TOPIC GUIDE:
Carbon Management of Infrastructure Services

Paul Jowitt and Adrian Johnson

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EVIDENCE ON DEMAND
CLIMATE & ENVIRONMENT
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About Topic Guides

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- Provide links to current best 'reads' in an annotated reading list
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About the Topic Guide: Carbon Management

The purpose of this Topic Guide is to contribute to the professional competence of DFID's Infrastructure Cadre. The guide assembles evidence on reducing the emissions of greenhouse gases (or 'carbon emissions') arising from infrastructure services. This evidence will increase readers' awareness of the issues relating to carbon management. The guide also familiarises readers with carbon accounting methodologies.[1]

Climate change science and policy provide the context and basis for this Topic Guide. Since the guide is concerned with practical approaches for mitigating carbon emissions from infrastructure services, the underlying rationale for reducing carbon emissions provided by the science and policy are not covered here. The UK government's continuing commitment to infrastructure carbon reduction is reflected in the publication of a dedicated Infrastructure Carbon Review by the Treasury in 2013. Although the review focuses on UK infrastructure, the principles contained therein are widely applicable.

The specific objectives of this Topic Guide on the carbon management of infrastructure services are to ensure that Infrastructure Advisers:

- Understand the principles of carbon content in infrastructure, and can distinguish between the carbon content of materials and the carbon content of processes;
- Understand the practical application of carbon analysis in the sector, with particular understanding of its application in 'special circumstances' such as working in fragile states;
- Understand where and how carbon analysis can be effectively integrated into DFID Business Cases and procurement processes and what the sustainability outcomes might be;
- Are able to provide operational advice on carbon content for a range of typical infrastructure sectors and processes, including providing comparison tables to illustrate practical choices.

Following consultation with DFID advisers, the guide focuses on sectors that are of core interest to DFID: water and sanitation, solid waste, energy, and surface transport. Other sectors such as ports, air transport and other infrastructure, where DFID is less active, could be included in the future using a similar methodology.

This Topic Guide:

- Provides an overview of the assessment and management of carbon emissions from infrastructure in developing countries;
- Sets infrastructure carbon management in context and provides commentary on relevant trends and significant impacts with respect to wider development of the urban environment;

[1] The use of the term 'carbon emissions' in this guide is shorthand for the carbon dioxide equivalent of relevant greenhouse gas emissions.

- Sets out a framework and technical guidance to assist the practitioner plan, direct and/or influence carbon management for infrastructure in less developed countries, drawing on international standards and best practice;

- Provides some specific guidance on assessing and managing carbon emissions in the energy, water, transport and waste sectors, as well as emissions, resulting from changes in land use or other emissions arising as a consequence of infrastructure services;

- Provides additional commentary on recommended reading material and references to support more detailed investigations and carbon-management activities.

Glossary of key words and phrases

Asset quantity is a quantity of asset construction or operation (such as tonnes of steel or kilowatt-hours of power), which when multiplied by a corresponding emission factor, gives the carbon emissions associated with that quantity.

CapCarb (or Capital Carbon) refers to greenhouse gas (or carbon) emissions associated with the construction of an asset. It is quantified in tonnes of carbon dioxide equivalent (tCO_2e). Commonly known as embodied carbon (as described in this Topic Guide) or embedded carbon, 'CapCarb' is now being adopted as preferred terminology within the infrastructure sector in the UK because it accords with the concept of capital cost. This terminology has been adopted in the recently published UK Government Infrastructure Carbon Review (HM Treasury, 2013). Although capital (embodied) emissions are covered by this Topic Guide, the term 'CapCarb' is not explicitly used.

Capital equipment, also known as capital goods, includes factories, buildings and machinery used to manufacture products, lorries used to transport materials and construction machinery used on site.

Carbon emissions (*or* 'carbon impacts' *or* just 'carbon') is common shorthand for emissions of the Kyoto Protocol 'six-pack' of greenhouse gases – Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF_6) – expressed as equivalent emissions of carbon dioxide (CO_2e) (see Table 12).

Carbon management is the process of developing and implementing solutions and technologies for reducing carbon emissions. It often includes carbon accounting and life cycle analysis. Carbon management generally refers to the measurement and reduction of emissions of the six greenhouse gases covered by the Kyoto Protocol (Carbon Trust, 2009).

Climate change mitigation involves taking action to reduce the probability and limit the extent of climate change (HM Treasury, 2013).

Cradle-to-gate is a term used in carbon accounting to describe the stages of production of a good or service from the extraction or acquisition of raw materials to the point at which the product leaves the organisation undertaking the carbon accounting (BSI, 2011b, p2).

Cradle-to-grave describes the life cycle stages from the extraction or acquisition of raw materials to the recycling and disposal of waste.

Commercial energy conventionally applies to coal, oil, gas, and electricity on the basis that they are widely traded in organised markets. They are distinguished from other fuels such as firewood, charcoal, and animal and crop wastes, which are described as biomass or non-commercial fuels. (The distinction between them can be misleading, particularly in the context of developing countries, as some non-commercial fuels are also widely traded (US Congress, Office of Technology Assessment, 1991).)

Direct emissions are those emissions arising directly from a company's activities, e.g. on-site fuel use.

Embodied carbon emissions are the direct and indirect emissions of greenhouse gases resulting from the extraction, transportation and processing of raw materials and from site construction activities required to create or maintain a built asset, or part thereof, expressed as equivalent emissions of carbon dioxide. (Note: this does not refer to any carbon that may be stored (sequestered) within the material.)

Embodied energy is the total energy that is sequestered from a stock within the earth's crust in order to produce, transport, maintain and dispose of the materials within a specified product or built asset, such as a building.

Emission factor is a factor of operational or embodied carbon emissions per unit asset quantity. An emission factor may be a composite of several sub-factors (e.g. an emission factor for a particular work item used in construction may be comprised of sub-factors for the materials, plant and temporary works needed to create one unit of that work item).

Global warming potential describes the radiative forcing impact of one unit of a given greenhouse gas relative to one unit of CO_2 (WRI & WBCSD, 2011).

Greenhouse gas or GHG is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range.

Indirect emissions are emissions, such as those resulting from the generation of grid electricity, which occur as a result of activities undertaken by others on an organisation's behalf, but which are nevertheless necessary for the successful running of the organisation.

Infrastructure within the context of this report refers to the physical structures required for the effective operation of a society, such as water and sanitation, transport, waste or energy infrastructure. The implementation of the physical infrastructure enables the delivery of **infrastructure services**.

OpCarb (or Operational Carbon) describes greenhouse gas (or carbon) emissions associated with the operation of an asset. It is quantified in tCO_2e/year. The term 'OpCarb' has been adopted in the recently published UK Government Infrastructure Carbon Review (HM Treasury, 2013). Although operational emissions are covered by this Topic Guide, the term 'OpCarb' has not explicitly been used.

Operational carbon emissions are direct and indirect emissions of greenhouse gases from an organisation's operational activities, expressed as equivalent emissions of carbon dioxide. In this guide, they are used to refer the emissions arising from the operation of infrastructure services.

Scope 1 emissions arise from activities owned or controlled by an organisation that release emissions straight into the atmosphere. They are direct emissions. Examples of scope 1 emissions include emissions from combustion in owned or controlled boilers, furnaces and vehicles; emissions from chemical production in owned or controlled process equipment (DEFRA & DECC, 2012, p10).

Scope 2 emissions are those released into the atmosphere associated with the consumption of purchased electricity, heat, steam and cooling. These are indirect emissions that are a consequence of an organisation's activities but which occur at sources it does not own or control (ibid, p10).

Scope 3 emissions are those that are a consequence of an organisation's actions, which occur at sources which it does not own or control and which are not classed as scope 2 emissions. Examples of scope 3 emissions are business travel by means not owned or controlled by an organisation, waste disposal, or purchased materials or fuels (ibid, p10).

UseCarb (or End User Carbon) is greenhouse gas (or carbon) emissions from the end users of infrastructure assets. Although not directly controlled by infrastructure asset owners, UseCarb can be influenced. It is quantified in tCO_2e/year. The term 'UseCarb' has been adopted in the recently published UK Government Infrastructure Carbon Review (HM Treasury, 2013). Although use emissions are covered by this Topic Guide, the term 'UseCarb' has not explicitly been used.

Whole life carbon is the cumulative total of carbon emissions arising from the construction, periodic maintenance/renewal, operation and use of an infrastructure asset over its lifetime.

SECTION 1

Overview

1.1 Developing country infrastructure and carbon emissions

Emerging and developing economies dedicate a large proportion of their national income just to meet human development needs for infrastructure. It is estimated that US$57 trillion will need to be invested between now and 2030 simply to provide and maintain the infrastructure to support global economic growth (MGI, 2013). While developed country infrastructure accounts for over 70% of past investment, there is a significant shift to developing economies; many lower income countries are expected to increase their investment in the coming years, particularly to support the growth of urban centres.

Clearly, such growth in infrastructure will lead to significant increases in the use of material and energy resources, which in turn will affect the emissions of greenhouse gases (GHGs).[2] Atkins et al (2013) identified 49 cities in less developed countries (LDCs) – mainly in South Africa, Nigeria, India, Pakistan, Thailand and Indonesia – which can already be categorised as ‘high carbon and high energy use’ cities. This was the result of their study looking at 130 medium-to-large cities in 20 countries across Sub-Saharan Africa and South Asia. As well as being at significant risk of becoming locked in to carbon-intensive development, a number of these cities have vulnerable populations with poor infrastructure services (in terms of electricity, water and sanitation, etc.). Given that the proportion of the world’s population living in cities is expected to increase from 50% to 75% by 2050, ‘high carbon and high energy use’ cities are set to become increasingly prevalent.

The demand for carbon-efficient development from developing countries is still low but addressing whole life carbon will also often address whole life costs and, in most cases, carbon efficiency will result in cost efficiency over the long term.

Climate change creates developmental opportunities in the infrastructure sector, including access to new sources of finance and the potential for creating green jobs. In short, there are synergies between climate change initiatives and developmental priorities. Overall, infrastructure policymakers and practitioners have a crucial role to play in meeting the challenge of climate change in the developing world (Ryan-Collins et al, 2011). It is therefore incumbent upon those engaged in advising, funding and implementing infrastructure development to adopt a robust carbon-management approach to ensure that such investment is as carbon efficient as possible.

While the overall carbon impact of economic development in LDCs is of primary importance, the scope of this guide is focused on the assessment and management of the carbon emissions that arise from the development, use and maintenance of engineering infrastructure (energy, water and sanitation, transport, ports and waste) which underpins this development. Nevertheless, it is important to understand the significance of infrastructure-related emissions in the context of wider development activities and specifically the

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2 GHGs are taken to refer to the Kyoto ‘six-pack’ of atmospheric gases that trap Earth’s radiant heat energy (listed in Appendix 1, alongside their global warming potentials (GWP)), as per the principles and guidance set out by the Intergovernmental Panel on Climate Change (as explained in Section 3.3).

significance of the carbon emissions of particular infrastructure projects relative to the wider emissions of the development that such infrastructure supports, including: primary, secondary and tertiary industries; residential, public and commercial building developments; agriculture and food production. Clearly, wherever DFID is funding and/or directing infrastructure to support such developments, it is important to understand the total carbon impacts.

1.2 Carbon management and its use in decision making

The science of carbon accounting has developed significantly in recent years. Although commonly used for reporting historical emissions, the real value to DFID in carrying out carbon accounting is its use in providing evidence for carbon reduction to support better decision making.

Carbon accounting of past infrastructure projects, together with action to reduce their carbon emissions, may be used in conjunction with conventional technical and economic appraisal to influence:

1. Policy decisions relating to proposed LDC infrastructure, its type and size (e.g. the optimal mix of fossil fuel energy and renewable energy for generating power, or whether to build a road or railway to meet needs for increased transportation capacity);

2. The carbon efficiency of LDC infrastructure solutions, i.e. to ensure they are designed to deliver their required outcomes for minimum carbon emissions over their life (e.g. the effective design of water infrastructure will help minimise future emissions from year-on-year operation).

