Carbon dioxide accounting

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Carbon dioxide accounting: 2014 Commonwealth Games Athletes' Village

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A spreadsheet-based tool for whole-life carbon dioxide accounting of soil remediation projects has been created. The tool carries out whole-life analysis of projects, including supply chain emissions. It was applied to the Glasgow 2014 Commonwealth Games Athletes' Village remediation project, for which a calculated total 'carbon footprint' of 2328 t of carbon dioxide equivalent emission (tCO_2e) was obtained. This is 71 tCO_2e/ha of the site or 13·3 $kgCO_2e$/t whole life of soil treated. These figures are not comparable with those reported for other projects, which have typically not included supply chain emissions. Fuel use was the main contributor to emissions, but the contribution made by staff transport and carbon dioxide embodied in construction plant was also found to be significant. A comparison was made with an excavate and disposal (E&D) approach, which required considerable use of estimation for the hypothetical E&D. However, it was determined that the carbon footprint of E&D may have been 14% higher than the soil washing actually used. It was concluded that fuel efficiency would be key to future reduction of the carbon footprint of remediation projects, that the accounting tool would be useful for ongoing project management, and its application over time could lead to a database of values for optioneering at the process design stage.

1. Introduction

Remediation of contaminated soil ostensibly creates an improved environment, yet at the same time produces carbon dioxide emissions from commissioning, operation and decommissioning of the remediation processes themselves. With increasing environmental awareness, clients, designers and contractors are expected to demonstrate environmentally sound practices. It is thus now common practice to calculate the 'carbon footprint' of engineering projects through the use of specially designed carbon dioxide calculators or by using simple estimates. However, there is little guidance available for carbon dioxide accounting in the remediation industry, and supply chain factors are typically not accounted for.

This paper explores carbon dioxide accounting for soil remediation. An accounting tool has been created to carry out the study, and has been applied to the 2014 Glasgow Commonwealth Games Athletes' Village (CGV) remediation project designed by Grontmij and carried out by VHE on behalf of Glasgow City Council. The remediation project started in September 2009 and was completed in 2010.

2. Review of previous work

2.1 Carbon dioxide accounting methodologies for remediation

A number of standards govern carbon dioxide accounting, including ISO 14064 (BSI, 2006) and PAS 2050:2008 (BSI, 2008). Most standards are somewhat high level in their guidance, but PAS 2050 is more specific. According to PAS 2050, all significant contributions to greenhouse gas (GHG) emissions should be included, but the standard also notes that data availability often means supply chain emissions, for example emissions from manufacture of plant and a corresponding proportion of those from the building of the factory that made the plant, cannot be included.

Harbottle *et al.* (2008) conducted an overview of the sustainability of remediation projects. They noted that many of the published case studies in this area are employed on a single site to be remediated in order to select the most sustainable remediation technique for that site. They went on to consider a life cycle analysis (LCA) for remediation projects, but their approach, although comprehensive, does not include enough detail on the methodology to be able to use this for carbon dioxide accounting.

A recent literature review by Lemming *et al.* (2009) shows that most studies relevant to soil remediation have their focus on core components of the remediation project, and generally exclude emissions from landfill for various reasons, in contrast with Harbottle *et al.* (2008), who did include this in their LCA approach. The core contributors to carbon dioxide emissions, transport of equipment, materials and soil, as well as plant use and electricity, were found to be commonly included, but often not as carbon dioxide emissions, but rather as energy (Beinat *et al.*, 1998; Volkwein, 2002). Only a single study (Cadotte *et al.*, 2007) included sample transport for monitoring, but this still excluded the testing itself due to its limited impact. Lemming *et al.* (2009) noted that on-site consumption of diesel and electricity is generally found to be among the most important causes of environmental impacts. As remediation does not create anything, the consumption of materials such as plastics and steel generally contributed little, although the production of activated carbon dioxide for water treatment was found to be a major contributor to the environmental burden.

The potential carbon dioxide issues in recycling of material such as crushed concrete have not generally been considered. An interesting recent development, however, is that crushed concrete can under certain circumstances become a net absorber of carbon dioxide, thereby reducing carbon dioxide emissions from a project (Renforth *et al.*, 2009).

