A FRAMEWORK FOR APPRAISING CONSTRUCTION PROJECTS USING CARBON FOOTPRINT

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The construction industry contributes over 50% of the United Kingdom's total CO_2 emissions. Given the need to reduce CO_2 emissions, the role of the construction industry in this endeavour cannot be overemphasized. The construction industry has traditionally addressed similar matters of optimizing performance using project appraisal techniques. The appraisal techniques provide a good basis for decision making but have mostly concentrated on financial performance. Although some appraisal techniques that address non-financial performance have been devised, none to date directly address the crucial issue of CO_2 emissions. This paper presents work undertaken to develop a framework for appraising construction projects using the carbon footprint of the construction project, and other, processes over the life cycle of a reinforced concrete building project. The framework is based on process and energy analysis and aggregates CO_2 outputs from materials manufacture through to project disposal at the end of the project life. The framework was developed to facilitate decision makers to estimate the quantity of CO_2 emissions and the impact different alternatives have on this quantity. It is argued that the proposed framework will facilitate decision makers to appraise construction projects on the basis of carbon footprint.

Keywords: carbon footprint, environmental impact, modelling, project appraisal.

INTRODUCTION

The carbon concern

Widespread scientific consensus exists to affirm that the activities of man are altering global and regional climates, mainly through the emission of carbon dioxide (Lowe 2000). The United Nations Framework Convention on Climate Change (UNFCCC), and its Kyoto Protocol of 1997, emerged to guide policy in many countries, including European Union (EU) countries (Shackley and Green 2007). The EU has reacted to the need for reduction in carbon emissions through its Green Paper on energy efficiency, which calls for action to decrease energy use and thus achieve increased competitiveness, fulfil the environmental targets and increase security of supply (Nilsson 2007). As a result, the United Kingdom maintains a commitment to some level of decarbonization as shown in the legislative provisions, such as the Energy White Paper of 2003 (Shackley and Green 2007). Whereas various attempts to track and deal with the global problem of carbon emissions, Lowe (2000) maintains that carbon dioxide is and will remain the most important of the greenhouse gases, both in terms of magnitude of emissions, and the technical and political difficulties posed by the task of reducing them.

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Construction and carbon emission

Any kind of development will inevitably consume energy and lead to depletion of environmental assets. The construction industry however remains one of the biggest contributors to energy consumption and carbon dioxide emissions (Dias and Pooliyadda 2004). All construction projects have an impact on the environment. These impacts exist through the whole life of the structure, including the production and manufacturing of construction materials, actual construction process, service use, re-use and maintenance, and demolition (Scheuer, Keoleian and Reppe 2003). In addition, impacts may be of a global, regional or local nature (Weir and Muneer 1998). Analysis of the life cycle impact of building will therefore require a multi-disciplinary approach entailing various features such as energy saving, better use of materials, reuse and recycling, waste disposal requirements, and emissions control (Asif, Muneer and Kelley 2005). Carbon dioxide (CO_2) however is the largest environmental concern in the UK's building and construction industry. The industry contributes over 50% of the UK's total CO_2 emissions (Weir and Muneer 1998).

Construction project appraisal

The methodology of project appraisal should aim at assessing the overall viability of the project. However, surveys of actual practice show that most project appraisals in the private sector concentrate on financial and technical viability (Lopes and Flavell 1998; Akalu 2001). Traditional project appraisal techniques can be divided into two major categories: economics-based techniques and non economics-based techniques (Rogers 2001). In economic appraisal, many engineering economists have preferred the present worth concept because it is simple. It provides a single valuation that is less open to misinterpretation than other models. The method's major limitation is however associated with its dependency on the selection of an appropriate discount rate. Discount rates are essential in time value mechanics since they help to translate monetary payments of different amounts occurring at various times to a single equivalent monetary value.

