ESTABLISHING ABATEMENT ALTERNATIVES IN CONSTRUCTION

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Construction operations consume energy and due to the associated emission of greenhouse gases (GHG), leave negative environmental impacts. Many construction contractors look on emission mitigation efforts as being counter to profit and of secondary priority. However, due to increased social pressure, contractors are being obliged to reduce energy consumption and mitigate emissions. This paper focuses on emissions during construction. The aim of this research is to provide construction contractors with an understanding of the effectiveness and cost of available abatement alternatives and aid them in making profitable decisions while minimizing project emissions. Based on data from a road construction project, required material quantities, available suppliers, delivery vehicles and the NONROAD model, the cost and emissions of each possible procurement alternative are compared. The abatement curves are used to present the results. It is shown that by simply considering emissions in decision making, changing material supplier can help mitigate emissions. It demonstrates that for contractors who intend to make environmental friendly decisions, there exist affordable alternatives.

Keywords: construction operations, abatement curves, greenhouse gases, emissions, energy consumption.

INTRODUCTION

The push to examine carbon emissions is driven by obligatory and voluntarily regulations aimed at reducing greenhouse gases (GHG) set in response to global concerns over climate change issues. Minimizing carbon footprint is seen as a global priority and an important step towards sustainability (Piratla *et al*., 2012).

Construction industry not only consumes energy, but also emits GHG which lead to climate change and global warming (Guggemos and Hovarth, 2005; Dixit *et al*., 2010). Although compared with other industries, each individual construction project may not contribute to a large quantity of GHGs but the aggregate GHG product of the large number of construction projects is significant. For example, the construction industry is responsible for 40% of the primary energy use, and 36% of the energy related CO_2 emissions in industrialized countries (Blengini and Di Carlo 2010). In addition, in the United States, the construction industry ranks third after cement and steel production industries which supply construction projects with required material for its CO_2 emissions per unit of energy used as input (Avaetisyan *et al*. 2012).

However, when it comes to mitigation efforts, construction contractors, look at environmental issues generally as being counter to profit and secondary priority

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Ebrahiminejad, M, Shakeri, E and Ardeshir, A (2014) Establishing abatement alternatives in construction *In:* Raiden, A B and Aboagye-Nimo, E (Eds) Procs 30th Annual A*RCOM Conference*, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 163-172.

(Carmichael and Balatbat, 2009). With the increasing global scrutiny on environmental issues, contractors are being obliged to adopt carbon abatement efforts.

Contractors might see some competitive advantage through managing their GHG emissions during construction. They can start from activities producing greater emissions. The uniqueness of each construction project and the variety of construction activities makes it difficult to say which activity has the biggest contribution to GHG emissions. Previous research affirms that because of their dependence on fossil fuel for energy, transport of material to and from the site is among the top GHG emissions contributors in construction projects (Ren *et al*., 2012). Thus including emissions as an emerging criterion in construction related decision-making makes it possible to reduce project emissions through thoughtful supplier selection. This can be accomplished with little or no increase in project costs.

Contractors require both the cost and efficiency of any abatement alternative to make win-win decisions for themselves and the environment. Such information can be presented in many ways including the form of cost curves known as the marginal abatement cost (MAC) curves.

The overall aim of this paper is to provide construction contractors with an understanding of the effectiveness and cost of available abatement alternatives. It seeks to aid construction contractors in making profitable decisions regarding supplier selection at the same time minimizing project emissions. The problem of optimal selection of material supplier for a project subject to simultaneously minimize emissions and project cost given different types and quantities of material, different distances and delivery vehicle emission rates is formulated as a bi-objective optimization problem. The application and benefits of using abatement curves is demonstrated on a case study involving an infrastructure project known as Project M. The cost and carbon footprint associated with supplying material from different quarries are compared using abatement curves. The paper shows that there exist abatement alternatives that do not incur cost on the contractor. This approach will be of interest to contractors seeking affordable ways of making environmental friendly decisions.

This paper first discusses the process of identifying abatement alternatives by measuring emissions in construction. The emergence of emissions as a criterion in construction decision-making is addressed. The paper then investigates abatement alternatives by presenting a case study. MAC curves are then derived for identified alternatives demonstrating the cost effectiveness and potential abatement of each alternative. Conclusions follow.