The effect of boundary conditions was studied by Matthews *et al.* (2008) who found that accounting for only direct emissions and energy use leads to relatively small footprints when compared to the life cycle carbon footprint.

In summary, while there have been a wide range of studies, with no entirely consistent approach, the exhaustive consideration of supply chain emissions to gain a fully inclusive value of the carbon footprint has not been common.

2.2 Carbon dioxide accounting data and tools

Data availability for carbon dioxide accounting is highly variable, and there is a clear need for standardisation and collaboration. A study at Bath University (Hammond and Jones, 2008) compiled a database of emission factors for carbon dioxide only, for materials used in the UK (known as the Bath ICE), while Defra/DECC (2009a) produced detailed guidelines and direct emission factors for fuels and transportation. Materials institutions (such as the International Iron and Steel Institution) commonly produce annual carbon dioxide emission statistics (based on the latest composition of materials) of relevance to their own areas of interest.

Regarding accounting tools, UK Water Industry Research has produced guidelines for carbon dioxide accounting in the water industry, together with a carbon dioxide calculator which is in use by many of the UK water companies (Ainger, *et al.*, 2008). These guidelines outline a number of important principles for the production of a carbon dioxide accounting tool. Both operational and embodied (through construction processes) carbon dioxide are calculated, and raw material processing, product manufacture, transport of materials and staff to site and site services are all considered in detail. However, the tool only considers carbon dioxide, and does not take account of supply chain emissions such as plant manufacture.

Although there is a vast amount of research and legislation surrounding environmental sustainability, there are only a few calculation tools specific to the remediation industry. These are

- the Environment Agency carbon dioxide calculator (EACC) (Environment Agency, 2008)
- the US Air Force Center for Engineering and the Environment sustainable remediation tool (USAFCEE SRT) (US AFCEE, 2009)
- the Atkins Ltd remediation options carbon dioxide calculator (ROCC) (Bollan, 2008).

The EACC calculates emissions for materials (embodied carbon dioxide and emissions arising from haulage), waste disposal (transport only, no further treatment), plant (direct emissions only), site accommodation (generation of energy) and personnel travel. There is limited flexibility for calculating emissions from plant movement. It is possible to calculate direct carbon dioxide emissions from fuel use, but there is no breakdown depending on plant type and activity, and carbon dioxide embodied in the fuel (upstream emissions including crude oil extraction, transport and processing) is not considered. The tool also does not specifically account for temporary works or other activities such as dewatering. The calculator only considers carbon dioxide emissions, and not any of the other five GHGs mentioned in the Kyoto Protocol (United Nations, 1998).

The USAFCEE SRT is designed to calculate sustainability metrics for remediation projects. This involves calculating not only a carbon footprint but also cost, health and safety, and natural resource use indicators, making it more detailed than a carbon dioxide audit. The tool uses some out-of-date data sources, and concentrates only on the technologies used; there is no component for effects of setting up site and transportation of plant to site. GHG emissions are based only on fuel use and direct emissions from the remediation processes, and do not include those embodied in construction plant or other temporarily used items. Again, carbon dioxide is the only GHG considered.

ROCC is Atkins' remediation options carbon dioxide calculator, intended for options appraisal through assessing the carbon dioxide difference among a range of remediation options for the same project. It is clear that the tool is intended to accurately describe direct carbon dioxide emissions associated with the treatment phase of a number of technologies, and it does not include ancillary activities or carbon dioxide embodied in fuel and plant. Although perhaps suitable for decision making, the lack of flexibility and transparency limits the tool's use for detailed carbon dioxide accounting.

Although there are many recurring themes in all these tools and guidelines, it is obvious that there is no consistent reporting layout. An important observation of the latest tools is that they usually only account for carbon dioxide emissions in core processes, ignoring ancillary activities such as enabling works and supply chain emissions.

3. Aims and objectives

This study aimed to extend previous work, producing a whole-life carbon dioxide account including supply chain emissions. This will allow judgements to be made as to the true carbon footprint of a remediation process, as well as the usefulness of the approach in a practical context. The specific objectives were

- to create a data collection and analysis tool for carrying out a whole-life carbon dioxide analysis of remediation projects
- to apply the tool to a study of the CGV remediation project and evaluate its performance
- to draw conclusions regarding the usefulness and feasibility of carbon dioxide accounting in the remediation industry.