The carbon-management framework in this guide (Section 3) has been developed to assist practitioners apply carbon accounting and develop approaches for carbon reduction to promote low-carbon infrastructure decision making and solutions.

An effective framework for carbon management will address the carbon emissions arising from engineered infrastructure. This will encompass everything from the decision-making process on the type and extent of infrastructure, to its design, construction, operation, use, maintenance decommissioning and disposal. In short, such a framework should promote the management of carbon emissions throughout the lifespan of constructed assets. This is the basis of a whole life approach to carbon appraisal. This approach is consistent with the UK Government's Infrastructure Carbon Review (HM Treasury, 2013), which sets out actions for infrastructure clients and the supply chain to realise the value of lower carbon solutions and embed carbon reduction as routine practice in infrastructure development.

The framework embodies a number of principles to help ensure that carbon accounting for infrastructure services is not only consistent with international standards but also ensures that decisions are made on a whole life basis. More specifically, this carbon Topic Guide draws on current best practice protocols such as the Greenhouse Gas Protocol (WRI & WBCSD, 2004), ISO 14064 (BSI, 2006a), PAS (Publicly Available Specification) 2050 (BSI, 2011a) and Jowitt et al (2012), as relevant to the development of engineering projects. These are further discussed in Sections 3.3.

Carbon emissions over the lifetime of infrastructure projects arise primarily from:

- Initial construction (including excavations and other enabling works) and/or asset upgrading/refurbishment;

- Operation, maintenance and rehabilitation;
- Changes in use of infrastructure as a result of the project;
- Decommissioning, dismantling and demolition.

The significance of emissions from initial construction relative to those from operational activities, maintenance and change in use depends on the type of infrastructure, materials/methods of construction, operational parameters and asset lifespan. The framework presented in this Topic Guide addresses each of the stages in whole life emissions and provides guidance on accounting for emissions arising from the use of materials, products, energy and transport through the different stages. Further guidance on opportunities for carbon reduction is then presented based on a hierarchy of avoid, reduce, replace and mitigate.

Ensuring development funding and assistance is channelled to encourage low-carbon growth is a significant challenge, but one which provides great opportunities for DFID and its partners. The following recommendations are presented to DFID as choices for the development of future policy to help improve its own practices and to increase its wider influence in this arena:

- Develop and apply formal protocols, on the basis of the principles set out in this guide, to influence DFID's criteria for funding, project selection, procurement and project-management processes.
- Understand and apply available international carbon finance mechanisms supported through the European budget and other sources to secure funding for low-carbon growth projects.
- Collaborate with other funding institutions to influence their policy, procedures and tools for carbon management.
- Carry out capacity building and training activities for DFID staff, national governments and partner organisations working on infrastructure projects.
- Champion the concepts of responsible sourcing and sustainability alongside carbon reduction by producing and communicating guidance on sustainable design, covering:
    - The use of materials with high BRE (Building Research Establishment) Green Guide ratings, particularly for imported materials and products.
    - The use of responsibly sourced timber for 100% of timber utilised in construction and hoarding and ensure that only appropriately certified timber is procured.
    - The use of responsibly sourced expertise and vendors (of construction products and equipment), with certification to ISO 14001 (or equivalent), widely regarded as the minimum acceptable standard of certification) or equivalent.
- Undertake further research to address knowledge gaps and build the evidence base on best practice. A particular need is to research, develop and apply carbon metrics for common types of engineering assets and projects using information from previous projects (by DFID or others) to facilitate rapid high-level carbon assessments of options included in Business Cases for future projects and programmes.

1.3 Carbon management in DFID planning and implementation

Assessing and managing carbon emissions are important in climate and environment assessments (CEAs), a mandatory component of the strategic and appraisal cases compiled for DFID business cases. As stated in DFID's *Writing a Business Case How to note*, all feasible options need to be assessed to establish potential impacts, risks and opportunities related to climate and the environment. More specifically, for all interventions, two objectives are to minimise and mitigate negative impacts and to maximise positive impacts on the environment or on climate change (DFID, 2012a). A climate and environment assurance note must be completed for preferred options where carbon emissions go beyond the minimum threshold set in the *Climate and Environment Appraisal How to note* (ibid, p14). Annex B of the *Climate Change and Environment Assessment How to note* (DFID, 2012b) lists three possible impacts of interventions on climate change: increases/reduces CO_2 emissions; increases/decreases mitigation capacity; does/does not support low-carbon development. This Topic Guide provides guidance for DFID advisers and other practitioners on how to assess and reduce such impacts.

1.4 Use of this Topic Guide

It is intended that this guidance will be used by DFID advisers and other actors involved in the scoping, funding, procurement and ongoing provision of infrastructure for developing countries, ranging from policy makers, advisers, funding agencies, consultants and designers through to contracting and operating organisations.

SECTION 2

Context, trends and impacts

2.1 Low-carbon infrastructure in developing countries

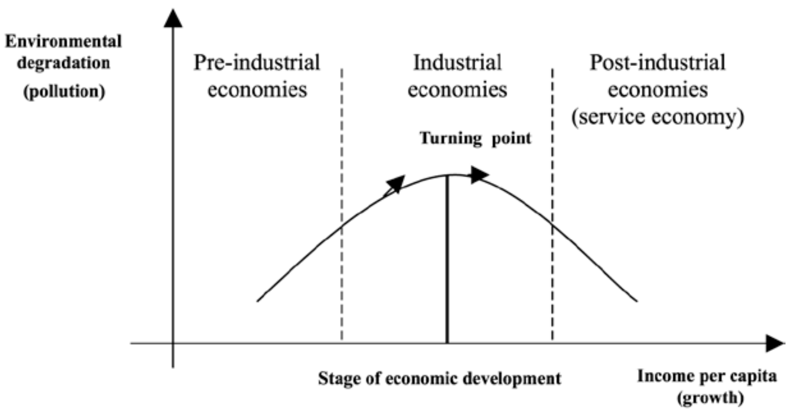
Emerging and developing economies dedicate a large proportion of their national income just to infrastructure to meet human development needs, such as water and sanitation, energy, roads and waste management. Populations, urban centres and economies in less developed countries (LDCs) are growing.

It is estimated that U$$57 trillion will need to be invested between now and 2030 simply to provide and maintain the infrastructure needed to support global economic growth (MGI, 2013). While developed country infrastructure accounts for over 70% of investment in infrastructure to date, there is a significant shift to developing economies. China has overtaken the US and the UK to become the largest investor in infrastructure. Many lower-income countries are expected to increase their investment in the coming years to support growth. By 2030 emerging economies are expected to account for 40-50% of global economic spending on infrastructure.

Clearly, such growth in infrastructure will lead to significant increases in the use of material and energy resources, which in turn will affect the emissions of GHGs as well as wider environmental impacts. For example, the growth in the provision of services for citizens of LDCs will involve significant increases in the demand for energy, which in turn will drive new energy generation infrastructure (typically using fossil fuel combustion technology) and investment in transmission infrastructure, as well as growth in the local combustion of fossil fuels for vehicle transport and for meeting domestic and industrial needs for power, heating and cooling. Therefore, it is likely that gross emissions will increase (Olivier et al, 2012).

History shows that, in general, environmental degradation, as a result of resource consumption and polluting activities, increases during the initial phases of development, reaches a peak and then decreases as economies mature and develop.

Figure 1 Environmental Kuznets Curve



(Source: *Panayotou, 1993*)

As Panayotou (2003) states, “the relationship between economic growth and environmental quality, whether positive or negative, is not fixed along a country’s development path; indeed it may change from positive to negative as a country reaches a level of income at which people demand and afford more efficient infrastructure and a cleaner environment”. The inverted-U relationship between environmental degradation and economic growth, known as the “Environmental Kuznets Curve”, is illustrated in Figure 1.

Climate change also creates development opportunities in the infrastructure sector, including access to new sources of finance, the potential for creating green jobs, and synergies between climate change initiatives and development priorities. Overall, infrastructure policy makers and practitioners have a crucial role to play in meeting the challenge of climate change in the developing world (Ryan-Collins et al, 2011). As the World Bank states, “[t]he development community is looking with increasing interest, particularly in the aftermath of the Rio+20 summit, at concepts such as ‘green growth’ and ‘low-carbon development’ and how these principles can be translated in[to] concrete policies and investments” (Cervigini et al, 2013). It is therefore incumbent upon those engaged in advising, funding and implementing infrastructure development to adopt a robust carbon-management approach to ensure that carbon efficiency is maximised.

More specifically, it is important that opportunities are sought to de-carbonise energy generation and seek lower carbon solutions in infrastructure. Overall, it is vital to ensure that the drive for more and better infrastructure avoids poor carbon performance through good governance of project scoping and delivery processes.

Global issues such as carbon reduction may not be a priority for many LDCs (Wilson et al, 2012, p12) but economic development can be achieved through low-carbon infrastructure with little or no detriment to economic objectives. Although demand for carbon-efficient development from developing countries is still low, addressing whole life carbon will also often address whole life costs and, in most cases, carbon efficiency will result in cost efficiency over the long term.

While carbon management is a critical aspect of new infrastructure, it needs to be considered together with other criteria important to sustainable infrastructure solutions, such as:

- Availability and allocation of funds;
- Resilience (including climate change adaptation);
- Resource scarcity;
- Community and wider socio-economic impacts;
- Biodiversity.

The challenge is well illustrated by a study of the situation in Nigeria (Box 1).

Box 1 Case Study – Low-carbon Growth: opportunities for Nigeria

Nigeria has experienced steady growth averaging more than 7% per annum in the last five years and aims to become one of the world's largest economies by 2020. The World Bank has worked with the Nigerian government and others to explore opportunities for low-carbon development in four key sectors. The study investigated how the country could work towards a more productive and climate-resilient agriculture sector, cheaper and more geographically balanced power generation, a more efficient oil and gas industry, and more efficient use of transport services.

The study identified a reference scenario, assuming no specific effort to reduce emissions, leading to a doubling of emissions by 2035. A group of 30 economically attractive technology and management options for the four sectors were then identified, which if implemented would stabilise emissions by that date.

The study argues that lower carbon growth offers not only the benefits of reducing contributions to climate change globally but also net economic benefits to Nigeria, estimated at about 2% of GDP. While possible and economically attractive, low-carbon development is by no means easy. A combination of better knowledge, expanded human capacity, policy reforms and suitable financing is needed to overcome the barriers.
(Source: *Cervigini et al, 2013*)

2.2 Emissions from engineering infrastructure in the context of wider emissions from development

The primary sources of the increased atmospheric concentration of carbon dioxide, methane and nitrous oxide since the pre-industrial period result from fossil fuel use (for the production of energy and industrial products) as well as agriculture and land use change (IPCC, 2007b).

The scope of this guide is the assessment and management of the carbon emissions that arise from the development, use and maintenance of infrastructure (energy, water and sanitation, transport, and solid waste). However, it is important to understand the significance of infrastructure emissions in the context of wider development activities. Specifically, it is important to understand the significance of the carbon emissions of particular infrastructure projects relative to the wider emissions of the development that such infrastructure supports. Thus, although not addressed in detail, the following wider development issues should be borne in mind when considering infrastructure carbon management.

Energy generation: As mentioned above, as countries develop, their domestic and non-domestic demand for energy (heat and power) increases, leading to the need for increased energy generation, the majority of which has traditionally been obtained from the combustion of fossil fuels. This increasing energy demand is the fundamental driver of increased carbon emissions across all sectors of infrastructure service delivery.