What remains a major challenge for making environmental friendly emissions in construction is the demonstration of the cost effectiveness of abatement alternatives. Contractors require both the cost and efficiency of abatement alternatives to make win-win decisions for themselves and the industry. Such information can be presented in many ways including the form of cost curves known as the marginal abatement cost (MAC) curves.

BACKGROUND

Identifying abatement alternatives

Measuring emissions is the perquisite of managing emissions. Contractors are responsible for emissions from owned or controlled machinery and equipment, through activities such as transportation of materials, products, wastes and employees.

These activities represent scope 1 and 2 emissions based on the GHG Protocol Corporate Standard (Ranganathan *et al*., 2004) which is one of many emissions reporting standards.

To help measure GHG emissions in construction several approaches have been made. Park *et al*. (2003) estimates emissions by multiplying total fuel consumption by fuel to emissions conversion coefficient. The conversion coefficients in this model are not equipment specific. Focusing on seven different types of equipment, Lewis (2009) proposed a model that provides detailed emission factors for ten engine modes. By using the fuel-to-emissions rates of each engine mode the fuel use rate is then converted to an emission factor. In a more comprehensive and general approach, the NONROAD model (EPA, 2008) developed by the U.S. Environmental Protection Agency (EPA) provides specific emission rates for each type of off-road equipment based on their power and year of make. The emissions are estimated using: (1) the emission factor which is the average emissions rate for a given pollutant and (2) the load factor which accounts for idle, partial load and transient operating conditions. The NONROAD model (EPA, 2008) is used for measuring emissions in this paper.

By measuring and reporting emissions, abatement opportunities are identified. Abatement is basically achieved by output cuts from polluting sources, by technical change or through cleaning up pollutants in the environment (Beaumont and Tinch, 2004). Every field has different abatement alternatives. In the transportation sector, they can include less expensive hybrid vehicles and bio-diesel while for climate change, its carbon capture and sequestration (Baker *et al*., 2008).

Contractors can achieve abatement by focusing on main polluting sources. In construction, primary sources of GHG emissions are off-site transportation of material and equipment to/from the site and the operation of on-site equipment (Cole, 1998; Ahn *et al*., 2010; Ren *et al*., 2012). For a profit driven contractor reducing transport distance, equipment idle time and power usage are *"low hanging fruits"* which achieve abatement at least cost. Using well-maintained or new equipment with improved emissions controls are examples of technical changes in construction equipment, which aids emissions reduction at jobsites. For example, upgrading the diesel equipment fleet by 8 years reduces CO, NO_2, and HC emissions by 30–68% (Guggemos and Hovarth, 2005). However, changes in technology by upgrading the equipment fleet, requires investments and are expensive.

Adopting abatement alternatives

Construction contractors traditionally deal with problems such as optimal equipment selection, selecting among multiple sources of material that can serve a project, the route selection and the issue of replacing current fleet with new machines focusing on minimizing cost and maximizing productivity (Oglesby *et al*., 1989). Classic decision-making problems in construction are no longer merely a cost and time minimization problem for contractors.

The objective function of these problems is now reducing emissions while minimizing the effect on cost. This approach has gained popularity in the construction industry and efforts have been made to solve construction problems with emissions in mind: construction method selection in tunneling (Ahn *et al*., 2010), solving the equipment selection problem (Avetisyan et. al., 2012) and path selection model for construction material delivery (Koo and park, 2012).

As a common element in all decision-making problems, the contractor needs to know whether an abatement alternative is worth the cost. An abatement alternative merits performance if and only if a contractor deduces it would be better off adopting it. This is the heart of marginal decision-making.

Therefore achieving a win-win position for the contractor and the environment requires an understanding of available GHG abatement alternatives along with its associated costs and benefits. One of the ways to provide such information is the MAC curve.

CASE STUDY

An 11.5 kilometre road infrastructure project in the Australian Capital Territory (ACT), known as Project M is selected as the case study to measure the impact of supplier selection on cost and emissions. The contractor requires different quantities of material delivered to the site.

The contractor provided the bill of quantities, suppliers' descriptions (cost, location and supply capacity) and delivery vehicle descriptions. Four quarries can supply the required material. Bogie and trailers (15 m^3) are used as delivery vehicles to haul the material from the quarry to the site. The two-way travel time from each quarry to the site and back is calculated based on the loaded travel speed (50 km/h) and the empty travel speed (60 km/h) of the delivery vehicle (**Error! Reference source not found.**).