3.1 The CGV remediation project

Consultant Grontmij and contractor VHE have applied a range of remediation techniques to remove a number of pollutants from the CGV site in Dalmarnock, Glasgow. The majority of the remediation work involved soil washing, although soils containing asbestos were transported directly to landfill, and some lime stabilisation and bioremediation is also in use. On the face of it, these techniques offer a more sustainable approach to traditional excavate and dispose (E&D) methods, helping to achieve Glasgow City Council's vision of a low carbon dioxide, sustainable games.

The project site occupied approximately 33 ha, and during the works 175 000 m^3 (approximately 325 000 t) of material were handled for recovery, treatment or disposal as required, of which 116 000 m^3 (approximately 215 000 t) of soil was treated, primarily by soil washing.

The principle of soil washing is based on a combination of grain size and density separation by means of screens, flocculation, hydro-cyclones and counter-current washing. The objective is to separate out gravel and sand from the fines (typical silt and clay) to which the bulk of the contaminants are sorbed. The soil washing plant can, by physical means, wash sands and gravel, but the remaining fines are often not treatable by washing and the residual contamination is therefore concentrated into this fine material. Only limited contaminated material unsuitable for soil washing (ie clay soils), along with the contaminated fine fraction produced from the soil washing operation, requires disposal off site. Consequently, soil washing significantly reduces the contaminant mass, so that maximum site material is recovered suitable for re-use with minimum unsuitable (contaminated) material disposed of off-site, and no requirement for importing replacements; this allows for sustainable cost-benefits to be reached. Wastes from the wash process are the fines (where the residual contaminants are concentrated). This undergoes minor treatment in the form of physical stabilisation (through lime addition) prior to landfill disposal.

3.2 The soil remediation carbon dioxide auditing tool

A carbon dioxide auditing tool for soil remediation was created using a system of spreadsheets. Carbon dioxide auditing is comparable to financial auditing, except that GHGs are counted, rather than money. The spreadsheet tool created thus has much in common with a bill of quantities, but was refined to facilitate ease of input and interpretation of the relevant data.

Two data input approaches were created: an activity breakdown, which groups activities for each project phase (Table 1), and log sheets in the spreadsheet, grouping similar items for all phases (Table 2). The latter reflected data availability for a project in progress. The CGV audit used primarily the log sheets and only a few sections of the activity sheets to examine some of the more significant or special contributors such as fuel used by soil washer. Using this format, the carbon footprint of the entire project could be comprehensively estimated. Care was taken to avoid double counting of activities where they were already covered by the log sheets.

Sheet name	Meaning
EL	Exploratory locations
PI	Preliminary investigation
SI	Site investigation
SP	Site preparation (enabling works)
SW	Soil washing
ED	Excavate and dispose
PT	Pump and treat
MNA	Monitored natural attenuation
Bio	Bioremediation
SS	Solidification/stabilisation
TD	Thermal desorption
SD	Site decommissioning
SA	Site activities (e.g. services, energy generation)

Table 1. Activity sheets

The following items were included in the carbon footprint analysis, which covered the site investigation, enabling works, the remediation process and site decommissioning

- staff transport (direct emissions and embodied carbon dioxide in fuel)
- plant used for all stages of project
  - plant delivery (direct emissions and embodied carbon dioxide in fuel)
  - carbon dioxide embodied in plant (embodied in materials and emissions during production)
  - fuel used by plant on site, broken down into fuel used by the washing plant, the on-site generator for the site compound, the plant used to feed the soil washer and other plant use (direct emissions and embodied carbon dioxide in fuel)
- materials used during project, including lime for soil stabilisation and coagulants

  - material delivery (direct emissions and embodied carbon dioxide in fuel)
  - carbon dioxide embodied in materials
- other items
  - fuel used during transport of soil samples (direct emissions and embodied carbon dioxide in fuel)
  - site compound (carbon dioxide embodied in units and direct emissions and embodied carbon dioxide in fuel used for transport)
  - waste disposal (direct emissions and embodied carbon dioxide in fuel used for transport)

3.3 Emission factors

Carbon footprint is calculated in the spreadsheet by totalling an item, for example fuel used, and multiplying it by an emission factor for that item. Emission factors are included in an additional spreadsheet within the tool. In view of the aim to carry out whole-life carbon dioxide analysis, emission factors were selected to include supply chain emissions as well as those directly embodied in or produced by project components.