Whereas it can be understood that most organizations, especially private sector organizations, concentrate on financial viability so as to ensure their survival as businesses, the non-financial aspects of projects should also be given due consideration during appraisal (Lopes and Flavell 1998). Lopes and Flavell (1998) also argued that a major reason why non-financial and non-technical aspects are not considered in project appraisal is the lack of an analytical framework that decision makers can use to that effect. It is therefore important to have a framework that will aid decision-makers to appraise projects basing on their life cycle carbon footprint.

Carbon footprint

Carbon footprint is the total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO_2) (Time for change n.d.). The carbon impact of a construction project would depend on the type of project, whether building, water, nuclear, or road. The footprint can however be defined in three major energy uses: Operational energy, Capital energy, and Transport energy (Aye, Bamford, Charters and Robinson 2002).

Some projects involve measures to enhance the environment by carbon sequestration. This could be done by artificially capturing and storing carbon, or by enhancing natural sequestration processes. Several techniques of sequestration are being used globally and more are being explored (Feng 2005; Brack and Richards 2002).

Modelling techniques
Baird and Chan (1983), cited by Dias and Pooliyadda (2004), identified for commonly accepted methods of energy analysis: statistical analysis, input-output analysis, process analysis, and eco-energetics, depending on the overall objectives of the analysis and the availability of data. Dias and Pooliyadda, however cited process analysis as the most frequently used method, involving a study of the inputs and outputs in a process and a determination of the energy requirements from all the material, equipment and energy inputs into the process. Figure 1 below shows a breakdown of the life cycle stages of a typical building project.

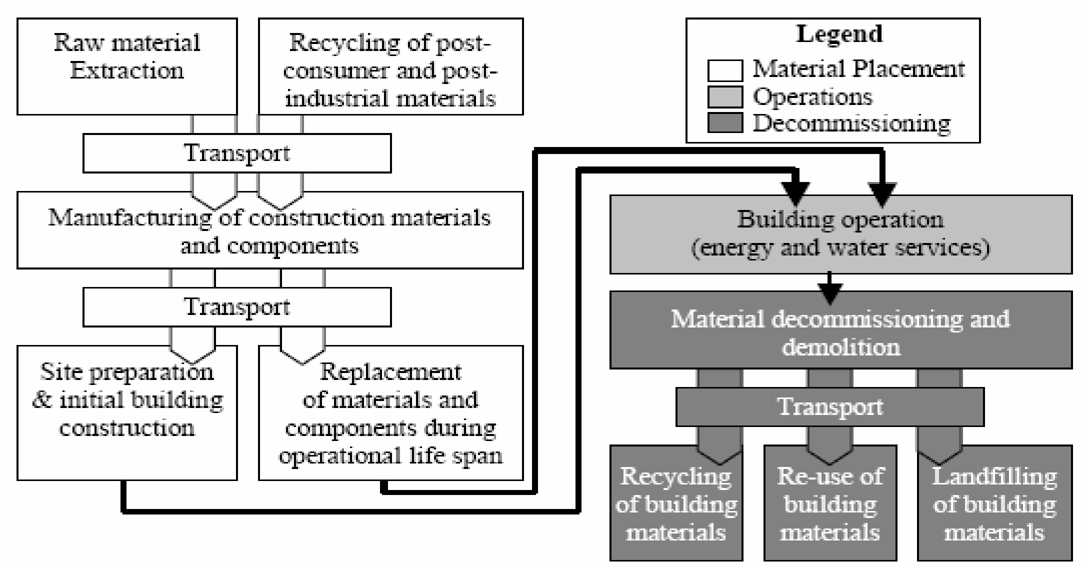

Figure 16: Life cycle phase diagram (Scheuer *et al.* 2003)

Aim and objectives
The aim of the research was to develop a framework for appraising construction projects using carbon footprint. The framework is intended to appeal to a wide range of construction decision makers and stakeholders, including client organization executives, project and programme managers, equity investors and lending organizations, and also designers in evaluating design options. External stakeholders, such as environment activists and local councils representing public interests, may also benefit from the framework. The objectives included providing a guideline on assessing the life cycle carbon dioxide emissions of a project to a detail that will allow the analyst to locate and manage individual work packages that may impact the most. In addition, the framework was to incorporate useful aspects of currently available appraisal techniques, such as the cash flow, discounting, and net present value evaluation.

