Carbon Abatement and its Cost in Construction Activities

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ABSTRACT
There is a growing awareness of the need for adopting sustainable practices in the construction industry. Included in this is an emphasis on reducing the carbon footprint of site construction activities, as a supplement to the more commonly reported pre-construction-phase design and material selection issues. To date, only a modest amount of attention has focused on reducing the direct carbon emissions of site activities but, with growing legislation and social pressure, this will change. Construction activities rely on high-energy-use equipment and so there is a case for looking at emission abatement options and their costs. The paper examines a number of major-energy-use site activities on two construction projects, their direct emissions, associated abatement options and the respective costs of these abatements. Earthworks, demolition and concrete placement are focused on. Abatement beyond business as usual (BAU) is examined and options ranked. Interestingly, it is found for the cases studied that simple options, such as reducing travel distances, sawcutting, and stockpiling waste prior to removal, have the most cost-effective abatement potential. It is acknowledged that each project is unique and best options may vary from project to project, however the methodology presented in the paper will stay the same across all projects, and the need to do similar studies across each project will remain in order to improve sustainability of the overall construction industry.

INTRODUCTION
Attention is becoming increasingly focused on sustainability in the construction industry. Particular emphasis has been placed on reducing the carbon footprint (equivalently the Kyoto greenhouse gas – GHG – emissions expressed as CO2 equivalents, CO2-e) of construction projects in terms of design and material selection, however little attention has focused on reducing the carbon footprint of site activities. Construction projects tend to consume large amounts of fuel and power in the operation of equipment, and generate large quantities of waste.

This paper reports on a study, where site activities are analyzed to determine the carbon footprint of current practices (business-as-usual – BAU) and the influence of alternative practices is examined. Two construction projects involving earthworks, demolition and concrete placement, are investigated, and activity emissions and costs calculated for the existing and suggested alternative practices. Interestingly, it is found that simple options such as reducing travel distances, sawcutting, and stockpiling waste prior to removal have the most cost-effective emissions abatement
potential. It is acknowledged that each project has its own unique carbon footprint, and abatement options may differ between projects, however the methodology presented in this paper will be the same across all projects. The methodology will prove useful at the planning stage of construction projects, and also as a value management style tool.

The aim of the study behind this paper is to gain an understanding into current construction practices and their associated carbon footprint. Highlighting activities that have particularly high carbon emissions enables abatement options to be suggested and considered. Ultimately, this may lead to more sustainability within construction. The paper will be of interest to construction engineers and managers.

The paper presents a first in using marginal abatement cost curves (MACC) (sometimes referred to as McKinsey MAC curves – for example: McKinsey, 2008; Ekins et al., 2011) to portray the cost effectiveness abatement options on construction projects. Marginal abatement cost is defined as the present worth of abatement divided by the associated emissions saved. With a MACC, the cheapest potential abatement option is given to the left of the diagram, and the most expensive to the right hand side of the diagram, with the ordered or ranked range in between. The width of each column represents the emissions abated for each option, that is, the column with the greater width has greater abatement potential. A MACC not only indicates marginal abatement cost, but also average and total cost (present worth) by integrating the curve.

The order of the paper is as follows. Some background to emissions and carbon footprinting within construction projects is first discussed. Two field studies are described, and abatement options are considered and ranked for each. Some general conclusions follow on the installation of emissions thinking into project management practices.

BACKGROUND

In the US, construction accounts for approximately 2% of all GHG emissions (EPA, 2009). Similar figures are believed to apply worldwide for equivalent economies, and reducing for smaller economies; for example in Australia this figure is approximately 0.5% (Garnaut, 2011). These percentages are based solely on construction activities and do not account for any GHGs associated with the manufacture of materials. They are largely due to a dependence on fossil fuels to operate heavy equipment and for transportation of materials. Off-road equipment, including trucks and excavators, tends to produce a higher rate of emissions than on-road vehicles due to the fuel type, engine technology and power required for their operation (Avetisyan et al., 2012).

It appears inevitable that future construction projects will, as a matter of course, monitor their GHG emissions with a view to mitigation. Legislation covering this has already started to appear. For example in Australia, the Clean Energy Act (2011) (legislates a price on carbon) and the National Greenhouse and Energy Reporting (NGER) Act (2007) are already leading the construction industry to rethink current practices in order to avoid extra costs and reduce emissions. Major construction companies fall within this required reporting of emissions, but all construction companies are affected in some way by a price on carbon. The Energy
Efficiency Opportunities Act (2006) attempts, among other things, to identify energy efficiency opportunities and encourage cost-effective energy efficiency.