In most cases, the Bath ICE was found to be the best source for emission factors. The major exception to this was for carbon dioxide embodied in fuels, where a figure was derived from a well-to-wheels analysis used by the UK Petroleum Industry

Worksheet	Items covered
Staff transport	Embodied and direct emissions from fuel used for staff transport to and from site.
Plant transport and embodied carbon dioxide	Embodied and direct emissions from fuel used for plant and equipment transport to site; carbon dioxide embodied in plant and equipment.
Material delivery and embodied carbon dioxide	Embodied and direct emissions from fuel used for material transport to and from site; carbon dioxide embodied in materials.
Exploratory locations	Fuel used during site investigation (materials and transport are covered in material and plant transport respectively).
Testing	Embodied and direct emissions from fuel used for sample transport to and from site; embodied and direct emissions from the testing process.
Fuel deliveries and direct and embodied carbon dioxide	Embodied and direct emissions from fuel used for fuel transport to site; embodied and direct emissions from fuel (for total figure for fuel used on site).

Table 2. Log sheets

Category	Item	Source(s)
Staff transport	Journey details	Personal account, contractor daily diary, site log book, project estimate (or expenses claims, fuel/VAT receipts).
Any transport	Journey distances	Google maps/other route planning applications.
Plant/materials	Journey details	Delivery notes/invoices, personal account, contractor daily diary, site log book.
Plant	Material volumes	Manufacturers' specification, plant manual.
Plant	Plant cost	Trade websites, contractor.
Plant use	Total hours used	Project estimate, indirectly by gauging fuel used, personal account, contractor
Materials	Material quantities	Delivery notes/invoices, personal account, contractor daily diary, site log book, project estimates.
Supply chain emissions	Emissions and percentage which can be attributed to the project	Industry averages, contact with supply chain.

Table 3. Data sources for calculation input

Association (Edwards *et al.*, 2006). A revised figure is now included in the latest Defra/DECC guidelines for company reporting, which is based on a more recent well-to-wheels analysis.

No previous example was found for calculating carbon dioxide embodied in construction plant, so one was created using Defra/DECC supply chain emissions (Defra/DECC, 2009b). These emission factors are based on an input–output model of the economy to describe the various monetary exchanges which take place in the production of a product, which include raw material extraction, processing, manufacturing, transportation and so on. These monetary exchanges are then converted to emissions based on the emissions for that industry sector. The category chosen for plant manufacture was 'machinery and equipment'. Although figures generated using this factor should be treated as estimates, they should give a good indication as to the relative importance of carbon dioxide embodied in plant.

The project specific data input for the calculations were collated from a range of sources, as shown in Table 3. Once all necessary data were collected, the final calculation was fairly simple using the spreadsheet tool, as outlined in Table 4.

The distinction should be made as to what is and what is not attributable to a project and who is responsible for these emissions. The aim of this project was to extend the boundary conditions of the study as much as possible, so as to present a clearer picture of the actual carbon dioxide impact the project has by combining all possible attributable emissions. If the project takes full responsibility for these emissions, the supply chain will consist of 'zero emission' companies, so some discussion is required as to who is responsible for the emissions.

4. Results

The results from the application of the carbon dioxide audit tool to the CGV remediation project are shown in Figure 1 and Table 5. These figures include estimates for the carbon dioxide in the whole supply chain – for example, the carbon dioxide emitted in making the steel to construct the plant which operated on site, and in turn a proportion of the carbon dioxide emitted in making the plant that made that steel.

The total emissions for the project were determined to be 2328 t of carbon dioxide equivalent emissions (tCO_2e). This is 71 tCO_2e/ha of the site or 13·3 $kgCO_2e$/t of soil treated.