Methodology
The work described in the proceeding sections was conducted in two major stages. First a literature review was undertaken. The process was aimed at identifying the need to manage carbon emissions and the role of the construction industry in this endeavour, the financial and non-financial project appraisal techniques currently used in the industry, and also some major gaps associated with the management of CO_2 emissions during construction project appraisal. This strategy is supported by similar research work, including that of Lopes and Flavell (1998), and Shackley and Green (2007). Second a framework of analysis and appraisal was constructed to meet the

aims and objectives stated above. The analysis of carbon emissions through an evaluation of plant, labour and materials was adopted because it fits in easily with the already successfully used project management economic appraisal techniques of decomposition, resource planning, and cost estimating (PMI 1996). The technique also subscribes to the process analysis method which is widely used for energy analysis (Dias and Pooliyadda 2004). The appraisal technique used in the framework is based on the present worth evaluation technique, which has been successfully applied to economic project appraisal (Rogers 2001).

THE FRAMEWORK

The CO_2 evaluation of a construction project will involve the analysis of emissions, expressed in mass of CO_2, which occur at different times during the life of the project. The framework is divided into two complimentary sections. The first section deals with life cycle assessment of the project to determine the carbon dioxide emission at each major phase of the project. Although the phases are used to break down the project into more manageable units, CO_2 emissions are computed and recorded for finite time periods to aid the appraisal process. It is recommended that emissions are computed at an annual basis. The second section sets out the appraisal technique based on the present worth evaluation technique.

Life cycle carbon assessment

The construction project was divided into phases based on the Scheuer *et al.* (2003) phase diagram as shown in Figure above. However, for the purposes of time equivalence of CO_2 emissions, replacement of materials and components should be considered under the building operation phase. The framework seeks to track carbon emissions from the three major resources deployed on construction projects: Plant, Labour, and Materials. Computations for the plant, labour, and materials CO_2 contributions will be made at each major phase of the project, and for finite time periods, as detailed in the steps below.

Plant

The actual plant used will usually be different at the various stages of the construction project. In addition, each plant is associated with a fuel type and rate of fuel consumption, both of which will affect the amount of CO_2 emitted. At this stage, it is required to establish the type(s) of plant, type of fuel used, and rate of fuel consumption for each.

Step 1: Create a list of the plant that will be required to deliver the activities of the construction phase in question. A work breakdown structure would help in identifying all the major plant. Table 1 illustrates this step by showing the plant required for surface mining of limestone as a raw material for cement manufacture.

Step 2: For each plant, determine the fuel type used and the fuel consumption associated with the plant (see Table 1). Fuel or energy consumption is given in various units for different plant. The analyst will be required to take the units into account so as to aid the conversion which is done in step 3. To illustrate this, the percussion drill as given in Table 1 is used. Using Table 9, 5,570 Btu/ton are equivalent to 5,570 x 0.2931×10^{-3} = 1.63 kWh/ton.

Step 3: Convert the energy used to equivalent CO_2 emission using the appropriate carbon emission factor (see Table 10). Assuming the percussion drill used in the example above uses diesel oil, the carbon dioxide emission associated to the plant will be equivalent to 1.63 kWh/ton x 0.25 kg CO_2 /kWh = 0.41 kg CO_2/ton. This value will then be multiplied by the total number of tonnes of limestone required to manufacture the amount of cement under consideration. The product will thus represent the carbon footprint of the cement at raw materials extraction.