Primary and secondary industry: Increased economic development also leads to increased activity in primary extractive industries and the demand for manufactured products. More specifically:

- Within the factory gate – change in production rates and changes in technology application will affect direct emissions (combustion) and indirect emissions (grid energy use) used to process materials and manufacture products, as well as increase demand for water, chemicals and wastewater treatment services.

- Beyond the factory gate – increased production rates will lead to more coal/gas use and more/larger power stations, and increased transport miles to distribute manufactured goods resulting from the need for increased road construction or other transport modes.

The most significant opportunities for carbon efficiency in these industries are initiatives that improve the energy and resource efficiency of production processes together with local recovery of energy using technologies (such as combined heat and power plants), which have a lower carbon intensity than energy otherwise supplied from centralised sources.

Tertiary industry: Increases in commerce, communications and IT infrastructure also increase the use of energy and resources, which in turn lead to more carbon emissions.

Buildings – residential, public and commercial: The construction of homes, schools, hospitals and other public buildings will lead to carbon emissions and, once built, these structures consume energy 'in use' for thermal control (heating, cooling), power, cooking, etc. Significant advances have been made in developed countries to develop low-carbon building construction and operation; the challenge is to ensure this knowledge is transferred to developing country building developments. Ryan-Collins et al (2011) suggest that climate change mitigation funding may be "excessively skewed towards the energy sector at the cost of the buildings sector". Incorporating a requirement to adhere to a recognised international standard for carbon efficient building development – such as the BREEAM (International) Excellent Rating developed by the Building Research Establishment or LEED (Leadership in Energy & Environmental Design) designed by the US Green Building Council where appropriate – within DFID's Business Cases may help address this. In addition, both the RICS (Royal Institution of Chartered Surveyors) and the RIBA (Royal Institute of British Architects) have produced guidance to measure and reduce the carbon emitted during construction, occupation and end of the life of domestic and non-domestic buildings (RICS, 2012; RIBA, 2012). Of course, the applicability of such specifications and guidance would need to be supported by appropriate piloting to demonstrate and refine their applicability within the LDC context, together with the necessary staff training.

Agriculture and food production: Fundamentally, clearing land for agricultural production will reduce the land's capacity for carbon sequestration. Any movement away from unmanaged or semi-managed landscape, not just forested landscapes, to agricultural land use will see a reduction in carbon sequestration.

Land use change, such as agricultural intensification, has an impact on carbon emissions:

1. Inside the farm gate – increases in energy and water use arise from adoption of mechanised techniques for growing and harvesting crops; increases in the use of fertiliser and increases in livestock farming as people shift from vegetarian to meat diets.
2. Beyond the farm gate – increases in the volume of goods transported to market, as well as increases in food processing and storage, lead to increases in energy and water use and the need for more transport infrastructure.
3. Increasing amounts of food waste. Food waste includes food produced that does not get beyond the farm/market as well as food wasted by consumers. Food waste could potentially be used as fuel to generate energy locally.

Clearly, wherever DFID is funding and/or directing infrastructure to develop industry, housing, public services or agriculture, it is important to understand the total carbon impacts of the overall development process. There is little point in detailed assessments of carbon emissions related to construction of a new road or water treatment plant if the new housing or industrial developments they are intended to serve are profligate in their use of fossil fuel energy. Similarly, while the carbon emissions associated with the construction of a new highway between a port and a city may be significant, these need to be considered in the wider context of land use change and increases in energy-intensive activities at the port that will occur as a result of road development.

In short, the approach to planning and implementing infrastructure projects should be holistic and, wherever practical, seek to influence wider development activities to deliver the optimum overall carbon efficiency.

SECTION 3

Carbon-management Framework

3.1 Carbon management and its use in decision making

This framework for the carbon management of infrastructure services addresses the management of carbon emissions throughout the lifespan of constructed assets.

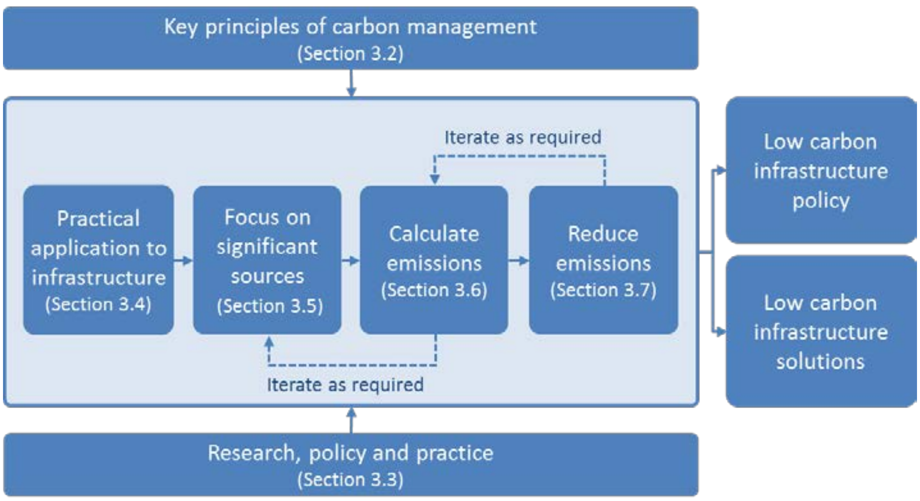
The science of measuring and reporting greenhouse gas (GHG) emissions (carbon accounting) has developed significantly in recent years. Although commonly used for reporting historical emissions, the real value to DFID's Infrastructure Cadre is its use in providing evidence for carbon reduction to support better decision making. Carbon accounting of infrastructure projects, together with action to reduce their carbon emissions, may be used in conjunction with conventional technical and economic appraisal to influence:

1. Policy decisions relating to proposed LDC infrastructure, its type and size (e.g. the optimal mix of fossil fuel to renewable energy generation, or whether to build a road or railway to meet needs for increased transportation capacity);

2. The carbon efficiency of LDC infrastructure solutions to ensure that they are designed to deliver their required outcomes for minimum carbon emissions over their life (e.g. the effective design of water infrastructure will help minimise future emissions from year-on-year operation).

The Topic Guide abides by the principle that 'you can't manage what you don't measure'. Effective carbon management depends on careful carbon accounting to provide the evidence to support action to reduce emissions from the most significant sources. Thus, after setting out some key principles of carbon management, this framework provides information to assist practitioners to first use carbon accounting and then develop approaches for carbon reduction to promote: i) low-carbon infrastructure decisions and ii) low-carbon infrastructure solutions (see Figure 2).

Figure 2 Summary of carbon-management framework for infrastructure



3.2 Key principles of carbon management

An effective framework for carbon management will address the carbon emissions arising from engineered infrastructure from decision making on what type and extent of infrastructure is needed through to its design, construction, operation, use, maintenance decommissioning and disposal.

In short, such a framework should promote the management of carbon emissions throughout the lifespan of constructed assets. This is the basis of a whole life approach to carbon appraisal. This is consistent with the UK Government's Infrastructure Carbon Review (HM Treasury, 2013), which sets out actions for infrastructure clients and the supply chain to realise the value of lower carbon solutions and embed carbon reduction as routine practice in infrastructure development. Besides the benefits to projects in hand, this approach also enables early-life assumptions to be validated post-implementation to inform future projects (Jowitt et al, 2012). Any changes occurring during the asset life – perhaps as a result of technological advancements and/or adaptation or modified use patterns – can be modelled to facilitate action to control and reduce emissions.

The purpose of the framework set out below is to inform infrastructure decisions by referring to the carbon impacts over the whole life of a project based on the data available during the decision-making period. This requires a transparent and consistent approach and must facilitate the ongoing whole life management of carbon emissions, with the adaptability to be applied across different infrastructure sectors – including energy, transport, solid waste, water and sanitation.

The framework is designed to be consistent with international standards and guidance on carbon accounting. The key principles (adapted from Jowitt et al, 2012) are to:

- Focus on the asset or assets to be provided, maintained or operated;
- Ensure assessment is independent of the procurement method and does not encourage 'game playing';
- Build on established approaches for assessing GHG emissions and life-cycle analysis;
- Be applicable to the various sectors of civil engineering infrastructure;
- Set boundaries that are consistent across projects of a similar type;
- Be equally applicable to the different stages of project development – feasibility, design, construction, operation, in use and decommissioning;
- Allow comparison of alternative options in terms of their whole life carbon emissions;
- Allow comparison pre- and post-implementation to take proper account of secondary effects upstream or downstream of the project;
- Recommend sources of emission factors and how to deal with changes over time;
- Cover the aspects which practitioners have the opportunity to manage or influence, and assign responsibility accordingly;
- Follow similar principles to financial accounting, i.e. account for everything that is included in the financial budget for the asset, but ensure account is taken of non-costed aspects that are nevertheless affected by the project (e.g. land use change);
- Encourage reporting of carbon intensity (i.e. tCO_2e emissions per unit of capacity or per user) to enable comparison between projects and to determine project performance;
- Inform the process of project appraisal as required for a DFID business case;
- Recognise and include informed estimates of uncertainty.

3.3 Research, policy and practice in carbon management

As discussed above, carbon accounting has developed significantly in recent years. Following the principles and guidance set out by the IPCC, there are now a number of international and national standards for carbon accounting.

In this guide, GHGs are taken to refer to the Kyoto 'six-pack' of atmospheric gases that trap Earth's radiant heat energy. These are listed in Appendix 1, together with their global warming potentials (GWP) relative to carbon dioxide. They are generally quantified in tonnes of 'carbon dioxide equivalent' (tCO_2e), with one tCO_2e being a tonne of carbon dioxide or an amount of any other GHG with the same global warming potential over an agreed period (usually 100 years).

The GHG emissions of greatest significance from infrastructure development are carbon dioxide, methane and nitrous oxide. The use of the term 'carbon' in this guide is shorthand for the carbon dioxide equivalent of relevant GHGs. In general, the carbon emissions of any activity are a product of the quantity used and emissions per unit quantity. Carbon emissions per unit quantity depend on various factors (see Section 3.4).

The most common application of carbon accounting is the reporting of CO_2e emissions arising from an organisation's annual operational activities, according to standards such as the Greenhouse Gas Protocol (WRI & WBCSD, 2004) and guidelines published by the UK Department for Environment, Food and Rural Affairs (DEFRA, 2009).

The widely accepted approach is to identify and categorise emissions into three scopes:

- Scope 1 (direct emissions – including fossil fuel combustion);
- Scope 2 (indirect emissions – including purchased energy);
- Scope 3 (other emissions – e.g. from construction activity).

Setting appropriate boundaries for carbon accounting is fundamental to consistent reporting, making effective comparisons and transparent decision making. ISO 14064 provides governments, businesses and other organisations with a formalised set of tools for measuring, quantifying and reducing GHG emissions and allows for participation in emissions-trading schemes using a globally recognised standard.

While the development community has started to embrace the low-carbon agenda, most of the effort to date has focused on the potential impacts of climate change on developing countries and much of the published literature has focused on adaptation strategies to improve resilience to climate change. The International Institute for Environment and Development (IIED) and the Overseas Development Institute (ODI), for example, have both produced briefing papers on the subject for different sectors and countries, although some papers, such as that by Nazu (2013) on mainstreaming climate change resilience into development planning in Kenya, show that, for example, mitigation measures for energy efficiency and renewable energy are being specifically included in national strategies.

A report for the European Commission examining the extent to which European and international financial institutions are incorporating 'climate-related standards and measures for assessing investments in infrastructure projects' states that "there is already some experience with integrating climate change mitigation at a project level, for example by incorporating carbon accounting into the cost-benefit analysis of large projects (see Box 2). The DG REGIO has published a common guide to CBA, which can aid public authorities to examine project ideas or pre-feasibility studies at an early stage of the project cycle" (Varma, 2013).

