildings

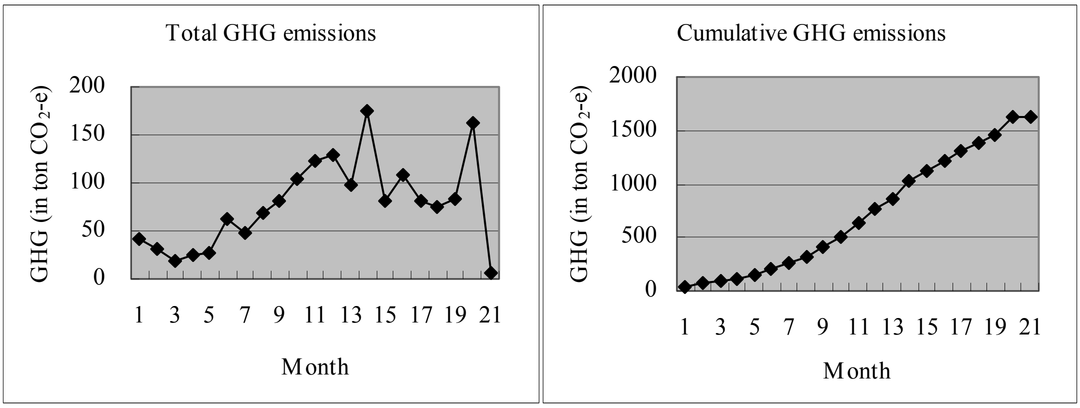

Fig.3: Monthly GHG emissions of One Peking for E_{iii}-E_{vi}

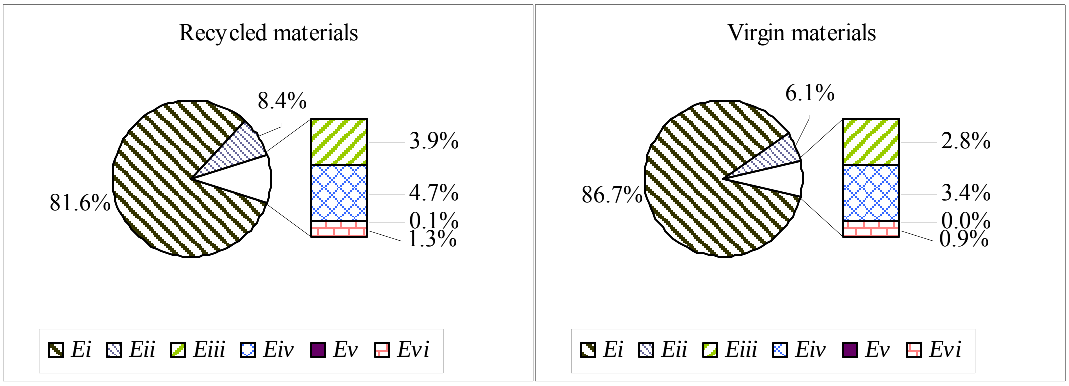

Fig.4: Percentage of six parts of the total GHG emissions of One Peking

Tab.1: GHG emissions sources in building construction included in previous studies

Literature sources in chronological order	Included GHG emissions sources					
	(1)	(2)	(3)	(4)	(5)	(6)
Reference [3]	√			√		
Reference [4]	√			√		
Reference [5]		√	√	√	√	
Reference [6]	√					
Reference [7]	√			√		
Reference [8]		√	√	√		√
Reference [9]	√			√		
Reference [10]	√					
Reference [11]	√					
Reference [12]	√	√	√			
Reference [13]	√	√		√		√
Reference [1]	√					
Reference [14]				√		

Notes: (1) Manufacture of building materials; (2) Transportation for building materials; (3) Transportation for construction equipment; (4) Energy consumption of construction equipment; (5) Transportation for workers; (6) Disposal of construction waste.