It should be stressed that the figure is not one that can readily be used for comparison with other projects. For example, current auditing practice would not typically have included carbon dioxide embodied in fuel, or accounted for supply chain emissions. Omitting this would have reduced our calculated total carbon footprint by 24%, to 1779 tCO_2e. If, like other audits, only the core remediation processes had been considered, the total would be reduced by a further 9% to 1612 tCO_2e.

As the figure is not appropriate for inter-project comparison, we believe the main interest is the proportional contribution of

Component	Method
Staff/plant/material transport	Fuel use (estimated using distances and Defra efficiencies) multiplied by direct and embodied emissions.
Carbon dioxide embodied in plant	Carbon dioxide embodied in materials used is based on embodied emission factors for the dominant materials. Masses can be obtained from manufacturers. Supply chain emissions resulting from the production of the plant were obtained by multiplying the plant/item cost when new by a supply chain emission factor. A factor was applied to the total to account for the percentage of the plant service life used.
Emissions from plant use	1. By recording the total amount of fuel delivered to site and multiplying by direct and embodied emission factors. 2. By recording which plant is on site each day (or by using the hire quote) and applying a fuel use (l/h) and utilisation (h/day) rate. This should be a relatively accurate approach, especially if calibrated using total fuel deliveries. This was used for the CGV audit. 3. By gauging fuel used by each item of plant, and for what activities it has been used.
Carbon dioxide embodied in material	Mass of material multiplied by relevant emission factor.
Exploratory locations (e.g. trial pits)	This section is included to show a breakdown of this particular item. It is not a necessary step, as any materials used can be incorporated into the materials sheet, and plant use is also covered by the plant use sheets.
Testing	Sample transport (covered in material transport section) added to the emissions arising from the test centre. This figure can be requested directly from the testing company, and factored for the number of tests completed.
Total fuel use	For calculating the total emissions arising from fuel used (as well as from the transport of fuel to site) for option 1 in plant emissions. This can also be included in the materials sheet, but was included separately for clarity.
Other components	Other contributors, such as grid electricity, may be included on materials sheet, despite having no transport component.

Table 4. Methods used for calculating the carbon footprint of the project

the different project aspects. As expected, fuel was the most significant factor, and embodied carbon dioxide/supply chain emissions were also shown to be important.

5. Discussion

5.1 Quality of results

Emission factor data availability was found to be highly variable. A key issue is that many carbon dioxide factors did not include non-carbon-dioxide GHG emissions. This results in an invalid comparison between the different components of the audit. In our case, the contribution was relatively low. For example, non-carbon-dioxide emissions accounted for just 1·1% of the diesel direct emission factor. However, certain industries primarily emit non-carbon-dioxide gases, for example petrochemical processes and coal mining emit mainly methane (Defra/DECC, 2009b).

The process data (such as plant delivery details, fuel use rates and material properties) input into the tool was often of relatively low quality, as a number of estimates had to be made. This was a result of the availability of information (the level of detail required made some information hard to come by) and the fact that the project was still in progress when the audit was carried out. This meant that activities not yet completed had to rely on project estimates. This could, of

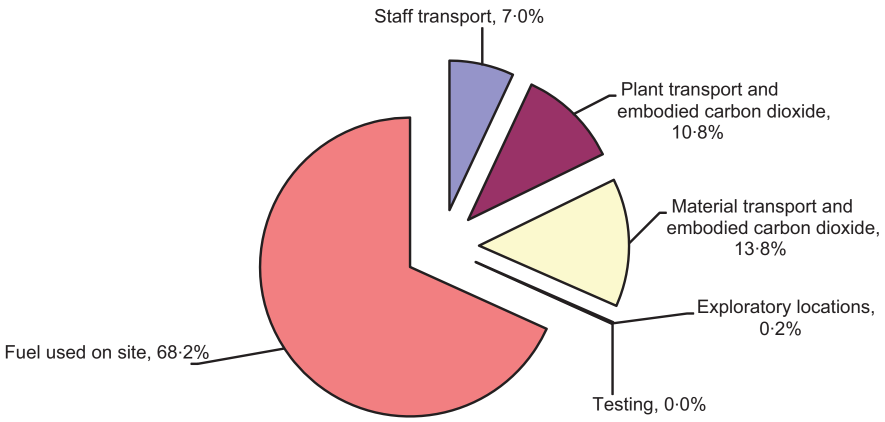

Figure 1. Breakdown of CGV remediation project carbon dioxide emissions

course, be remedied by using updated logs after the project was complete.