However, economic analysis will seek to assign monetary value to carbon outcomes as part of an overall aggregation of costs and benefits rather than focusing on carbon reduction as a goal in its own right. As discussed in Jowitt et al (2012), this is potentially problematic. This topic is not addressed in this Topic Guide, which focuses on the practicality rather than the economics of measures for carbon reduction on infrastructure projects.

Box 2 Climate-related standards and measures for assessing investments in infrastructure projects

A key part of the study was to review whether climate change is mainstreamed into the investment activities of public financial institutions (FIs), specifically sectorial strategies, such as clean energy and transport. The report concluded that mainstreaming takes place in four distinct ways:

- Environmental and climate change-related commitments and targets;
- Definition and tracking of climate finance and project impacts;
- Screening criteria and appraisal tools for climate related finance;
- Greenhouse gas accounting tools.

Among its various findings, it reports that a number of FIs have defined specific eligibility criteria or performance standards to screen carbon-intensive or climate-sensitive activities. For example:

- The European Investment Bank has specific eligibility criteria for carbon-intensive industries, as captured in sector-lending policies for transport, energy and water, and is the only institution which applies a cost-benefit screening tool and carbon pricing for all investment and framework loans, using a shadow price for carbon.
- The Asian Development Bank has developed sectorial guidelines for climate resilience; thus far, however, only for the transport sector (guidelines for other sectors are currently under preparation).
- The World Bank has established criteria for screening coal projects (to be integrated into the expected review of their energy strategy), limiting financing to cases in which a country has no other options to respond to urgent demands for electricity.

The European Bank for Reconstruction and Development ranks each country using a traffic light approach to screen out projects, taking into account both physical and non-physical factors and tries to capture not just the impact on the total tonnes of CO_2 saved by a project, but also the impact on the low-carbon economy.
(Source: *Varma, 2013*)

3.4 The practical application of carbon accounting to infrastructure projects

When evaluating the carbon emissions from infrastructure projects, those arising from the construction process (commonly termed ‘embodied carbon’) – which include the production of materials such as cement and steel – will be significant and require evaluation as part of a whole life assessment.[3]

[3] In accordance with framework introduced in Section 3.3, construction-related emissions are typically accounted as Scope 3 emissions and, where significant, need to be calculated and reported together with emissions under Scope 1 and 2.

While significant progress has been made on approaches to assessing emissions from operational activities, there appears to be a lack of understanding within industry on how to capture embodied energy levels and the true significance of embodied energy to project life cycle energy (Davies, 2013). Since embodied carbon assessment depends on the quantities of materials used and activities carried out during the construction process, contractors could have a pivotal role in advancing the carbon-reduction agenda because of their significant involvement in project procurement, as detailed in Box 3.

There is now a range of general and sector-specific standards and guidelines to support such assessments, including:

- PAS 2050:2011 – Specification for the assessment of the life-cycle greenhouse gas emissions of goods and services (BSI, 2011a);
- Corporate Value Chain (Scope 3) Accounting and Reporting Standard published by WRI and WBCSD (2011);
- Forum for the Future – Carbon Management Framework for Major Infrastructure Projects – e21C Project Report (FFTF, 2009);
- UKWIR's Framework for accounting for 'embodied carbon' in water-industry assets (UKWIR, 2012).

These are discussed further in Section 8.

Box 3 Case Study – Assessing embodied energy during construction

A research project undertaken on behalf of the Centre for Innovative and Collaborative Construction Engineering at Loughborough University and VINCI Construction UK Limited under the EPSRC EngD programme is investigating the key challenges and opportunities for achieving increased embodied energy efficiency within UK non-domestic sector projects. Multiple in-depth case studies are being explored, the initial findings of which have highlighted which existing practices could help capture the proportion of project life-cycle energy during construction up to project practical completion. The results have demonstrated shortcomings within the contractor's bespoke practices towards capturing and assessing construction-related energy.

Case studies are exploring the practicality for contractors to capture and assess project life-cycle energy in terms of material, transportation and construction-related energy use. These have helped to develop some embodied energy indicators, accompanied by new data-capturing mechanisms, to assist in identifying which construction packages, activities and sub-contractors are more significant in terms of total project life-cycle energy. Future work is intended to increase knowledge of how embodied energy levels differ by project type, by creating embodied energy benchmarks for each type of construction package, activity and sub-contractor. It is anticipated that the outcomes will support the decision-making process during design and encourage supply-chains to develop low-energy solutions across the full project life cycle.
(Source: *Davies, 2013*)

3.4.1 Scope of influence and control – scope and boundaries

All infrastructure projects (and indeed the development that they support) should be subject to whole life carbon assessments from concept and option appraisal to construction, operation, use and maintenance, through to decommissioning and disposal (Jowitt et al, 2012; RICS, 2012; RIBA, 2012). Care needs to be exercised to ensure that all significant carbon emissions arising from project implementation are taken into account, including those beyond the conventional engineering boundary – i.e. it is important not only to address those emissions resulting directly from the intervention but also any significant indirect effects occurring 'upstream' or 'downstream'.

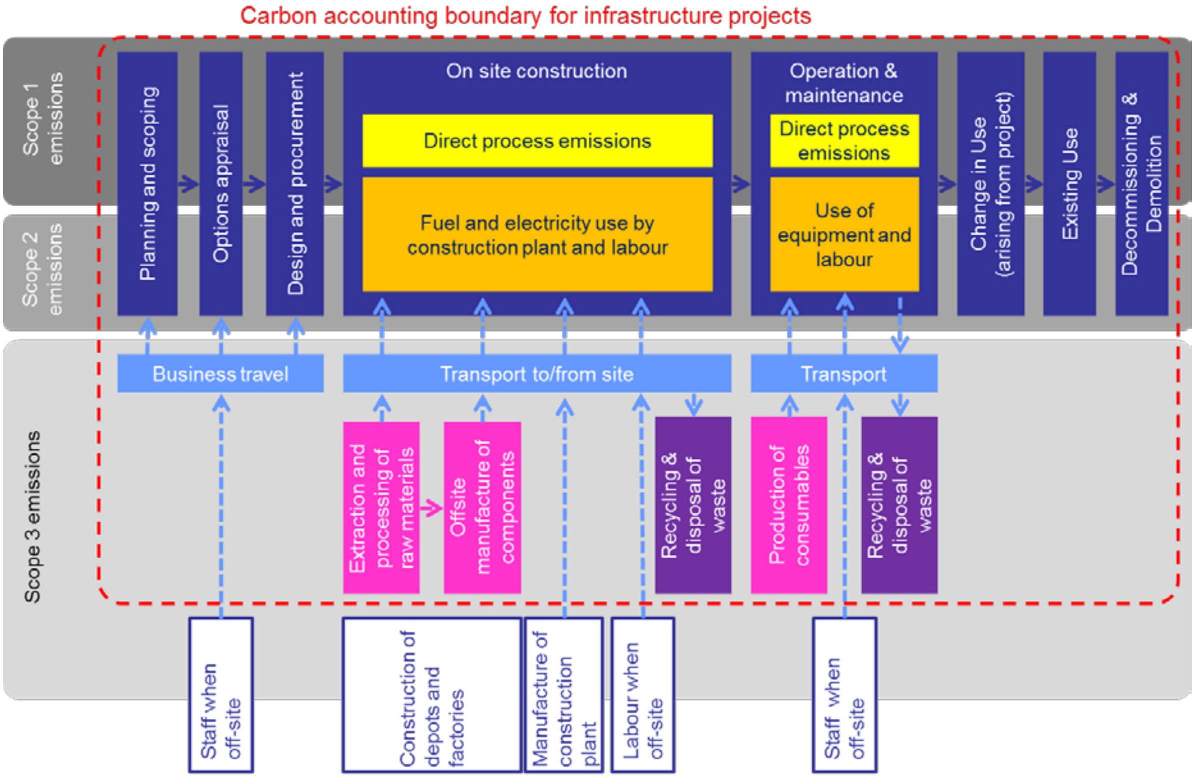
PAS 2050 (BSI, 2011a) advises that all sources within the system boundary that have the potential to make a material contribution to the assessment of GHG emissions should be included,[4] and at least 95% of the anticipated life-cycle GHG emissions and removals associated with each source.

For example, if an infrastructure project is likely to result in a change in land use and, with it, a significant reduction in existing carbon storage, this should then also be included in the carbon assessment (ibid). The Inventory of Carbon & Energy's (ICE's) *Protocol for carbon emissions accounting in infrastructure decisions* (Jowitt et al, 2012) provides guidance on appropriate boundaries based on significance. Although the principles for carbon accounting have been developed for a developed country (DC) context, their application to infrastructure development in LDCs will be broadly similar.

3.4.2 Carbon emissions from delivery of infrastructure services

As shown in Figure 3, the carbon footprint over the various stages of an infrastructure project will encompass different sources of emissions from all three scopes within specified boundaries.[5]

Figure 3 The carbon-accounting boundary for engineering infrastructure



(Source: *Jowitt et al, 2012*)

4 More than 1% of the anticipated total GHG emissions.

5 These different emission sources are categorised as Scope 1, 2 or 3, as defined in Section 10.

Carbon emissions over the lifetime of infrastructure projects arise primarily from:

- Initial construction (including excavations and other enabling works) and/or asset upgrading/refurbishment;
- Operation, maintenance and rehabilitation;
- Changes in use of infrastructure (or other consequential impacts) as a result of the project;
- Decommissioning, dismantling and demolition.

The significance of emissions from initial construction relative to those from operational activities, maintenance and change in use depends on the type of infrastructure, materials/methods of construction, operational parameters and asset lifespan.

The individual components are discussed under separate sub-headings below.

Initial construction

The embodied carbon emissions associated with a *manufactured product* are the direct and indirect emissions of greenhouse gases (GHGs) expressed as a carbon dioxide equivalent (CO_2e), resulting from the extraction, transportation and processing of raw materials used to create that product plus any emissions associated with its subsequent maintenance and disposal. In practice, estimates of embodied carbon are normally based on estimates of embodied energy and other emissions derived from life cycle analysis according to an agreed standard. The embodied carbon[6] emissions associated with an *infrastructure asset* include not only the emissions associated with the materials and manufactured products used, but also from on-site construction and off-site disposal of any waste.

Carbon emissions from the construction of infrastructure arise primarily from:

- material resources used on site;
- the off-site manufacture of equipment;
- fuel and electricity used during construction;
- transportation of construction materials and equipment;
- recycling and disposal of waste;
- land use change.

Since a significant proportion of these emissions arise from the use of energy, the emission factors used for energy significantly affect the embodied carbon calculations. Emission factors for energy and other commodities are discussed under *Calculating the emissions*.

The emissions arising from the decommissioning, reuse, recycling and/or demolition of existing facilities affected by a new infrastructure project should be included in the carbon accounting of the construction of new infrastructure (see also comments under *Disposal of construction waste* and *Asset decommissioning, demolition and disposal*).

Material resources – extraction, processing and transport to site: This covers emissions from the extraction and processing construction materials such as aggregate, concrete, timber and fill materials, plus emissions from transport to the factory gate. The emissions arising from the extraction and processing of raw materials are commonly quoted in terms of the cradle-to-gate boundary condition (BSI, 2011a, p2). This also covers the emissions from the processing of recycled materials. Adding the emissions from the transport of materials to

[6] Note: to be clear, ‘embodied’ here is different to, and does not include, carbon *sequestered* in the structure of the material.

site and then the emissions arising from on-site construction activities gives an overall estimate of total emissions to construct a new engineering asset.

Particular points to consider when assessing the carbon emissions arising from the use of construction materials in LDCs include:

- Quantities of materials: Overall, the use of minerals (indigenous and imported) and minerals processing in LDCs is expected to increase with development across all sectors. This will result in corresponding increases in embodied emissions attributable to relevant sectors.
- Production methods: Emissions arising from the use of materials depend on the methods of extraction, processing and construction. In some cases – such as aggregate used for concrete – these may be significantly less energy-intensive than in developed countries where large-scale manual labour (with very low-carbon emissions) is predominately used instead of mechanised plant.