Table 1: Two way travel time calculations from quarries to the site

Quarry code	Distance from site (km)	Travel time (h)		Total two way travel time (h)
		loaded	empty	
A	33.1	0.66	0.55	1.21
B	17.8	0.36	0.3	0.65
C	20.3	0.41	0.34	0.74
D	14.9	0.3	0.25	0.55

Based on the total quantity of different types of material required for the project and the capacity of the delivery vehicle used to haul the material, the number of two way trips required to transport the total quantities of material from the quarry to site and back is calculated (**Error! Reference source not found.**).

Table 2. Number of trips required to deliver required material to site

Material code	Material description	Quantity (tonne)	Number of two way trips
Type I	Surge rock 150mm size	110000	3667
Type II	Drainage blanket ballast 63mm	14500	483
Type III	Bedding material	25000	833
Type IV	Aggregate material (20mm granite)	15000	500

To calculate emissions produced through the transport of material from the quarry to the site the NONROAD model (EPA, 2008) is used. The model calculates the emission factors of equipment based on their horsepower (hp) and the year of make. The emission factors related to the delivery vehicle used in this case study are presented in **Error! Reference source not found.**.

Table 3. Emission factors for the equipment used to haul the material to site

			Emission factors (kg per hour)					
Item	HP	Year	CO_2	SO_2	HC	CO	NO_x	PM
Bogie and trailer	425	2003	227.7	0.35	0.08	0.65	1.79	0.1

In a process called characterization, the global warming potential (GWP), is used to convert the emissions to one single carbon dioxide equivalent (CO_2-e) value. CO_2-e is the standard unit for measuring carbon footprint.

The GWP for carbon dioxide and methane are respectively 1 and 23 and there is no GWP associated to CO, NO_x, and SO_2 (IPCC, 2007). Hence, a CO_2-e value of 229.5 kg per hour use is considered for the bogie and trailer.

For every quarry, the cost of material delivery is calculated based on the unit cost of material delivered to site and the total quantities of required material. The total time required to deliver the required material to the site (delivery time) is obtained by multiplying the total two way travel time in **Error! Reference source not found.** by the number of two way trips required in **Error! Reference source not found.**. Total carbon footprint associated with supplying material form each quarry is then calculated by multiplying the delivery time of material by the CO_2-e value.

RESULTS AND DISCUSSIONS

The results from the case study are outlined below. They compare the cost and carbon footprint associated with supplying material from different quarries. Quarry selection is associated with a cost and a carbon footprint.

As traditionally contractors seek minimized cost, the contractor's choice is quarry A. This decision in return is associated with the highest emissions (Figure 5). It is eminent that the closest quarry to the site (D) produces the lowest emissions which in this case is incurs the highest cost for the contractor.

An estimate of 1500 tonnes of CO_2-e produced from material transport to the site in Project M over the construction period is made on the basis of the required quantities of material, quarry distance from the site and capacity and emission rate per delivery vehicle.

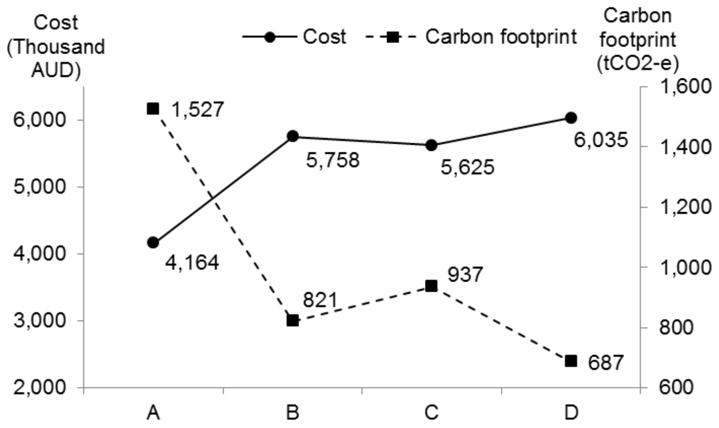
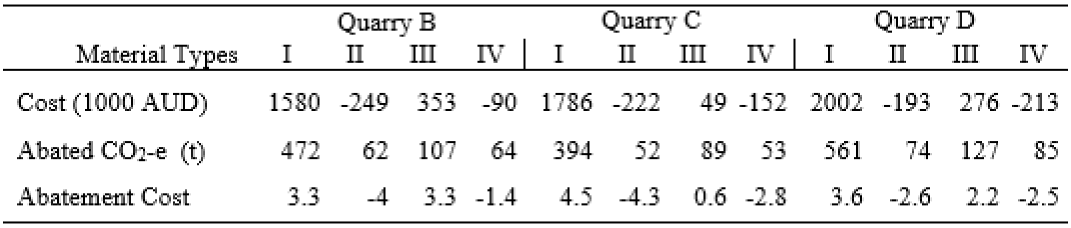