Using a 'whole life' approach to carbon dioxide accounting relies on having adequate information about the supply chain. However, unless and until all suppliers (and the suppliers' suppliers) have audited their own activities and can pass on their emissions data, simplifications need to be made. The only suitable method to account for most of the supply chain emissions in our audit found was to use Defra's supply chain emission factors (Defra/DECC, 2009b). A key limitation of these is that they do not include a consideration for capital goods, such as machinery and buildings.

Component	$kgCO_2e$	% of total
Staff transport	162 120	7·0%
Plant total	251 499	10·8%
Plant transport	*33 341*	*1·4%*
Plant embodied	*218 158*	*9·4%*
Material total	321 184	13·8%
Material transport	*88 382*	*3·8%*
Material embodied	*232 802*	*10·0%*
Exploratory locations	4 394	0·2%
Testing	237	0·0%
Fuel use total	1 588 307	68·23%
Fuel delivery	*3401*	*0·1%*
Plant use (soil washing)	*1 027 850*	*44·2%*
Soil washing	*131 862*	*5·7%*
Compound energy	*425 193*	*18·3%*
Total	2 328 171	100%

(items in *italics* denote subcomponents)

Table 5. Project emissions summary and sensitivity analysis

A comparison was made with an alternative estimate for carbon dioxide embodied in the construction plant, using the carbon dioxide embodied only in the materials used (i.e. no processing and manufacture). This was found to total around 42 tCO_2e (cf. 218 tCO_2e supply chain emissions based on Defra emission factors); it is clear that there is a significant contribution of emissions relating to the manufacturing of the construction plant in addition to the carbon dioxide embodied in the materials used.

There remained considerable uncertainty in the final figures. For fuel, this was a result of having to estimate fuel usage. For the carbon dioxide embodied in plant, this was a result of uncertainty in virtually all data entered into the tool; including constituent materials, plant life and plant cost. Furthermore, no previous evidence was found of the use of Defra's supply chain emission factors for calculating carbon dioxide embodied in construction plant, so significant uncertainty will remain in these estimates. Nevertheless, the magnitude of the final figures in these categories will give a good indication as to whether the inclusion of these terms is important.

5.2 What could be done to change the carbon footprint of the CGV remediation project?

After analysing the results, the carbon dioxide accounting tool was used to test different scenarios to determine possible strategies that might reduce (or increase) the carbon footprint of the soil washing process.

Specialized subcontractors were widely used, and many of these employed staff that travelled a considerable distance to the site. Recalculating assuming all staff came from within a 150 km radius meant that staff transport dropped from 7% to 2·7% of the total project emissions.

Within plant transport, the transport of the wash plant alone accounted for 76% of plant transport (33·3 t). Calculation showed that, if this machinery could have been sourced from within a 200 km radius, the total project emissions would be reduced by 0·9%.

Although the estimates are not directly comparable, comparing the carbon dioxide embodied in construction plant materials with supply chain emissions (which includes materials) indicates that materials account for around 24% of carbon dioxide embodied in plant, the remaining 76% being a result of plant manufacture and related processes. The supply chain emission factors used, from Defra, were of a very general nature, based on plant item cost. For our study, this was estimated using trade websites and adding a margin to arrive at an item cost when new. Approximate costs of soil washing plant components were obtained from the plant hire company. A further calculation was carried out in which these costs were arbitrarily decreased by 80% to see if extreme changes in costs had much effect. This reduction led to embodied carbon dioxide being reduced to 43·6 tCO_2e/ha: of a similar order to materials only. Despite this, the carbon dioxide embodied in plant was still significant (2% of project emissions).