In other cases – such as the production of steel – emissions may be higher where the energy efficiency of the production process is lower or the material is imported.

A large proportion of the carbon emissions from construction activity arises from the production of cement used for concrete; Eriksen et al (2006) state that the production of Portland cement emits 1.25 tonne of CO_2 per 1 tonne of cement produced. However, there has been a recent drive towards the use of pozzolan materials to stabilise roads in many LDCs. A good example of this is the Danish-funded Dar-Mlandizi road in Tanzania, where pozzolanic materials such as volcanic ash were mixed with lime, acting as a substitute binding material to Portland cement. This had three major benefits: 1) the road was cheaper to build; 2) local mines sprung up to supply pozzolanic materials; 3) the embodied carbon of the road was considerably less (ibid).

- Alternative materials: By using alternative low-carbon materials, the footprint of a project may be dramatically reduced. In certain circumstances, reinforced soil may be used as a potential alternative to reinforced concrete, with the former calculated to create only 25% of the carbon emissions of the latter (as stated by the manufacturer of the product, Nehemiah Reinforced Soils (India) Pvt. Ltd). This was used for the construction of the viaduct on the Benz Circle Flyover, Andhra Pradesh, India.
- Profile of materials use: There will also be a different profile of materials use, for example, greater use of lower-cost local or recycled materials for non-structural components in place of higher-cost virgin materials, with higher-embodied carbon values. For example, the use of recycled plastics for manhole covers, in addition to lower cost and embodied carbon emissions, has the added benefits of being less susceptible to theft and vandalism, as well as lower health and safety risks due to their lower weight.
- Reuse of demolition material: The reuse of materials from demolished assets as suitable construction aggregate is often overlooked due to the method of demolition, as well as poor planning at early project phases. Thus, a pre-demolition audit should be undertaken to identify opportunities to salvage materials in their original form (e.g. glass from windows, lime bound bricks), to reuse them in the new construction (e.g. particular grade of aggregate, soil for compaction) or at an alternate building site, or to be stored at a central repository rather than being used as landfill.

Advice on selecting appropriate emission factors is provided in Section 3.6.

Off-site manufacture of products and transport to site: This covers emissions from manufacturing products (such as reinforcement steel, pipes, and structural steel), mechanical equipment (such as pumps) and electrical equipment (such as panels and cabling).

Some suppliers have prepared, or are in the process of preparing, Environmental Product Declarations, which include the carbon emissions arising from the manufacture of their products. It is important to ensure that information from suppliers is carried out to a recognised standard (such as BSI's PAS 2050:2011 or the WRI 2011 Product Carbon Footprint Standard) and verified. It is equally important that the boundaries of these calculations are agreed and made transparent to help reduce discrepancies in the carbon factors for similar products from different suppliers.

Again, the addition of the emissions from the transport of materials to the cradle-to-gate emissions gives an estimate of emissions from cradle to site.

Emissions from the provision of equipment used in engineering infrastructure depend on the materials used and the manufacturing process. Although less M&E equipment tends to be incorporated in LDC infrastructure projects, more equipment is likely to be shipped from overseas, particularly specialist process equipment. An example of this, as GTZ (2003) cite, is "no special waste-treatment equipment – waste comminutors, homogenizing drums, screeners, etc. – is to be found in any of the project (LD) countries".[7]

Advice on selecting appropriate emission factors is provided in Section 3.6.

Fossil fuel and grid electricity used during construction: This covers emissions from on-site construction activities where plant, labour and temporary works are deployed to carry out enabling works and then build assets from raw materials and components. This would also cover emissions from the use of an on-site concrete batching plant or other preparatory works. Strictly speaking, the emissions associated with design and project management (e.g. the heating and lighting of staff offices, water use and staff travel) before and during the construction process should be included, but these will be small in comparison to the construction works.

The emissions from the use of fuel and electricity by construction equipment on developed-country projects can be significant contributors to overall construction-related emissions. In contrast (with the exception of large national IFI-funded or privately funded projects, e.g. dams for hydropower), the contribution of emissions from fuel and electricity use on construction projects in LDCs is likely to be lower due to the high proportion of manual labour for activities normally undertaken by mechanised construction plant in developed countries.

Advice on selecting appropriate emission factors is provided in Section 3.6.

Disposal of construction waste: This covers emissions associated with transport and off-site recycling/disposal of construction waste. In general, construction waste is inert; therefore, emissions arising from decomposition will be small and so most emissions arise from vehicle fuel used to transport waste to landfill. However, diverting construction waste from landfill and recycling back into the constructed asset displaces the use of virgin materials. The carbon (and wider environmental) benefits of doing so should be taken into account by substituting recycled material emission factors for those of virgin materials for the quantity displaced in initial construction.

7 Note: the carbon emissions from the manufacture of construction plant (e.g. excavators and bulldozers) are normally excluded from project carbon assessments since such plant is used on many projects and the proportion attributable to the individual project is small.

The addition of construction waste emissions to those associated with extraction and processing, off-site manufacture, transport to site, and on-site construction gives the overall emissions for the construction of the asset.

Land use change and other consequential impacts: Where development of infrastructure leads to significant land use change, the resulting changes in emissions that may occur as a result should be taken into account. For example, the loss of forest as a result of road construction will reduce carbon storage. Section 5.6 of PAS 2050 (BSI, 2011a) provides a method for taking account of land use change and provides default land use change values in its Annex C. In addition, where wood from any deforestation caused by the project is subsequently burned for fuel, this should also be included in the carbon account.

Of course, there may be other consequential impacts on the local environment, including habitats and biodiversity that need to be taken into account. The non-linearity of such impacts and the fact that that one process can feed back into another means that carbon emissions and other impacts may be difficult to estimate. For example, the construction of a road itself may have little direct impact in this respect, but if the route cuts through a wildlife habitat the resulting impact could be significant.[8]

Operations and maintenance

Accounting for the emissions that arise from the operation and maintenance of a constructed asset by the asset owner or operator (as well as changes in emissions that arise elsewhere as a result of this) is an important part of the whole life carbon assessment. These emissions are typically divided into:

- Direct emissions: arising from fuel combustion (e.g. use of a diesel generator), chemical processes (e.g. cement production) and 'owned' transport emissions.
- Indirect emissions from the use of grid electricity (and any heat) purchased for operation of the asset or for maintenance activities.
- Other emissions from the use of consumables (e.g. chemicals), third-party transport, and other indirect activities, such as the recycling and disposal of waste.

Such emissions are typically accounted for on an annual basis and then accrue for year of operation. Clearly, operational emissions depend on the type of asset. Although the use of appropriate technology solutions in LDCs may involve lower energy use than developed-country solutions, the carbon intensity of such energy use (particularly grid electricity) may be higher, since the electricity generation from fossil fuel sources is likely to be less efficient.

Although emissions per litre of vehicle fuel consumed will be similar, transport emissions in LDCs may be greater than equivalent journeys in DCs due to less efficient fuel consumption per kilometre travelled per tonne of goods transported (on account of older, less efficient vehicles and poorer state of roads).

Advice on selecting appropriate emission factors is given in Section 3.6.

Emissions arising from changes in use or other consequential impacts

These include the primary emissions that arise from changes in an existing activity as a result of the project, for example, a new road leading to greater use of motorised transport. Quantities will be entirely project specific, but emissions can be calculated where emission factors per unit of activity are available or can be determined.

[8] Impacts on habitats, biodiversity and other aspects of the local environment are assessed within DFID's wider Climate and Environment Assessment, using guidance set out in the *Climate and Environment Appraisal How to note* (DFID, 2012b).

In addition to the carbon emissions arising from the use of new infrastructure, there may also be other consequential impacts that give rise to other secondary emissions (similar to those discussed under construction above). For example, over its lifetime, a new road through a previously undeveloped area may lead to significant changes in agricultural land use and/or biodiversity in the surrounding hinterland. This may lead to a much larger change in GHG emissions than would arise from the increased volume of traffic alone. It is also important to account for the dynamism of land use systems, for example, rapid changes in infrastructure use may have slower and longer-term impacts on the wider environment. While it may be difficult to account in detail for such consequential changes, these secondary emissions could be significant and should at least be considered alongside the primary whole life carbon impact resulting from the project.

Decommissioning, demolition and disposal

Although this could be a significant element, these are future emissions with a high level of uncertainty. Materials and components used in construction have very different design lives and there is varied uncertainty about disposal routes, including the amount of recycling that will occur. Given the long timescales and the considerable uncertainties involved, it is difficult to make a reasonable assessment of emissions that would result from the decommissioning, demolition and disposal of an asset at the end of its life. Rather, it should be assumed that any recycling or reuse of assets or parts thereof are accounted for in the embodied emissions calculations for the initial construction of a new asset.

Equally, in selecting emission factors for materials and components used in initial construction, care needs to be taken to understand which materials and components are derived from recycled sources. A transparent approach is required, supported by evidence of robust, auditable and certified information provided by suppliers.

Of course, designing infrastructure in ways that facilitate easy dismantling and reuse in the future – for example using pre-fabricated elements and modular construction techniques – will also provide a carbon benefit by reducing the amount of new build requirements.

Responsibilities

The responsibility for carbon accounting (and by implication carbon reduction) must reside with the most appropriate party in the decision hierarchy. For example, the responsibility for providing carbon emissions information for a particular material, product or subcontract should lie with the provider of that particular material, product or sub-contract. This follows the principles of cost accounting and avoids the problem of the main contractor or asset owner being faced with having to obtain gross quantities at the level of the main project. The responsibility of the overall project manager, designer, contractor or owner is then to assemble the information from the various asset groups and perform the necessary checks to verify the calculations.

3.5 Proportionality – focus on most significant carbon emissions

As discussed above, the carbon emissions arising from some elements of infrastructure development will be relatively small in comparison to others. Therefore, effort should be focused on areas of most significance and where actions to reduce emissions are most achievable. However, with so much information and guidance, practitioners may find it difficult to determine where efforts should be concentrated. Some rules of thumb in this respect are provided in Table 1. More sector-specific guidance is provided in later chapters.

Element/Stage	Actual emissions	Opportunity to influence emissions
Planning and design	**Very low** – As very few emissions are generated in the planning and design phases of projects.	**Very high** – Effort during planning and project scoping activities, land selection, construction materials and methods, asset management regimes and operational criteria can bring very significant savings in overall emissions from infrastructure.
Construction	**Low to medium** – Depending on the type of infrastructure. For example, while emissions from the construction of a new road are likely to be large in comparison to those from its operation, they will be small compared to the emissions from use by vehicles.	**Medium** – Opportunities to reduce the embodied carbon emissions from construction include adopting lean construction techniques and selecting low-carbon materials. In general, embodied carbon reduction should not be at the expense of operational emissions.
Land use change	**Uncertain** – While any land use change is likely to increase with any construction, efforts to identify non-green field land or virgin forests will reduce emissions.	**Potentially high** – Any reduction in forest area or arable land will have a recurring year-on-year carbon impact due to any loss of carbon sequestration.
Operation	**Low to high** – Depending on the type of infrastructure. For example, emissions from operating a new road are likely to be small in comparison to those from its construction. By contrast, annual operational emissions from a water supply project may be large in comparison to its construction emissions.	**Low** – Once infrastructure is built, there is likely to be limited opportunities to significantly reduce emissions during operation, unless there is opportunity to reduce energy use through optimisation of equipment. Robust procedures, training, and constant monitoring are required to guard against deteriorations in operational efficiency.
Maintenance	**Low –** Unless large items of equipment need frequent replacement, emissions from asset maintenance will generally be low.	**Low** – Once infrastructure is built, there is likely to be limited opportunity to significantly reduce emissions through planned maintenance. Robust procedures, training and monitoring will help ensure maintenance schedules are adhered to, to avoid deteriorations in operational efficiency.
Use	**High** – In general, the greatest proportion of infrastructure lifetime emissions will occur during the use period, for example: • fuel used by road vehicles; • electricity used by domestic and non-domestic consumers.	**Low** – Many of the emissions here will be beyond the direct control of the asset owners or operators. Efforts for carbon reduction must concentrate on demand management measures for energy efficiency and water conservation as well as waste reduction.
Decommissioning and demolition	**Uncertain** – Overall, the proportion of emissions is low when compared with use phase but the long life of infrastructure assets leads to significant uncertainty here.	**Low to medium** – In cases where there is an opportunity for a significant reduction in emissions through recycling and the reuse of materials in old assets to be demolished.