Some studies of carbon footprinting of construction activities have been reported. See, for example Melanta et al. (2013), and a number of papers in the ASCE Construction Research Congress (2012). The majority of the published literature however focuses on the design and material selection phases of projects. Avetisyan et al. (2012) reviews the literature on emissions reduction in construction, and makes mention of low-cost emission reduction strategies suggested by others, including, for example: reducing equipment idling time and power usage; preventative maintenance; operator training; use of ultra-low-sulfur diesel, biodiesel or other low-emitting fuel sources; mechanical changes to the equipment engine or engine upgrade; and electrification of equipment. Cost and emissions, in different contexts, are further examined by for example: Lewis and Hajji (2012); Hajji and Lewis (2013); Carmichael et al. (2012, 2014); Ahn et al. (2009, 2010a, b, c); and Hughes et al. (2011).

FIELD STUDIES

Field studies were carried out in order to develop the carbon footprints of some energy-intensive site activities and to examine potential abatement options and their cost-effectiveness. Two available project sites – an infrastructure project and a building project - were examined over their durations. The infrastructure project had extensive earthworks activities. The building project had dominating demolition and concreting activities.

Industry-developed models and data were used for calculating CO2-e emissions, based on observed equipment fuel and power usage. Examples: the NONROAD model (EPA, 2008) was used for on-site construction equipment; and crane power usage data were used, and converted to emissions. For possible abatement options, the emissions are calculated by factoring the existing 'observed' CO2-e emissions. For example, in the case of substituting petroleum diesel with B20 biodiesel in equipment, a reduction factor of 15% in CO2-e emissions was used (Department of Energy, 2012), though this may not be exact because of the varied sources of biodiesel. Fuel usage of newer vehicles was factored down from the values for existing, older vehicles. Where abatement options changed the duration of an activity, the existing CO2-e values were factored by the altered duration. For present worth calculations, discount rates ranging from 5% to 20% were used in order to examine the sensitivity of the results to discount rate assumptions. In order to generate the MACC, the abatement potential (or cost) of each option was calculated from the difference in emissions (or costs) of the existing method (business as usual – BAU) and the proposed option.

Infrastructure project - earthworks

The project consisted of the construction of an underground car park for an existing CBD building. The project required extensive earthworks including excavation and some tunneling, and was reliant on heavy equipment. Equipment used included excavators (1.5-35 t) with buckets and hammers, air legs and a diesel compressor.
The data for the excavation of approximately 30,000 m³, were recorded over a four-month period. The excavated material largely comprised (based on tonnage) 77% sandstone, a material difficult to excavate due to its strength and abrasive properties. The remainder of the excavated material was concrete (5%), mixed material (6%), and spoil (12%). The majority of the rock was excavated using hammers and buckets attached to 35 t excavators. Some material was used as fill at other construction sites and therefore required further fragmenting before hauling. This meant that equipment was required for longer durations than in a typical excavation, thus consuming more fuel and producing more emissions.

The haulage distance off site and dumping cost of the excavated material was dependent upon its composition. Once material was excavated it was separated into stockpiles based on type of material, as best as practically possible, and then loaded into 32 t trucks for removal.

**Building project - demolition and concreting**

This CBD building project combined new work along with refurbishment of an existing building. Within the new work there was concrete slab, beam, column and wall work. The refurbishment required extensive demolition.

Refurbishment and demolition were done using 1.1-20 t excavators with hammer attachments, intermittently over a period of 7 months. The composition of the demolished material was brick (57%), concrete (4%), demolition waste (15%), special, asbestos soil (16%), bitumen (1%), and black iron (7%) and was hauled distances ranging from 5 to 49 km depending on the material in trucks ranging from 5-15 t.

Over a period of seven months, approximately 3000 m³ of concrete were poured. All large pours used a concrete pump while the smaller pours, including elevator and riser walls, used a kibble and tower crane. Concrete was transported to site using 6 m³ concrete trucks from an off-site batching plant.

**FIELD STUDY RESULTS AND ABATEMENT OPTIONS**

The results of the study of the projects and proposed abatement options follow. MACCs are given below for a 10% discount rate. Varying the discount rates from 5% to 20% had little effect on the present worth, primarily because of the short durations of the activities. In some cases, the proposed abatement option not only reduced the carbon footprint of an activity, it also proved to be more cost-effective.