Plant design life is extremely variable. By reducing the design life of all plant by 50% to cover a 'worst case scenario', the total embodied emissions increased from 9·4% to 16·8% of the project total, increasing the project total emissions by 8·8%. This is a large increase, and could be a major source of emissions.

In practice, many of these factors are imponderable, and are certainly beyond the control of the client, designers or contractors. The benefit in analysis will probably only accrue when a standard approach, allowing inter-comparison among projects, is adopted. However, the carbon dioxide accounting tool provided a useful framework for testing different scenarios and possibly managing them to advantage. It also highlights that some components of the carbon footprint which are often not included can have a significant effect on the overall carbon footprint.

5.3 Responsibility for supply chain emissions

The whole life approach taken in our study clearly suggests that the client, designers and contractors of the remediation process take some responsibility for supply chain as well as direct emissions. In some sense, a project is responsible for supply chain emissions, as they would not have occurred without the project, but the control of the emissions lies with the supplier and the corollary of including them in the project carbon dioxide audit is that the supply chain then appears to have zero emissions – which is, of course, untrue. Project actors can take some actions, such as switching suppliers, to minimise these emissions, but a true picture clearly requires a joined-up approach across the whole supply chain so that emissions are both completely accounted and apportioned to their true owners.

5.4 What was the effect of choice of calculation method?

The results of the carbon dioxide accounting tool clearly depended on the choice of emission factors for various project components, and in most cases there was no clear way of selecting the best alternative.

This is most notable for carbon dioxide embodied in plant; our initial estimate, based on supply chain emissions, was more than five times the carbon dioxide embodied in the materials only. Clearly there will be emissions relating to plant manufacture, but no research was found to indicate what factor might be applied to carbon dioxide embodied in materials. The category used, 'machinery and equipment', may have been too broad for use in estimating these emissions.

Site compound energy generation was a major component of the project emissions. Our study, using contractor's estimates for compound fuel use, indicated the total emissions to be 354·6 t. Using the Environment Agency's calculator, a value of 564·9 t was obtained, and this was not intended to include embodied carbon dioxide. Use of this figure would have increased the total project emissions by 9%. The discrepancy could have arisen for a number of reasons such as the scale of the site; for smaller sites the compound contribution is likely to be relatively higher owing to the need for a minimum level of site accommodation.

It is clear that, until a standard methodology is agreed, results will be highly variable and probably not appropriate for comparison with other projects.

5.5 Was soil washing the best choice for carbon footprint?

This is a question that cannot really be answered from our study. Analysis of the soil washing project was only possible in such detail because access to data was available as the project was in progress. While one of the possible benefits of carbon dioxide accounting is for process choice, it was clearly not possible to do comparative analyses of alternative remediation strategies for the CGV on a like-for-like basis, as the alternative strategies were obviously not being carried out on the CGV site, and thus no definitive data existed for them in the way that it did for soil washing.

However, a partial recalculation was done to consider the simplest of remediation approaches, E&D, being used on the CGV remediation project. As E&D mostly consists of transportation, its emissions were completely controlled by fuel, and hence were susceptible to changes in fuel factors of the type discussed previously. The E&D emission recalculation showed that 93% of the carbon footprint of the entire project would be due to fuel, up from 81% for soil washing.

The E&D recalculation contained some broad estimates, mainly relating to the quarrying of new material. This means the overall figure will not be directly comparable to the more detailed soil washing study although the relative contribution of each component remains applicable. Staff transport contributes only 1·2% to the E&D project total emissions, compared with 7·0% for soil washing. This is due to the fact that fewer specialists are required for E&D and more local staff can thus be employed. The 'material transport' category, which contains a much larger volume of disposed soil, as well as imported replacement material, contributes 21·4% to the project total emissions for E&D, compared with just 3·8% for soil washing.

Overall, the total project emissions for the E&D case have increased by 14% when compared with the soil washing scenario. It is perhaps a surprisingly small increase, but it is clear that, as well as being more sustainable from a carbon footprinting point of view, soil washing will outperform E&D for a range of other sustainability metrics.

In this comparison, it is assumed that the choice of remediation strategy makes no difference to the subsequent construction and use of the facilities built on the soil, as the post-remediation contaminant levels would be sufficiently reduced in both cases, and the engineering properties of the resulting soil would be suitable for the proposed development.