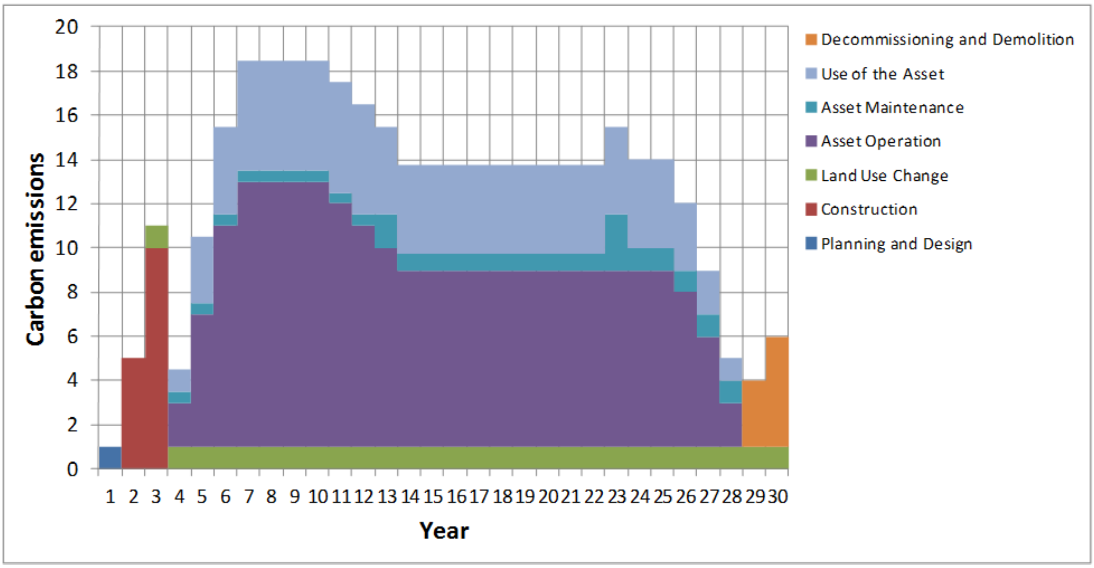
Table 1 Relative significance of carbon emissions for different elements and stages of infrastructure development

3.6 Calculating carbon emissions

Methodology

Whole life carbon emissions are determined by considering the time profile of carbon emissions associated with the project throughout its lifetime. As introduced above and illustrated in Figure 4, this will be the sum of the embodied emissions from initial construction, future operation and use, asset maintenance, and decommissioning and demolition, taking account of any upstream or downstream impacts (such as emissions from changes in land use).

Figure 4 Illustrative time profiles for different sources of carbon emissions for a generic infrastructure project



(Source: *Jowitt et al, 2012*)[9]

Whole life carbon emissions are calculated as follows:

- The embodied emissions from the initial construction of engineering assets are determined by multiplying construction quantities (e.g. m^3 or tonnes of work items), or are aggregated components by their respective emission factors. The emissions from periodic maintenance through the life of the asset are calculated in a similar way.

- Future annual operational emissions (incurred by the owner/operator of the asset) are determined by multiplying operational quantities (e.g. kWh of power used per year) for asset(s) by their respective emission factors. The emissions from users of the assets are calculated in a similar way.

- Changes in land use emissions are determined by multiplying the change in emissions per unit area (e.g. kg CO_2e/ha) by the number of area units affected by the project.

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9 The relative size of the bars is for illustrative purposes only.

An application of this process is illustrated in Box 4, within the context of the Climate and Environment Assessment of DFID's engagement in the provision of improved infrastructure through the Afghanistan Infrastructure Trust Fund.

Box 4 Case Study – Afghanistan Infrastructure Trust Fund (AITF)

DFID is engaged in supporting the development of national infrastructure in Afghanistan to assist the country's transition to taking full responsibility for its security, governance and development by 2025. Afghanistan lacks a national energy grid, irrigation systems are in a poor state of repair, and transport corridors are poorly developed. Developing Afghanistan's strategic national infrastructure is a pre-requisite for strengthening its economy and trade (DFID, 2013a). The Asian Development Bank (ADB) estimates a need for upwards of US$4 billion investment. DFID is supporting ADB to deliver a pipeline of projects as part of sector plans in transport, energy and water.

Although per capita GHG emissions are among the lowest in the world, the development of new infrastructure – particularly new energy infrastructure – is likely to lead to significant increases. While hydropower is currently a major source of energy, increasing seasonal vulnerabilities of river flows and the availability of coal and gas deposits are likely to lead to more carbon-intensive energy generation (DFID, 2013c). The Climate and Environment Assessment of DFID's Business Case categorised the impact of two options (without preferencing) and three other options (with preferencing) as 'medium/manageable potential risk/opportunity' (level B). Potential impacts include increased CO_2 emissions from the rehabilitation of national gas wells and increased electricity generation from fossil fuels; however, there is also potential for increased energy efficiency (through optimised gas engine operation, displacement of diesel generation and the burning of paraffin and wood for cooking), and for lower carbon emissions from reduced rates of deforestation.

Conducting high-level carbon emission assessments will provide information on the scale of carbon impacts of different implementation components as a criterion to aid decision making. As set out in Section 3, such assessments should estimate whole life emissions encompassing construction, operation and use phases, as well as maintenance activities over the lifetimes of the infrastructure projects.

Initial construction: An assessment of construction-related emissions (in accordance with the cradle-to-gate system boundary) requires information on:

- The type, number and scale of different types of projects;
- Construction materials (including recycled materials and wastage);
- Fuel and electricity used in enabling works, construction and transportation of materials to/from sites;
- Area of land use change equivalent to the aggregate footprint of the infrastructure.

Such assessments can either be built up from bottom-up estimates of quantities or use high-level metrics derived from previous projects (e.g. tCO_2e/MW of energy generation capacity installed for energy projects). The latter would be sufficient in the early stages of decision making, if relevant metrics can be obtained.

Operations: An assessment of changes in annual operational carbon emissions, arising from energy project development, will require information on:

- Increases in energy (MWh) generated per year for each project (or annual fuel use and corresponding fuel conversion efficiency, e.g. kWh/tonne or litre of fuel);
- Carbon efficiency of energy generation (kg CO_2e/kWh) for each project. In the

absence of in-country data, the emission factors provided by DEFRA and DECC (2012) can be used;

- Transportation of fuel and other consumables to site and waste from site (unless already included in the above metric), plus any emissions arising from the treatment/disposal of waste.

Operational emissions associated with road projects in Afghanistan will be small, although some allowance may need to be included for lighting and signalling in urban areas and for any winter weather work, as well as the maintenance and storage of service vehicles and equipment.

Use: An assessment of emissions during the use phase of road projects will require information on:

- Vehicular emissions over the life of the road. These may be estimated from projected use profiles, derived from local projections supported by published use data for similar types of roads elsewhere;
- Secondary impacts, such as displacement of traffic use from existing routes and increased overall use as a result of increased accessibility secured by the new infrastructure.

Use phase emissions associated with energy projects will arise predominately from the combustion of fossil fuels by consumers. In general it would be reasonable to assume that all fuel supplied is consumed.

Maintenance: Assessment of the emissions arising from maintenance activities (e.g. road repair) during the life of the infrastructure should be carried out in a similar manner to the approach used to calculate emissions for initial construction.

Once assessed, the above components may be combined into overall whole life assessments of projected carbon emissions, and into each sector of the programme and each option within each sector. For the purposes of decision making, the assessments need only be to a level of accuracy sufficient to allow discrimination between options and inclusion in the overall Climate and Environmental Assessment. Once choices have been made, carbon accounting can be refined with more specific quantities to provide a firm basis for delivering the selected solutions as carbon efficiently as practicable.

Emission factors

An emission factor is defined as a "factor allowing [carbon] emissions to be estimated from a unit of available activity data (e.g. litres of fuel consumed)" (DEFRA, 2009, p67) and is typically expressed in kg CO_2e. Some emission factors are broadly universal (e.g. emissions from diesel fuel), while others may be more country specific (e.g. emissions from grid electricity). The emission factor for grid electricity consumed in the UK in 2009 is quoted by DEFRA and DECC (2012) as 0.597kg CO_2e/kWh ('All scopes', Table 3c, Annex 3), which is significantly lower than that for South Africa (1.102kg CO_2e/kWh, 'All scopes', Table 10c, Annex 10), but significantly higher than that for Switzerland (0.052kg CO_2e/kWh). The UK has a much lower value than South Africa due to its mix of renewables and non-fossil fuel-based energy generation (mostly from nuclear sources). Incidentally, a low value is also quoted for Brazil (0.105kg CO_2e/kWh), due to its high proportion of hydropower; however, there is controversy over whether the methane emissions arising from rotting vegetation in valleys flooded by hydro dams are accounted for (Tegel, 2013; Fearnside, 2002). Where local data are unavailable, some judgement may be required in using data from other sources that are not specific to the LDC under consideration.

Although the publication of standards such as ISO 14064 and PAS 2050 provide a standardisation of approach for carbon accounting, there is little standardisation of emission factors to use in calculations as demonstrated by wide range of emission factor datasets. Care needs to be taken in selecting the most appropriate and up-to-date sources to ensure consistent accounting. Emission factors tend to be revised over time as a result of changes in the fossil/non-fossil mix of energy supply and changes in efficiency in relation to material processing, equipment manufacture and operational activities. Practitioners may wish to seek out any locally available datasets published in the LDC where the project or programme is taking place (or a country with similar development characteristics – particularly relating to the means of energy supply) and consider their use. For these reasons, in carrying out any carbon-accounting exercise it is vital that the sources, dates or version of the emission factors employed are recorded, along with the range of uncertainty. Ideally, sensitivity analyses should be carried out to help determine the upper and lower bounds of confidence.

Some of the most commonly used datasets of operational and embodied carbon emission factors are provided in Appendix 1. The datasets for embodied carbon commonly have global application, although some are country specific; an expanded list is available from the Greenhouse Gas Protocol website (WRI & WBCSD, 2012).

Worked example

A simple worked example is shown in Box 5 and Table 2 to illustrate the information requirements and calculation for a generic pumping station, of a kind that may be employed on a range of development projects. The calculation is presented for illustrative purposes only and does not take into account the specific factors relating to any particular location.

Box 5 Worked example for simple pumping station

A pumping station and pipeline is to be constructed in Pakistan to convey 20 Ml/day of water, 1km to a tank. The pumping station comprises a concrete wet well, two submersible pumps; a small steel-framed building with housing electrical control panel; design life 40 years.