Figure 5. Cost and carbon footprint trade-off for material procurement from different quarries

Let's now consider the objective function of reducing carbon footprint while minimizing the cost. For this, quarries B, C and D are considered as abatement alternatives for quarry A. The abated amount of CO_2-e with the associate costs of supplying material from an alternative quarry is then calculated. The comparison results are summarized in table 4. The abatement cost is simply the cost divided by the total amount of abated CO_2-e and negative costs indicate cost savings. The results are presented using abatement curves.

Table 4- Summary of the cost and CO2-e comparison between alternative quarries with the initial contractor's choice



	Quarry B				Quarry C				Quarry D			
Material Types	I	II	III	IV	I	II	III	IV	I	II	III	IV
Cost (1000 AUD)	1580	-249	353	-90	1786	-222	49	-152	2002	-193	276	-213
Abated CO_2-e (t)	472	62	107	64	394	52	89	53	561	74	127	85
Abatement Cost	3.3	-4	3.3	-1.4	4.5	-4.3	0.6	-2.8	3.6	-2.6	2.2	-2.5

For each alternative quarry, an abatement curve is derived to evaluate its abatement potential. Each abatement curve (figures 2, 3 and 4) compares the cost and carbon footprint associated with supplying the material from one of the alternative quarries (B, C and D) with quarry A.

Abatement curve

A marginal abatement cost curve is an intuitive way to represent the relationship between the cost-effectiveness of different alternatives and the total amount of GHG abated. Abatement curves have been used since the 1970s oil price shock. Under different names (for example saving curve and conservation supply curve) they are widely used concepts in environmental engineering. Despite being frequently used to examine climate change mitigation measures in various industries and sectors in different countries (Hasanbeigi *et al*., 2010) the construction industry has not yet utilized the advantages of these curves.

MAC curves transparently communicate available abatement alternatives and provide an estimate of cost for the contractor to reach an abatement target. This type of cost curves also help contractors select the most affordable abatement alternative (Beaumont and Tinch, 2004). Describing the costs and benefits of any abatement alternative in the format of an abatement cost curve persuades the construction industry (contractors in particular) to make environmentally preferable decisions.

As the MAC curves depict, moving along the curve from left to right the cost-effectiveness of each measure worsens. It means, as the total level of abatement increases, each tonne of abated carbon dioxide equivalent (tCO_2-e) becomes more expensive (Figure 6, Figure 7 and Figure 8).

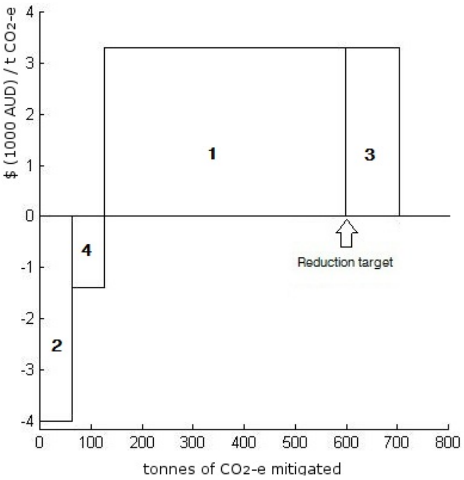


Figure 6. MAC curve for quarry B as an alternative material supplier.

Within each MAC curve, the cost benefit and abatement potential of each measure is demonstrated. In this paper, each measure represents the outcome of supplying a type of material from the alternative quarry instead of quarry A. For example measure 1 in Figure 2 represents supplying material type I from quarry B instead of A.

Measures below the horizontal axis are beneficial also in terms of cost reduction. In all three MAC curves, measures 2 and 4 which represent supplying type II and IV materials from any of the alternative quarries have both cost and carbon footprint savings for the contractor. On the other hand, measures 3 and 1 while reduce more emissions but incur a positive cost.