Various estimates were made for further technologies, including monitored natural attenuation (MNA) and permeable reactive barriers (PRB) for contaminated groundwater treatment. Again, owing to the lack of hard data for hypothetical cases, no meaningful emissions figures could be determined, but Table 6 summarises the qualitative findings of this analysis on the relative importance of various project emission categories.

5.6 What use is the carbon dioxide accounting tool created for this study?

The auditing tool presented here could potentially be applied to three different scenarios.

Factor	Effect of different technologies
Staff transport	No clear relationship – using a more specialised technology often means staff travel from further afield.
Plant transport	Using mobile, specialised plant (e.g. soil washer) increases transport. Using common earthmoving plant reduces this effect, as the plant can often be sourced more locally.
Carbon dioxide embodied in plant	Using very large plant (e.g. soil washer, desorber) results in high embodied carbon dioxide. MNA and PRB use less plant, so will be less affected.
Material transport	Off-site technologies will entail much higher carbon dioxide emissions from material transport. For on-site technologies, material transport is significant when chemicals, concrete or lime (for example) are used.
Carbon dioxide embodied in materials	Only significant where large quantities of materials such as chemicals, concrete, or lime are used (relative to project size).
Fuel used by plant and technology	Generally controls the carbon footprint of remediation, and is most significant where large volumes of earth are excavated, for technologies such as E&D, soil washing and thermal desorption.
Compound energy	Some technologies require little or no permanent presence on site (MNA, PRB). Others using staff from further afield on specialised projects require a larger compound with accommodation.

Table 6. Effect of technology choice on carbon footprint components

1. Pre-project: carbon dioxide constants developed from applying the tool to a series of remediation projects could be used to predict emissions to allow 'optioneering' for new projects.
2. During project: as carried out for the CGV, project-specific data can be collected during the works and potentially used to indicate processes and targets for emission reduction.
3. Post-project: the tool would allow a full carbon dioxide audit for fiscal or regulatory purposes and feeding into future emission management and project emission estimating.

Item 1 depends on a commitment to apply the tool and manage data over a longer timescale so as to develop future capability; 2 requires some resource to collect the data but would potentially feed into a management and indeed a service marketing strategy; the value of 3 will depend mainly on the future direction of regulatory and fiscal measures in respect of carbon footprint.

6. Conclusions

A new spreadsheet-based tool was created to allow the calculation of carbon footprint in soil remediation. This was applied to the Glasgow 2014 Commonwealth Games Athletes' Village remediation project.

The whole-life carbon footprint of the CGV remediation project was found to be 2328 tCO_2e. This is 71 tCO_2e/ha of the site or 13·3 $kgCO_2e/t$ of soil treated. These figures are not comparable with those reported for other projects, which have typically not included supply chain emissions.

Different calculation methods, for example use of different published emission factors, were found to make significant difference to the total footprint. The biggest issue, however, was the inclusion of supply chain emissions, which arguably should not accrue solely to the project but should be owned by the suppliers of plant and so on.

Various scenarios were tested to see whether the carbon footprint could have been improved; more local sourcing of plant and staff (if possible), use of recycled materials in plant manufacture and increasing the design life of plant would all have made some difference, but these are beyond the control of the project team. If anything can be done to improve fuel efficiency of transport or earthworks plant, then this can have a significant impact on the carbon footprint. It is clear that efficient management of on- and off-site transport is key to a sustainable solution, and that future fuel saving technology will be vital to this sort of project.

A comparison was made with an excavate and disposal (E&D) solution. This required a considerable amount of estimation for the hypothetical E&D project, but it was calculated that the whole-life carbon footprint for E&D may have been 14% higher than for the soil washing actually used. It was therefore concluded that, as well as in general terms being more sustainable, soil washing had a lower overall carbon footprint than the traditional E&D approach for the CGV remediation project.

The carbon dioxide accounting tool will be most useful for management of on-going projects, allowing significant reductions in carbon footprint to be identified. However, if used on a number of projects, the resulting data would also form a useful basis for optioneering in future situations.

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