- Wet well construction requires excavation: 450m^3 of soil to a depth of 5m
- Sheet piles required in ground around edge of excavation for stability: 266m^2
- Reinforced concrete (RC) required for 400mm wet well base: 12m^3 of C35A concrete, 150kg/m^3 steel reinforcement, 2m^3 blinding concrete
- RC required for 300mm thick walls: 36m^3 of C35A concrete, 150kg/m^3 steel reinforcement
- Backfill required to fill remaining area after construction of the wet well: 280m^3
- Ductile pipe required: diameter 700mm, length 1km, depth laid (in trenches) 2m
- Double-skin block required: 55m^2
- M&E kit required: 2 no. 34kW submersible pump sets, discharge valves, MCC panel, cabling

Part 1: Calculating embodied carbon emissions from construction

To calculate embodied carbon emissions (tonnes CO_2e) from construction, material quantities are multiplied by suitable emission factors, as discussed below. These calculations are set out in Table 2. Additional embodied emissions will arise from periodic maintenance through the life of the asset (but are not discussed here).

To calculate emissions from transporting materials to site, information regarding manufacturing locations of plant and raw materials is required. As noted previously, specialist plant is difficult to procure in some LDCs; hence, structural steelwork and ancillary items are assumed to be imported, and transported 5000km by maritime shipping (as general cargo). All other civil and M&E items are assumed to have been sourced locally. The total embodied carbon emissions from construction are estimated to be 893.4 tonnes CO_2e/yr.

Part 2: Calculating future annual operational emissions

The dominant component of future operational emissions for this example asset arises from the use of grid electricity (indirect emissions) for pump operation:

- *Annual grid electricity* use is estimated simply by multiplying the pump power rating (34kW) by the annual hours of operation (assumed to be 12 hours a day, 365 days a year).
  i.e. 34 x 12 x 365 / 1000 ≈ 150MWh/yr.
- Changes in operational emissions from electricity are calculated by multiplying *annual grid electricity* by the *emission factor* for grid electricity (in kWh) for each year of future operation,
  i.e. 150,000kWh/yr x 0.6216kg CO_2e /kWh (using figures from DEFRA & DECC, 2012, Annex 10, Table 10c, 2009 5-year rolling average for Pakistan) = 93.2 tonnes CO_2e/yr.

This example does not include any other changes in direct emissions (fuel combustion, fugitive emissions, etc.) or other indirect emissions, such as visits by operations personnel.

Part 3: Whole life carbon emissions

The change in future operational emissions (Part 2) is combined with the embodied carbon emissions of construction (Part 1) to determine its 'whole life carbon emissions'. No account is taken of periodic maintenance requirements.

Cumulative carbon emissions are obtained by adding the embodied emissions of initial construction (Part 1), and the additional operational emissions from 40 years' operation (Part 2). The cumulative total change in emissions for this pumping station is estimated at 893.4 + (93.2 * 40) = 4623 tCO_2e over 40 years. Although the construction emissions are almost 10 times the emissions from one year of operation, they only amount to 19% of 40-year whole life emissions. Thus, while it remains important to design a low-carbon constriction, the greatest carbon savings would be obtained through design to reduce energy use over the life of the pumping station.
(Source: *UKWIR, 2012, p30-31*)

Item	Quantity	Units	Data source	Emission factor *kg CO_2e/unit*	Tonne CO_2e
Excavation	450	m^3	Excavation for foundations, depth 2-5m	1.43	**0.6**
Sheet piling	266	m^2	Interlocking steel piles, Section modulus 800-1200cm^3/m, (Area of pile length 10m, split 75% materials	185	**49.2**
			25% energy used to drive piles)	61.67	**16.4**
Concrete blinding	2	m^3	Provision of grade 20 concrete, OPC with 20mm aggregate	336	**0.7**
			Placing of mass concrete, thickness 150mm	5.06	**0.01**

Item	Quantity	Units	Data source	Emission factor *kg CO_2e/unit*	Tonne CO_2e
Reinforced Concrete Base (no allowance for formwork)	12	m^3	Provision of grade 40 concrete: OPC with 20mm aggregate	419	**5.0**
			Placing of concrete base: thickness 300 500mm	4.21	**0.05**
	1.8	tonne	Reinforcement: plain round steel bars, Nominal size 16mm bent and cut to length (reinforcement density of 150kg/m^3)	1,730	**3.1**
Reinforced concrete walls and valve chamber (no allowance for formwork)	36	m^3	Provision of grade 40 concrete: OPC with 20mm aggregate	419	**15.1**
			Placing of reinforced concrete walls, thickness 300-500mm	5.62	**0.2**
	5.4	tonne	Reinforcement: plain round steel bars, Nominal size 12mm bent and cut to length (reinforcement density of 150kg/m^3)	1,733	**9.4**
RC roof (no allowance for formwork)	6	m^3	Provision of concrete: prescribed mix, 20mm aggregate OPC, grade 40	419	**2.5**
			Placing of concrete: Thickness 150-300mm	6.18	**0.04**
	0.9	tonne	Plain round steel bar reinforcement: 10mm dia. bent and cut to length (tonnage based on reinforcement density of 150kg/m^3)	1,733	**1.6**
Fill and compaction	280	m^3		1.00	**0.3**
Below-ground pipeline 700mm dia DI	1,000	m length	In trench to depth of 1.5-2m	585	**584.7**
Blockwork	55	m^2	Precast concrete block work, 140mm thick	26.87	**1.5**
Access road	130	m^2	Granular material DTp Type 1, 150-200mm	2.47	**0.3**
			Wet mix macadam, 100-150mm	1.92	**0.3**
Wet well submersible pumps	2 No. 34	kW	ITT Flygt – Submersible pumps. Flygt 3301.180 Environmental Product Declaration	37.6	**2.6**
400 mm dia. gate valves and NRVs	8	No.	Hand operated gate valve	660	**5.3**
Motor control centre & control panel	2	tonne	Assumed size 1.76m x 0.72m x 0.3m plus ancillaries; EF from Bath University ICE V2.0: general steel	2247	**4.5**
Cabling	100	m	PVC ins. cable copper multi-strand 6.0mm	1.21	**0.1**
Structural steelwork	78	tonne	Fabrication of members for frames, portal frames, span 15m, p250	2216	**172.9**
			Permanent erection	110	**8.6**
Ladder	3	m lengtl		245.50	**0.7**

Item	Quantity	Units	Data source	Emission factor kg CO_2e/unit	Tonne CO_2e
Flooring/handrails	0.3	tonne		3581	**1.1**
Shipping 5000 km to country	100	tonne	DEFRA and DECC (2012) Annex 7 – Freight conversion table: general cargo – average	0.013	**6.6**
Total					**893.4**

Table 2 Embodied carbon of construction items for example pumping station

(Source: *ibid*)

Calculations of the carbon emissions arising from an infrastructure project can be carried out at different levels according to the information and time available. In the early stages, when little information is available on individual projects, it is recommended that high level metrics are used to allow rapid top-down assessment for comparative purposes. Such metrics are derived from previous projects and are normally expressed in terms of a primary size yardstick (e.g. CO_2e per m^3 water treated or per capita served). The success of this approach depends on the availability of such metrics for the type of asset or project being assessed. In the later stages, when solutions have been selected and designs progressed, more detailed bottom-up assessments can be carried out using lower-level emission factors (e.g. CO_2e/unit work activity or CO_2e/kg of material used). Four levels are shown in Table 3.

Level	Typical metric	Comments
1. Work item	Kg CO_2e/kg or /m^3 of material or work item	The embodied CO_2e emissions associated with one unit of a particular work item, such as 1m^3 or 1 tonne of reinforced concrete, may be defined as the sum of the emissions from the raw materials, manufactured products, in-situ construction activities and off-site removal of waste necessary to create that one unit. Emission factors for materials and consumables can be obtained from third-party datasets for use in bottom-up assessments of the carbon emissions arising from known quantities of these commodities used in a project (similar to the way costs are estimated by quantity surveyors). Separate assessments may need to be carried out for work items carried out using different methods and/or materials (e.g. laying pipelines by open-cut or alternative no-dig methods).
2. Component of works	Kg CO_2e /unit of an equipment item, or Kg CO_2e = function [item size yardstick]	M&E plant items such as pumping systems and process packages typically comprise multiple components and/or materials assembled off site. Where items come in a range of sizes, emissions can be estimated from relevant carbon metrics (e.g. kg CO_2e/unit) or algorithms based on a number of data points. As discussed in the main text, eliciting emission factors directly from the suppliers is preferable. Hence, where practicable, it is advisable to make the supply of such information a procurement requirement. Where information is not available from suppliers, a secondary but more approximate approach is to identify the primary materials used in particular products and their quantities. These quantities can be multiplied by appropriate emission factors (from Level 1) to obtain generic carbon factors for such items. An allowance for the

Level	Typical metric	Comments
		energy used in manufacture can be added where this is significant and a reasonable estimate can be made (with assumptions and sources stated).
3. Process or project	kg CO_2e/unit of capacity or throughput, or kg CO_2e = function [capacity or throughput yardstick]	At this level, carbon emissions of a whole process or asset can be estimated from metrics expressed in terms of primary size yardsticks (e.g. CO_2e/MW energy generation capacity or CO_2e/km single lane road constructed). These metrics will be derived from previous projects and will be specific to particular sectors. By adapting existing models used for cost estimation, the embodied carbon emissions from different sizes of process unit or asset can be estimated.
4. Overall investmen t	Kg CO_2e/person served Kg CO_2e/£ spent	At the highest level, carbon emissions of an entire service or programme of activities (e.g. CO_2e/customer provided with clean water) are estimated. Typically, carbon metrics are expressed in terms of the primary measures used to assess the service or programme, e.g. carbon emissions of providing drinking water or an energy supply to a given population.

Table 3 Levels of carbon estimating and associated metrics

(Source: *ibid*)

3.7 Reducing carbon emissions

3.7.1 Principles

Carbon management is the process of developing and implementing solutions and technologies for reducing the carbon emissions associated with creating new infrastructure, and modifying or managing existing assets or operational activities. A focus on carbon reduction will also help to achieve efficiencies in the use of resources and in waste minimisation.

A carbon-efficient project is one which delivers the project objective for the maximum possible reduction (or minimum increase) in carbon emissions expressed in tonnes CO_2e. In order to make a judgement on project carbon efficiency, a comparative assessment of the carbon emissions before and after project delivery will be required. So, wherever possible:

- Undertake assessments of the carbon emissions from existing facilities and activities likely to be affected by the project (taking care to agree and report against clear boundary conditions);
- Undertake assessments of carbon emissions from the proposed project and compare with existing facilities and activities (applying the same boundary conditions in each case);
- Make a comparison between alternative project options to help determine and promote selection of the most carbon-efficient solution. The relative carbon efficiency of projects of a similar type may be compared by dividing the carbon emissions by a key project metric (e.g. kg CO_2e/capita served), as discussed above.

In developing project solutions, consider applying the ‘carbon management hierarchy’. More specifically and in descending order of preference:

1. **Avoid** carbon-intensive activities by, for example, avoiding the construction of unnecessary assets, shutting down processes or electrical equipment when not in use, and eliminating unnecessary transport;
2. **Reduce** carbon emissions by making existing activities more efficient, including replacing energy-intensive processes with ones that use less energy. This is a wide area of opportunity, for example, whenever energy is used for a treatment process, in a building, or for transportation;
3. **Replace** high-carbon energy sources with low-carbon sources through generating renewable energy to displace the use of grid power or other fossil fuel use. Give consideration to the use of heat as well as power generated from renewable sources;
4. **Mitigate** carbon emissions through approved carbon sequestration activities (as many off-setting programmes which are reliant on tree planting programmes are ineffective (Carbon Trade Watch, 2007) or, as a last resort, purchase the carbon reduction achieved by others.

Energy efficiency

The fossil fuels burned to produce energy for heat and power are the most significant sources of carbon emissions. So, wherever possible:

- Examine existing facilities and activities to identify opportunities for efficiencies that will lead to savings in the use of electrical power and fossil fuels;
- Review the scope of new infrastructure projects to minimise the use of energy through their lifetime (whether directly through reducing the power rating and/or running time of equipment or, indirectly, by designing the need for energy use);
- Implement a design to minimise transport and waste generation, and use other consumables during operation.