By supplying type II and IV materials from any supplier other than quarry A (adopting measures 2 and 4), 105 tonnes of CO_2-e mitigation is achieved. This achievement as the MAC curve clearly shows provides cost saving for the contractor.

Based on a reduction target, one or more of the measures have to be implemented. The reduction target is the amount of abatement a contractor is seeking to achieve. It can be set due to regulations or internally by the firm.

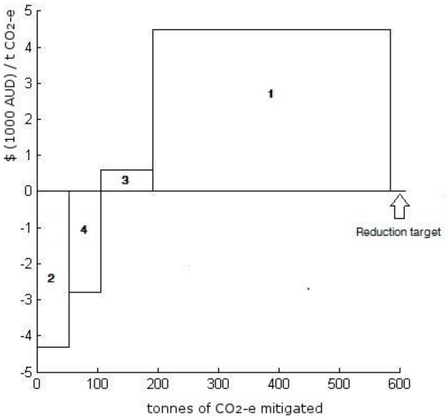


Figure 7. MAC curve for quarry C as an alternative material supplier.

For example if the reduction target is set to 600 tonnes of CO_2-e, by implementing measures 1, 2 and 4 (supplying material types II, IV and I) from quarry B the target is achieved (Figure 6). While the contractor can only achieve 588 tonnes of CO_2-e abatement by selecting quarry C (Figure 7). Therefore, it is clear that based on this reduction target, quarry C is not a suitable alternative for the contractor.

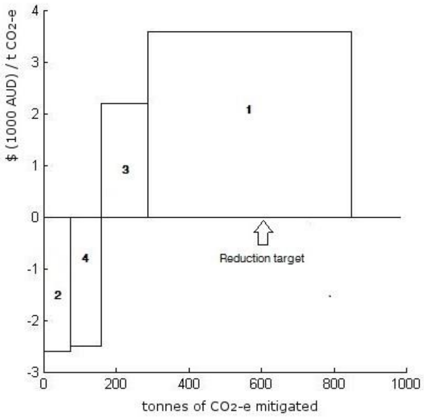


Figure 8. MAC curve for quarry D as an alternative material supplier.

On the other hand, if the reduction target were equal or less than 50 tonnes of CO_2-e, the abatement target would be achieved only by implementing measure 2 from any of the alternatives. This shows by simply changing the supplier of material type II, not only the reduction target is achieved but the contractor also benefits money saving. Finally it should be noted that the MAC curves show that the maximum amount of abatement achievable through changing the material supplier is 847 tonnes of CO_2-e. For greater reduction targets, the contractor has to think of other alternatives.

Previous research affirms that machinery and material transportation to and from the site are a major energy contributor in the construction phase (Cole, 2000; Guggamos and Horvath, 2005; Ahn, 2010 and Ren *et al*., 2012). Consumption of fossil fuels during the previously mentioned activities produces emissions thus supplier selection is an important management issue in reducing carbon emissions in the construction industry. Emissions are an emerging criterion in the supplier selection problem. Supplier selection based on the lowest prices is not efficient sourcing any more. Other criteria in the literature include supply variety, quality and delivery (Ng, 2008). The case study results clearly support the related literature findings (Peng and Pheng, 2011) which demonstrate how local supply of material compared to international supply can significantly reduce carbon emissions.

CONCLUSION

This paper incorporates emissions as a decision-making criterion in a supplier selection problem. In a case study it evaluates alternative suppliers, in terms of their impact on both cost and emissions. Marginal abatement cost curves are used to present the results. It is shown that simply changing the supplier of material types II and IV, at least 105 tonnes of CO_2-e is mitigated. As the abatement curves clearly show, this achievement not only imposes any cost on the contractor but also saves money. Contractors benefit from the abatement curve as a tool to make cost effective environmental decisions. It is demonstrated that for contractors who intend to make environmental friendly decisions, there exists affordable alternatives.

REFERENCES

Ahn, C, Xie, H, Lee, S H, Abourisk, S and Pena-Mora, F (2010) Carbon footprints analysis for tunnel construction processes in the preplanning phase using collaborative simulation. In: Buwanpura, J. (Ed.), *“Construction Research Congress”*, 2001, Alberta, Canada, ASCE, 1538-1546.