However for some phases, data may not be available on plant basis. Tables 2 and 3 illustrate cases where data is given on the entire process of extraction of stone aggregates and the kiln technology used for cement manufacture, respectively. Similarly, these values can be converted to kWh using Table 9, and then to kg CO_2 /kWh using Table 10.

Table 4 shows average values of energy consumption in the transportation of materials. If however truck specifications give the amount of litres or tonnes of fuel used, the litres or tonnes can be converted to kWh using Table 8. The kWh will then be converted into CO_2 equivalents using Table 10.

Table 1: Estimated energy requirements per ton of limestone for a surface limestone mine (U.S. Department of Energy 2002)

Equipment	Energy consumption (Btu/ton)	Equipment	Energy consumption (Btu/ton)
Percussion Drill	5,570	Service Truck	1,020
Hydraulic Shovel	5,140	Lighting Plant	60
Rear-Dump Truck	3,660	Front-End Loader	170
Bulldozer	3,100	Bulk Truck	133
Pick-up Trucks	2,040	Pumps	2,040
Water Tanker	1,060	Grader	6

Table 2: Energy consumption for extraction of stone aggregates (Gustavsson and Sathre 2006)

Aggregate type	MJ oil/ton	MJ electricity/ton
Natural aggregate	20	9
Crushed gravel	120	50

Table 3: Energy consumption values for cement manufacture

(Prism Cement, 2006)	76kWh/MT cem or 665kCal/Kg clk
By kiln technology (Office of Energy Efficiency, 2001)	
Wet kilns	6.0GJ/t cem
Dry kilns – single-stage preheater	4.5GJ/t cem
Dry kilns – multi-stage preheater	3.6GJ/t cem

Table 4: Energy consumption in transportation of materials (both raw and finished) (Gustavsson and Sathre 2006)

Mode	MJ oil/tonne-km
Truck	1.5
Train	0.5

Labour

The framework limits the contribution of labour to the CO_2 emissions associated with travel to and from the work location. This stage will involve an analysis of the different modes of transport used by employees and labourers, the fuel consumption associated with the modes of transport, and the travel distances covered.

Step 1: Create a list of the different travel modes that are used or likely to be used by employees, the number of employees using each, and the distance associated with each mode. Travel modes may include walking, cycling, private car (petrol/diesel), bus or train.

Step 2: Compute the CO_2 emissions associated with each mode of transport. Emissions associated with a private car (see Table 5) will normally apply directly to the individual using it. However, emissions from a bus will need to be distributed among all the passengers. Assuming that 10 employees travel by a 60-seater bus on the same 10km route (20km/day, each passenger's contribution amounts to 962gCO_2/km / 60 passengers = 16 gCO_2/km. The 10 employees will therefore have a total contribution of 16 gCO_2/passenger.km x 10 passengers x 20km/day = 3.2 kgCO_2/day. Table 6 gives emission factors for train travel depending on train occupancy and route (see Table 7) within the UK.

Step 3: Sum up the CO_2 contributions from the individual travel modes to obtain the total CO_2 emission from employee travel for the project phase in question.

Table 5: Car (Bauen and Hart 2000)

Type	g CO_2/km	MJ/km
Petrol ICE car	209	3.16
Diesel ICE car	154	2.36
Diesel bus	962	14.6

Table 6: Passenger train CO_2 emission factors (g/passenger.km) (Cox and Hickman 1998)

			Occupancy			
	Train type		100%	75%	50%	25%
Route 1	CLASS 323	Electric	323.8	431.8	647.7	1295.3
Route 2	CLASS 101	Diesel	137.4	183.2	274.8	549.7
	CLASS 142		123.8	165.1	247.7	495.3
Route 3	CLASS 43 Standard	Diesel	199.3	265.8	398.7	797.3
	CLASS 43 Pullman		211.1	281.4	422.1	844.2
Route 4		Diesel	165.0	220.0	330.0	660.0

Table 7: Train information (Cox and Hickman 1998)