Tab.2: GHG Emission factors for transportation of building materials

Method of transportation	**Energy use (MJ/ton·km)**[a]	**Fuel type**	**Fuel CO_2 emission factor (g CO_2/MJ)**[b]	**Fuel GHG emission factor (g CO_2-e/MJ)**[c]	**GHG emission factor (kg CO_2-e/ ton·km)**[d]
Deep-sea transport	0.216	Heavy fuel oil	74.8	76.2	0.0165
Truck	2.275	Diesel	68.7	70.0	0.159

[a] Reference [16];

[b] Reference [22];

[c]Adjusted by reckoning in CH_4 and N_2O, using the statistical data in EEA [23], wherein for 28 countries in Europe, for road transport category, CH_4 and N_2O account for 0.029% and 0.0043% of CO_2, and the global warming potential of CH_4 and N_2O is 21 and 310, respectively [21]);

[d] GHG emission factor = Energy use × Fuel GHG emission factor / 1000.

Tab.3: GHG emission factors for power company CLP (in kg CO_2-e/kWh) (Source: reference [21])

Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
GHG emission factor	0.48	0.56	0.53	0.52	0.53	0.57

Tab.4: GHG emission factor for fresh water and sewage (in kg CO_2-e/m^3) (Sources: reference [21])

Year	**2003**	**2004**	**2005**	**2006**	**2007**
f_1^v	0.4403	0.4627	0.4760	0.4375	0.4137
f_2^v	-	0.1715	0.1547	0.1596	0.1708

Tab.5: Description of One Peking (Source: reference [24])

Items	Value
Scope of work	Office + Retail
Structure	RC (Reinforced concrete)
Storeys	F30
CFA	43,210 m^2
Contract value	HK$ 550 million[a]

[a] http://www.gammonconstruction.com/hk/eng/projects/project_detail_68.html

Tab.6: Building material list of One Peking

Materials[a]	Country of origin[b]	Distance from site (km)[b] Land	Distance from site (km)[b] Sea	Quantity (Ton)[d]	Specific element	CO_2 emission factor (kg CO_2/kg)[e]	GHG emission factor (kg CO_2-e/kg)[g]
Ready mix concrete	HK	20.0[c]	0	59,628.0[b]	Concrete, 30 MPa	0.159	0.170
Sand	China	250.0	150.0	19,674.1	Sand	0.0069	0.0074
Reinforcement bars				6,089.0[b]	Steel, reinforced, recycled	0.352	0.377
					virgin	1.242	1.330
Lintel				1,445.9	Concrete, 30 MPa	0.159	0.170
Glass and glazing				190.3	Glass, float	1.735	1.858
Door frames / panels				96.2	Timber, glulam	-1.141	-1.141
Windows frames				65.7	Aluminum, recycled	0.622	0.666
					virgin	8.000	8.566
Stainless steel fire rated door				36.3	Steel, stainless	5.457	5.843
Cement				2.7	Cement, dry	0.967	1.035
Stainless steel cat ladder / Balustrade				0.3	Steel, stainless	5.457	5.843
Granite	India	3077.9	6797.0	35.1	Artificial stone	0.0404[f]	0.043
Aluminum suspended ceiling	UK	877.9	18240.0	0.6	Aluminum, recycled	0.622	0.666
					virgin	8.000	8.566
Aluminum suspended ceiling	USA	5463.4	18753.3	0.4	Aluminum, recycled	0.622	0.666
					virgin	8.000	8.566
Curtain walling	Singapore	4511.1	2496.7	0.2	Glass, float	1.735	1.858
Total				87,264.8[b]			

[a] As the uncertainty type of floor finish materials according to reference [24], these kinds of materials are not contained in this table;

[b] Reference [24];

[c] This is a assumed average value;

[d] Calculated as in direct proportion to the imported material from the origin country from CSD [25];

[e] Reference [22];

[f] Reference [9];

[g] Adjusted value by reckoning in CH_4 and N_2O, using the statistical data in EEA [23].