Avetisyan, H, Miller-Hooks, E and Melanta, S (2012) Decision Models to Support Greenhouse Gas Emissions Reduction from Transportation Construction Projects. "*Journal of Construction Engineering and Management"*, **138**(5), 631–641.

Baker, E, Clarke, L and Shittu, E. (2008) Technical change and the marginal cost of abatement. "*Energy Economics"*, *30*(6), 2799–2816.

Beaumont, N J and Tinch, R (2004) Abatement cost curves: a viable management tool for enabling the achievement of win–win waste reduction strategies? "*Journal of Environmental Management"*, **71**(3), 207–215.

Blengini, G A and Di Carlo, T (2010) The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. "*Energy and Buildings"*, **42**(6), 869–880.

Carmichael, D G and Balatbat, M C A (2009) Sustainability on Construction Projects as a Business Opportunity. *"SSEE"*, 2009, Melbourne, Australia.

Cole, R J (2000) Building Environmental Assessment Methods: Assessing Construction Practices, *"Construction Management and Economics"*, **18**(8), 949-957.

Dixit, M K, Fernandez-Solis, J L, Lavy, S and Culp, C H (2010) Identification of Parameters for Embodied Energy Measurement: A Literature Review, *"Energy and Buildings"*, **42**(8), 1238-1247.

EPA, NONROAD Model (Nonroad Engines, Equipment, and Vehicles) (2008) U.S. Environmental Protection Agency, http://www.epa.gov/OMS/nonrdmdl.htm

Guggemos, A A and Horvath, A (2005) Decision Support Tool for Environmental Analysis of Commercial Building Structures. In: Tommelein, I D (Ed.), *"Construction Research Congress"*, 2005, San Diego, California, ASCE, 1-11.

IPCC, Climate change, Synthesis report: Contribution of working groups I, II and III to the fourth assessment report. Intergovernmental Panel on Climate change, 2007.

Koo, K and Park, S (2012) GA-Based Fuel-Efficient Transfer Path Selection Model for Delivering Construction Materials. "*Journal of Construction Engineering and Management"*, **138**(6), 725–732.

Lewis, M P (2009), *"Estimating Fuel Use and Emission Rates of Nonroad Diesel Construction Equipment Performing Representative Duty Cycles"*, PhD Thesis, North Carolina State University.

Marshall, S, Rasdorf, W, Lewis, P and Fey, H (2012) Methodology for Estimating Emissions Inventories for Commercial Building Projects, *"Journal of Architectural Engineering"*, **18**(3), 251-260.

Ng, W L (2008) An efficient and simple model for multi criteria supplier selection problem, *"European Journal of Operational Research"*, 186 (2008), 1059-1067.

Oglesby, C H, Parker, H W and Howell, G A (1989) *"Productivity Improvement in Construction"*. New York: McGraw-Hill.

Palaniappan, S (2009), *"Environmental performance of on-site construction processes in post-tensioned slab foundation construction: A study of production home building in the greater Phoenix area"*, PhD Thesis, Arizona State University.

Peng, W and Pheng, L S (2011) Managing the Embodied Carbon of Precast Concrete Columns, *"Journal of Materials in Civil Engineering"*, **23**(8), 1192-1199.

Piratla, K R, Ariaratnam, S T and Cohen, A (2012) Estimation of CO_2 Emissions from the Life Cycle of a Potable Water Pipeline Project, *"Journal of Management in Engineering"*, **28**(1), 22-30.

Ranganathan, J, Corbier, L, Bhatia, P, Schmitz, S, Gage, P and Oren, K (2004), *"The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard"*. Revised ed. Washington DC: World Resources Institute and World Business Council for Sustainable Development.

Ren, Z, Chrysostomou, V and Price, T (2012) The Measurement of Carbon Performance of Construction Activities: A case study of a hotel construction project in South Wales. *"Smart and Sustainable Built Environment"*, **1**(2), 153-171.

Suzuki, M, and Oka, T (1998) Estimation of Life Cycle Energy Consumption and CO_2 Emission of Office Buildings in Japan. *"Building Energy"*, **28**(1), 33–41.

Yan, H, Shen, Q, Fan, L C H, Wang, Y and Zhang, L (2010) Greenhouse Gas Emissions in Building Construction: A case study of One Peking in Hong Kong. *"Building and Environment"*, **45**(4), 949-955.