	Train type	Mass of train (tonnes)	Total no. of seats
Route 1	CLASS 323	120	284
Route 2	CLASS 101	58	124
	CLASS 142	51	121
Route 3	CLASS 43 Standard	420	468
	CLASS 43 Pullman	420	442
Route 4		800	766

Table 8: Heat content of fuels (Carbon Trust 2006)

	By weight		By volume
Solid fuels	**kWh/tonne**	**litres/tonne**	**kWh/litre**
Coal (weighted average)	7,417	—	—
Coke	8,445	—	—
Liquid fuels	**kWh/tonne**	**litres/tonne**	**kWh/litre**
Crude oil (weighted average)	12,682	1,192	10.6
Petroleum products (weighted average)	12,751	—	—
Ethane	14,071	2,730	5.2
Liquefied petroleum gas	13,721	1,850	7.4
Aviation turbine fuel	12,845	1,251	10.3
Motor spirit	13,087	1,362	9.6
Gas/diesel oil	12,668	1,187	10.7
Fuel oil	12,087	1,031	11.7
Power station oil	12,087	1,142	10.6

Source: Annex A of the Digest of UK Energy Statistics 2005

Table 9: Conversion factors for energy units (Carbon Trust 2006)

To From	therms	kWh	Btu	MJ	Toe*	kcal
therms	1	100,000	29.31	105.5	2.52×10^{-3}	25×10^{3}
kWh	0.03412	1	3412	3.6	85.98×10^{-6}	859.7
Btu	1×10^{-5}	0.2931×10^{-3}	1	1.055×10^{-3}	25.2×10^{-9}	0.252
MJ	9.478×10^{-3}	0.2778	947.8	1	2.388×10^{-5}	238.8
toe	396.8	11,630	39.68×10^{6}	41,870	1	1×10^{7}
kcal	4×10^{-5}	1.163×10^{-3}	3.968	4.187×10^{-3}	1×10^{-7}	1

*toe = tonne of oil equivalent

Table 10: Carbon emission factors (Carbon Trust 2006)

Fuel	kg C/kWh	kg CO_2/kWh	Fuel	kg C/kWh	kg CO_2/kWh
Grid electricity Delivered	0.117	0.43	Petrol	0.0655	0.24
Natural gas	0.0518	0.19	LPG	0.0573	0.21
Coal	0.0817	0.3	Jet kerosene	0.0655	0.24
Coke	0.101	0.37	Ethane	0.0545	0.2
Petroleum coke	0.0927	0.34	Naphtha	0.0709	0.26
Gas/diesel oil	0.068	0.25	Refinery gas	0.0545	0.2
Heavy fuel oil	0.0709	0.26			

Material

Any other materials used will have embedded energy values associated with them. This stage will require a determination of two major components: the embedded energy of the material at the point of manufacture, and the energy consumed during transportation to the point of use. A CO_2 equivalent will then be computed for each of the two components. In addition, there may exist CO_2 emissions derived from carbon compounds in the raw materials that are converted to CO_2 during the manufacturing process, which Gartner (2004) referred to as ‘‘raw materials’’ CO_2 ($RMCO_2$) as opposed to the ‘‘fuel-derived’’ CO_2 ($FDCO_2$), which are produced as a result of burning fossil fuels. The $RMCO_2$ will need to be taken into account if it is found that they exist.

Whereas the model includes all three resources at each stage of the project, only one or two of the resources may be required for some activities. This notion will then be taken into account by inputting zero values where the resource in question is not applicable.

Carbon sequestration

The effects of carbon sequestration should be taken into account during the life cycle carbon assessment since they in effect reduce the carbon footprint of the project. The technique adopted for this assessment will depend on the technology being used to aid the sequestration process.

The appraisal technique

The appraisal technique is based on the more widely used present worth technique for economic project appraisal. The above section gives an output of CO_2 emissions, in mass of CO_2, which occur at different times during the life of the construction project. This output represents the carbon flow of the project option under consideration.