Tab.7: Fuel, electricity and water use and solid waste generated in the construction site of One Peking (Source: reference [24])

Month	Diesel(litres)	Electricity(kWh)	Water(m^3)	Waste(tons)
(Aug. 2001)-1	6,267	52,390	388	96
2	5,742	29,070	802	192
3	6,238	1,560	582	192
4	6,532	12,230	699	312
5	6,568	6,450	515	864
6	9,953	60,490	555	984
7	10,516	27,880	607	1,032
8	14,193	45,310	811	1,632
9	15,666	47,390	908	2,640
10	22,680	62,080	1,028	2,208
11	30,100	59,340	1,974	2,304
12	25,671	93,700	1,753	2,568
13	21,808	33,960	2,112	3,672
14	46,088	74,940	1,503	2,688
15	16,779	42,490	1,310	2,520
16	1,200	164,930	1,257	4,080
17		157,400		840
18		136,490		1,560
19		157,020		1,392
20		325,560		984
(Apr. 2003)-21				1,032
Total	246,001	1,590,680	16,804	33,792

Tab.8: GHG emissions in the construction of One Peking (in tons CO_2-e)

Parts	GHG Emissions (Recycled materials)	GHG Emissions (Virgin materials)
E_i	13,330.47	19,660.22
E_{ii}	1,377.05	1,377.05
E_{iii}	643.74	643.74
E_{iv}	763.53[a]	763.53[a]
E_v	9.70[b]	9.70[b]
E_{vi}	214.92[c]	214.92[c]
E	16,339.41	22,669.16

[a] As all the electricity used for construction of One Peking is from CLP, we use the emission factor of year 2002 as a mean value;

[b] It's assumed that 80% of the fresh water consumed enters the sewage system, mainly due to the water use in concrete curing. f_1^v and f_2^v are valued as 0.4403 and 0.1715;

[c] The double distance from the site to landfill for One Peking is 40 km.

Tab.9: Embodied GHG emissions of building materials by specific element

Specific element	**Quantity (tons)**	**GHG (Recycled materials) (tons CO_2-e)**	**Percentage**	**GHG (Virgin materials) (tons CO_2-e)**	**Percentage**
Concrete, 30 MPa	61,073.9	10,382.56	77.89%	10,382.56	52.81%
Steel, reinforced	6,089.0	2,295.55	17.22%	8,098.37	41.19%
Glass, float	190.5	353.95	2.66%	353.95	1.80%
Steel, stainless	36.6	213.85	1.60%	213.85	1.09%
Sand	19,674.1	145.59	1.09%	145.59	0.74%
Aluminum	66.7	44.42	0.33%	571.35	2.91%
Cement, dry	2.7	2.79	0.02%	2.79	0.01%
Artificial stone	35.1	1.51	0.01%	1.51	0.01%
Timber, glulam	96.2	-109.76	-0.82%	-109.76	-0.56%
Total	87,264.8	13,330.47	100.00%	19,660.22	100.00%

Tab.10: GHG emissions intensity in the construction of One Peking

GHG emissions intensity	Value (Recycled materials)	Value (Virgin materials)
in kg CO_2-e/m^2	378.14	524.63
in kg CO_2-e/HK$1000	29.71	41.22

Tab.11: GHG emissions intensity in the construction of referenced buildings (in kg CO_2-e/m^2)

No.	Building type	Structure	CFA (m^2)	Storeys	kg CO_2-e/m^2	Calculation method	Sources
1	Residential	SRC	10,339	F20+B1	715[a]	EIO analysis -based	Reference [3]
2	Residential	SRC	5,425	F12	985[a]		
3	Office	SRC	8,458	F9+B1	790[a]		Reference [4]
4	Office	SRC	1,358	F7	1,100[a]		
5	Office	RC	1,857	F7+B1	650[a]		
6	Office	RC	1,891	F5	266[b]	Process-based	Reference [1]
7	Office	RC	400	F3	386[b]		

[a] The value excludes GHG emissions from transportation for building materials and construction waste.

[b] This is a adjusted value, assuming that embodied GHG emissions of building materials account for 75% of the total GHG emissions.

Tab.12: GHG emissions intensity in USA and Hong Kong (in kg CO_2-e/HK$1000)

Year	**Country /Region**	**Scope**	**kg CO_2-e /HK$1000**	**Sources**
2000	USA	New office, industrial, and commercial buildings construction	81.99[a]	Reference [26]
2002	Hong Kong	Gross domestic product	35.7	Reference [27]

[a] US$100=HK$780