**Earthworks.** In comparison with the later reported concrete placement, the earthworks produced almost ten times more emissions. Earthworks are more reliant on equipment, and hence give a larger footprint. Upon analysis of the data, several emission abatement options (for the earthworks) were available:

i. A rock saw was not used during the excavation of the sandstone. This material was removed by alternating between a hammer and bucket attachment on the excavators. The use of a rock saw was estimated to have the potential to reduce the duration of the excavation by up to 20%. The excavators already on site were suitable to be fitted with a rock saw, and no new equipment was required.

ii. Fuel usage in haulage was large. An investigation of the area surrounding the site confirmed that there was potential to dump material at considerably closer
locations.
iii. Alternative fuel usage in trucks was possible.
iv. Fuel used to power the equipment on site was large, and so the use of alternative fuel was examined.
v. The use of newer excavators that had 20% lower emissions than that currently used was possible.
vi. The use of newer trucks with 6% lower emissions than that currently used, was possible.

Figure 1 shows the MACC for earthworks. The cost effective options are using a rock saw and closer dump location. The unattractive options are using biodiesel, using newer machinery and using newer trucks.

Demolition. The demolition was reliant on heavy equipment such as excavators, and produced large volumes of waste (both for recycling and dumping) that requires haulage off site, with both contributing to the carbon footprint for demolition. The demolition had a lower carbon footprint than the later reported concrete placement, partly due to its shorter duration. Upon analysis of the data, several emission abatement options (for demolition) were available:
i. A closer dumping location was available for both the demolition waste and asbestos waste.
ii. Waste from the demolition was segregated on site and then transported to a dumping location in 5-15 t trucks. Stockpiling waste and removing in larger trucks, or trucks with trailers, would reduce the number of trips.
iii. Alternative fuel usage in trucks was possible.
iv. Alternative fuel usage in site equipment was possible.
v. The option of substituting newer, larger trucks, which produce less emissions, for older vehicles was a possibility.
vi. The option of substituting newer machinery for older was a possibility.

The MACC in Figure 2 shows the effectiveness of each abatement option considered.
The most cost effective option was dumping waste at closer locations, followed by stock piling waste and removing in larger trucks. Of the options above the line, the options in order of increasing unattractiveness were: substituting petroleum diesel for B20 biodiesel in trucks was the least effective, using B20 biodiesel in equipment, using newer trucks and using newer machinery.

![Figure 2. MACC for demolition.](image)

**Concrete placement.** Upon analysis of the data, several emission abatement options (for concreting) were available:

i. A number of small pours occurred on the project, indicating that some mixer trucks were not at capacity. More effectively planning and combining pours could reduce the number of trips required by the concrete trucks.

ii. Transportation of concrete to site was found to be a primary contributor to the carbon footprint. An alternative batching plant was available and located closer to site than that used.

iii. The project used 6 m³ mixer trucks to deliver concrete to site. Increasing the capacity of these trucks to 10 m³ would reduce the number of trips required for a concrete pour. Although these larger trucks release more emissions per vehicle, the overall emissions per m³ of concrete are less than that for the smaller vehicles.

iv. The option of substituting a newer pump for the existing was a possibility.

v. Alternative fuel usage in trucks was possible.

vi. Alternative fuel usage in the pump was possible.

vii. Pump usage was a main contributor to the carbon footprint of concrete placement. Reducing the reliance on the pump by using a kibble attached to the tower crane could potentially reduce the emissions. This would reduce pumping hours and the volume of diesel consumed by the pump, but would increase the time taken for placement with associated labor costs, and increase electricity usage of the crane. Only smaller pours were considered to be eligible to be placed using a kibble because larger pours would take too long, potentially increasing the risk associated with cold concrete joints.
Newer equipment and newer concrete mixer trucks were also considered. The MACC for concrete placement is given in Figure 3. In order of decreasing cost-effectiveness these are: combining pours, closer batching plant, larger concrete trucks and newer concrete pump. Of the options with positive marginal abatement cost, in increasing order of decreasing unattractiveness, these are: changing fuel type in trucks, changing fuel type in pump, using a kibble and newer trucks. Substituting the kibble for a concrete pump was not only uneconomical, it only reduced emissions by a small amount. Given that using the kibble also increased durations, it was seen as the least useful abatement option and impractical to implement on site.

**Figure 3. MACC for concrete placement.**

**DISCUSSION OF RESULTS**

**General.** The results presented here show that emission abatement is possible in earthworks, demolition and concrete placement, that is the carbon footprints of these activities can be reduced. However, there may be constraints that may prevent the complete implementation of abatement options on sites. Commonly, project decisions are being made to benefit program, budget, quality and safety. Little emphasis may be placed on reducing the carbon footprint of site activities, because it is not viewed to have similar importance to these other issues. This may require a cultural change in priorities in order to reduce the carbon footprint of construction practices.