The present CO_2 emission evaluation entails transforming all emissions into a net equivalent CO_2 amount at time zero, that is, the present time. Emissions will be treated as positive values on the carbon flow diagram, with sequestered carbon dioxide, if any, given negative values.

Apart from the carbon flows, both in terms of amounts of CO_2 involved and their timings, discounting factors will also be required to carry out the present emissions analysis. Since the sources of carbon are varied in nature, it is not realistic to use one discount rate for the analysis. The decision-maker will develop a discounting rate basing on the nature of plant, labour, and materials relevant to the project option under consideration. Historically, carbon emissions have been affected over time by changes in energy consumption levels, types of fuels used, and energy efficiencies (Brannlund, Ghalwash and Nordstrom 2007). The changes are triggered by changes in lifestyles, technological advancements, and, to a large extent, government policy (Kelly 2006). These trends could be used as guidance in determining the discounting factors.

The discounted carbon flow yields a Net Present Emission (NPE), which represents the life cycle carbon footprint of the project option at the present time. Comparisons between project options will then be done by comparing the NPEs. On the basis of CO_2 emissions, the project option with the lowest NPE will be the preferred choice. The suggested project(s) NPE is a new criterion that can be used in the carbon emissions appraisal of the project(s) in the same way as the Net Present Value is currently used in economic project appraisal (Rogers 2001). This new criterion can be used on its own or in conjunction with existing project appraisal methods.

Summary and future work

The framework provides an easily understandable technique of computing the life cycle CO_2 emissions associated with construction project activities. Tables 1-10 are provided to illustrate this process and to provide some important data for use in energy and carbon conversions. The project-specific data obtained could be compared with data from previous projects or with set organization targets so as to identify excesses in emissions. The description of the contributing factors in their simplest forms of plant, labour and materials not only facilitates the carbon computation but also gives the decision-maker the opportunity to manipulate the project components so as to achieve a desired emission level. For example, a change of plant and/or fuel type could lead to carbon savings. Also, management may want to centralize accommodation of employees, or provide communal transportation for employees so as to reduce on the carbon emissions associated with transportation to work. These adjustments could help redeem a project option which may otherwise be deemed to be undesirable, especially, if it happens to be more financially viable.

It is evident that success of the analysis described is dependent on the availability of project specific data. It requires a good understanding of plant and material specifications, location of material manufacture, travel distances for material and labour, and the technologies and fuels used in all these processes. Considering the varying nature of construction projects, an exhaustive list of all possible specifications is not provided as part of the framework. However, a database can be built over time to encompass the various construction works. This database could also be updated to cater for technological advances, shifts in construction practice, and changes in energy consumption and efficiencies.

The appraisal technique used in the framework follows from the present worth evaluation technique used in economic appraisal. The method assesses different project options through the conversion of carbon flows into single-value present amounts. The Net Present Emission (NPE) is a very easily understandable indicator of a project's CO_2 emission. It is however also dependent on accurate discounting. Future work needs to be done in the area of carbon discounting, determination and assessment of trends in energy consumption and efficiencies within the construction industry and related industries.

CONCLUSIONS

There is a growing concern about CO_2 emissions and their impact on the global environment. The construction industry is a major contributor to carbon emissions and therefore has a big role to play in the management of carbon emissions. The framework proposed should be seen as a tool to appraise construction projects based on CO_2 emissions. The framework suggests a carbon assessment technique based on the major resources of plant, labour and materials. It also proposes an appraisal technique to determine the Net Present Emission of a project option. The whole method of appraisal is easy to use and understand since it bears similarities with already existing techniques. It also allows the decision-maker to manage project parameters to achieve desired emission levels. Whereas the framework can be successfully applied to any construction project, further work is required in developing information and specifications databases for the industry, and also achieving accurate carbon accounting.

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