A further issue affecting the implementation of abatement options on site is that it would require cooperation from subcontractors and suppliers. The majority of the options considered in this paper occur at the subcontractor level. For example, the supply of concrete in 10 m³ trucks is dependent on the concrete supplier. Similarly for demolition, substituting regular excavators for hybrid excavators is reliant on the earthworks subcontractor. A subcontractor would not be expected to change its equipment practices to suit one individual contractor on one short-term project. However long-term, should there be sufficient work, subcontractors might change. Ultimately, the push will need to come from all contractors who collectively have a desire to lower emissions.
Substituting B20 biodiesel for petroleum diesel may be effective on some sites. A 20% blend of biodiesel can reduce CO2-e emissions by 15%. If further biofuel substitution becomes readily obtainable, it will have the potential to reduce emissions further (Department of Energy, 2012). However, there are some negative aspects surrounding the use of various blends of biodiesel. Some vehicles may require engine modifications prior to using higher blends of biodiesel as a fuel. Furthermore, biofuel has various environmental and social implications (Koh and Ghazoul, 2008).

Using newer equipment has abatement potential. However, one of the issues associated with this option is that it requires the replacement of functioning equipment, and the manufacture of new equipment may produce more lifecycle GHGs than that released by the continuing operation of existing equipment.

Abatement options, in many cases, can be combined.

**Earthworks.** While possibly attractive on other sites, the rock saw option was not used because the won sandstone, in fragmented form, was required as backfill at a separate site.

**Demolition.** Although possible for the case study, stockpiling material may impede on other sites. Rehandling stockpiled material, to enable other construction to proceed, has attendant costs and possible delays. To prevent this situation, contractors commonly remove material regularly to keep the site clear. In order for stockpiling to be a possibility, the site layout would need careful design.

**Concrete placement.** There are several issues that may reduce the potential of combining pours on site, and would need examining on a project-by-project basis. For example: a small pour might need to be carried out in order to facilitate other work; and some elements, such as columns and slabs, requiring different strengths and properties, cannot be combined.

There are some issues that may prevent using the nearest batching plant. If a contractor has an alliance with a particular concrete supplier, or can obtain concrete at a cheaper rate, it will prefer concrete from those suppliers regardless of whether it is the closest or not.

Generally, the concrete supplier determines the truck type. As well, axle limitations on roads may prevent the use of larger trucks unless multi-axled. Larger trucks could be expected to have higher capital and maintenance costs, and this influences the preference for smaller trucks.

An issue with using a kibble for concrete placement is that it prevents the tower crane from servicing the rest of the project. Most large-scale building projects are heavily reliant on the tower crane for vertical movement of materials and façade installation. Concentrating large portions of crane time on concrete placement can negatively affect program and delay other areas of work. Ultimately this can end up costing money. Another issue with using a kibble for concrete placement is that the crane requires electricity for operation. Electricity generation by, for example, a coal-fired power station, produces GHG emissions. Given that this option produces a low abatement potential and causes delays within the project, it may not be favored.

**CONCLUSIONS**

This study provides insight into current practices on construction sites. It
highlights site activities, which produce high levels of GHG emissions. Potential abatement options were developed to target emissions reduction for these activities. The study demonstrated that cost-effective and implementable abatement options can be found in order to improve the sustainability of construction site activities.

The abatement options suggested in this paper are independent of the specific case studies examined, and carry over to other projects. All construction sites have the potential to reduce their emissions. However, specific conclusions could be expected to differ between projects and be dependent on local factors. It is recommended that similar emissions investigations be performed at the planning stage on all projects in order to determine the most cost-effective abatement options, reduce the emissions or carbon footprint of the construction industry generally, and entrench sustainability thinking. If left to the efforts of a handful of contractors, little impact on emissions reduction will occur.

There are several abatement options, considered almost universal, which should be considered by all contractors. Most, it is believed will also lead to cost savings: reduce travel distances where possible; substitute petroleum based fuels with biofuels (where there is no engine modification cost); combine small work items, for example small concrete pours; and combine multiple abatement options.

As more developments occur in the field of biofuels and efficient vehicles, further emission reductions will be possible.

While not directly investigated in this paper, it was observed during the study that changing the mindset of all project personnel in terms of sustainable construction is far from complete. Reducing the carbon footprint of projects needs to be given similar importance to that of program, costs and safety. Creating awareness and understanding within the industry will enable construction firms to contribute to climate change solutions.

REFERENCES