Energy savings will also lead to operational cost reductions.

Renewable energy

Review the scope of infrastructure projects to identify opportunities for energy recovery or renewable energy generation. Including a business case requirement that new developments generate a proportion of their energy demand from renewable sources could be a made a condition of procurement. While there is ample opportunity in many LDCs to exploit natural solar or wind resources or to apply digestion, care must to be taken to ensure that selected technologies (as is the case for any technologies deployed in LDCs) can be operated and maintained sustainably.

Materials

The construction of new infrastructure or improvement to existing infrastructure can lead to significant carbon emissions arising from the embodied carbon associated with the materials and equipment used. Wherever possible:

- Adopt efficient use of materials as a criterion in selecting solutions for new development;
- Review the scope of the project to minimise the quantity of construction materials and fabricated equipment required;
- Employ processes and construction elements which use the minimum of virgin material resources and produce the least waste;
- Incorporate existing structures into the design of new assets;
- Reuse materials from demolished or decommissioned assets;
- Specify the use of locally sourced recycled materials, such as aggregates and block work, where the production of such materials can be shown to be sustainable (i.e.

avoiding the use of recycled materials where the processes of grading, washing, and transportation are themselves energy intensive);
- Avoid excessive use of materials with high embodied carbon emissions (e.g. stainless steel);
- Where practicable and sustainable, specify the innovative use of local renewable materials (e.g. bamboo fencing instead of corrugated steel fencing) that reduce carbon emissions of conventional techniques or materials.

3.7.2 Integrating carbon management into policy options

The need to ensure development funding and assistance is channelled to encourage low-carbon growth is a significant challenge, but one which provides great opportunity for DFID and its partners. The following recommendations are presented to DFID as choices for the development of future policy to help improve its own practices and to increase its wider influence in this arena:

- Develop and apply formal protocols, on the basis of the principles set out in this guide, to influence DFID's criteria for funding, project selection, procurement and project management processes.
- Understand and apply available international carbon finance mechanisms supported through the European budget and other sources to secure funding for low-carbon growth projects.
- Collaborate with other financial institutions to influence their policy, procedures and tools for carbon management.
- Carry out capacity building and training activities for DFID staff, in-country governments and partner organisations working on infrastructure projects.
- Champion the concepts of responsible sourcing and sustainability alongside carbon reduction by producing and communicate guidance on sustainable design, covering:
    - The use of materials with high BRE Green Guide ratings, particularly for imported materials and products;[10]
    - The use of responsibly sourced timber for 100% of timber utilised in construction and hoarding, and ensure that only Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Commission (FSC) timber with relevant, auditable Chain of Custody (CoC) certification is procured;
    - The use of responsibly sourced expertise and vendors (of construction products and equipment), with certification to ISO 14001 (or equivalent),[11] widely regarded as the minimum acceptable standard of certification, and where appropriate verified BES 6001[12] certification.
- Undertake further research to address knowledge gaps and build the evidence base on best practice. A particular need is to research, develop and apply carbon metrics for common types of engineering asset and project, using information from previous projects (by DFID or others) to facilitate rapid high-level carbon assessments of options included in business cases for future projects and programmes.

[10] The Green Guide ratings range from A+ to E – the higher the rating the lower the impact on the environment.

[11] The ISO 14000 family addresses various aspects of environmental management. It provides practical tools for companies and organisations looking to identify and control their environmental impact and constantly improve their environmental performance.

[12] The BRE standard BES 6001 has been published to enable construction product manufacturers to ensure and then prove that their products have been made with constituent materials that have been responsibly sourced.

3.7.3 Planning for the future

Many LDCs still struggle to provide basic levels of infrastructure. Where investment is made, infrastructure design and construction is often carried out using conventional approaches and technologies to meet immediate needs at minimum expenditure. This can lead to short-term solutions, which are not consistent with carbon-reduction objectives.

To help to push forward these objectives, therefore, it is important to plan short-term design and construction of facilities with sufficient flexibility to allow them to be upgraded in a carbon-efficient manner as the country develops and more funding becomes available. This could involve adopting phased or modular approaches, with initial deployment tailored to meet the immediate need but with the capability to introduce more resource-efficient approaches and technologies over time. For instance, a coal-powered station may need to be commissioned to satisfy immediate energy needs, due to its familiar design and operation, as well as the availability of fuel. To facilitate transformation towards a low-carbon future, phased and/or modular construction approaches could be incorporated to facilitate a switch to a less carbon-intensive fuel (e.g. gas) in the future without the need for a major rebuild or for grid re-direction.

Of course, such approaches do require considerable foresight, collaboration and consensus. Therefore, they would best be addressed at the programme, regional or national level, where there may be greater opportunity to integrate infrastructure development with longer-term national policy, economic forecasting, spatial planning, and financing arrangements.

SECTION 4

Carbon management: energy

4.1 Carbon impacts of energy infrastructure

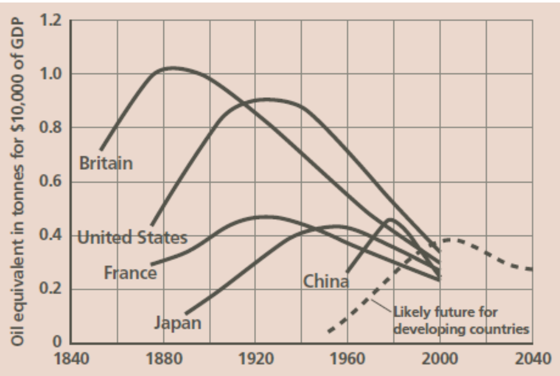
Emissions from the energy sector arise predominately from the extraction, processing and transport of fossil fuels and from the generation of electricity. Of course, the provision of the engineering infrastructure to enable these activities contributes further to carbon emissions. These emissions are fundamentally driven by the demand for energy.

LDCs are, almost by definition, low consumers of energy. Three quarters of the total energy used in LDCs is local use by households obtained from renewable biomass (firewood or charcoal) for domestic cooking (Scott, 2013). The remainder is commercial energy use, which is dominated by the electricity sector (nearly 50% of which was obtained from renewable sources in 2009, predominately hydropower) and by the transport sector (predominantly the combustion of fossil fuels). Some LDCs have significant natural resources and are accessing them to generate a significant proportion of their own energy – Owen Falls dam, for example, has long supplied Uganda with hydropower. Most are currently net importers of fossil fuels, particularly oil (for transport).

To meet their growth and human development objectives LDCs will need to increase their consumption of energy (Seth, 2012). Energy demand (aggregate and per capita) is expected to increase rapidly in urban areas. However, reliable electricity is frequently cited as a constraint on growth. This is highlighted by the fact that 11 out of 25 LDCs, for which data was available, spend 10% of their GDP on securing oil supplies (ibid, pvii).

According to Jowitt (2006), history shows that newly industrialised countries are less energy dependent during their primary growth period as they learn technologically from their predecessors. This will temper – but only to a limited extent – the impacts of newly emerging economies. This is illustrated by the curves (see Figure 5) produced by Dessus (2005), which show a trend of decreasing energy use per unit GDP over time for different economies, expressed in oil equivalent tonnes per US$1,000.[13]

Figure 5 Curves of oil equivalent tonnes for US$10,000 Gross Domestic Product (GDP)



(Source: *Jowitt, 2006*)

[13] Approximately £624.

At the national level, it would appear that economies become more energy efficient over time. This may be explained in part by the fact that, as countries develop, there is expected to be a transition from high-carbon intensity fuels to lower carbon intensity fuels used for energy generation over time, which will lead to reductions in carbon intensity of energy supply.

In an examination of scenarios for electricity generation to meet expected growth, Seth (2012) states that the current fuel mix used in LDCs, dominated first by biomass and waste, and supplemented by fossil fuels, will not be sustainable. LDCs have two basic options: (a) a fossil fuel trajectory or (b) one with renewables. However, the rising prices of fossil fuels, coupled with supply constraints, means that following option (a) could leave them vulnerable. Investing in cleaner technologies is likely to be more cost effective in the long term since the combination of rising fossil fuel prices and falling costs of renewable energy technology will favour increased development of renewable energy solutions. Such technologies "can enhance energy and financial security by contributing to reduced national debt, improving trade balances and providing a hedge against fossil fuel price" (ibid). Besides the development of large centralised energy-generation facilities, particularly in urban areas, significant benefits could be realised by developing multiple smaller decentralised energy sources – for example, in terms of reduction in the need for cross-country energy transmission infrastructure.

Notwithstanding this, individual LDCs will make particular energy technology decisions depending on their natural resources, on their progress along the "Dessus" trajectory and on other considerations; this will, in turn, affect the carbon intensity of energy supply – for example, hydropower will bring lower carbon intensity than coal-fired generation, but only in countries where the right geographical conditions for hydropower exist. A diversity of energy technologies and the extent to which fuel sources are indigenous or imported will lead to variations in the carbon intensity of energy supply within countries.

It is clear, therefore, that the scope of any new infrastructure to meet energy demand within a particular LDC requires careful planning and delivery to make best use of available resources, and taking account of local geographic and economic factors, while ensuring value for money and delivering energy with as low a carbon intensity as practicable. As discussed in Box 6, Nigeria is an example of a country looking to adopt low-carbon energy development to deliver a range of development benefits.

At this point, it is worth briefly mentioning the influence of international mechanisms for carbon reduction. The performance of the EU Emissions Trading Scheme only directly affects the economies of LDCs where Certified Emission Reductions (CERs) generated by facilities operated in LDCs under the Clean Development Mechanism are purchased by market actors. Theoretically, this provides opportunities for countries where the potential for low-carbon energy (predominately hydropower) is substantial but is largely unexploited (e.g. Nepal, Mozambique, Ethiopia and Congo). More specifically, this will help in exporting electricity to where electricity emissions are higher (Scott, 2013).

However, as Scott (2013) states, in January 2012 just 1% of active projects were located in LDCs and less than 30% of CER revenues were actually reaching LDCs on account of the costs of brokers, bankers and verification. In addition, the poor performance of the market has led to a large drop in the CER price below levels that justify investment in Clean Development Mechanism (CDM) projects. Therefore, under current market conditions, CDM finance is not seen as a primary driver of low-carbon infrastructure.

Box 6 Opportunity to benefit from emissions trading and carbon credits

Nigeria is Africa's largest exporter of crude oil; however 70% of a population of 167 million people live in poverty (Eleri et al, 2013). Low-carbon development provides a pathway to address energy poverty and environmental decline in Nigeria. Nigeria has set out development targets in its 'Vision 2020', wherein it plans to: become one of the 20 largest economies in the world; raise living standards; expand access to electricity to 75% of the population; decouple growth from dependence on oil. This vision aligns well with the low-carbon agenda (Choo, 2008; REEEP, 2007).

Although it does not have any binding obligation to reduce emissions, Nigeria is also a signatory to the UNFCCC and the Kyoto Protocol, which gives it access to technology transfer and financial assistance under programmes such as the Clean Development Mechanism. Besides helping a transition away from carbon-intensive fossil fuels, improving energy efficiency, and expanding the diversity of energy sources to include renewable energy, Eleri et al (2013) suggest that low-carbon development will also expand access to energy services for the poor and otherwise support poverty reduction.

Notwithstanding Nigeria's highly ambitious targets, progress has been slow to date. Low-carbon energy sources such as solar, hydropower and biogas are beginning to emerge – Nigeria has also committed to end all flaring of natural gas, which accounts for approximately 25% of its national emissions. Nigeria needs to agree binding national policies for energy management to enter into a sustainable growth pattern towards a low-carbon economy.

4.2 Identifying sources of emissions from energy infrastructure

The primary carbon impacts associated with energy supply infrastructure arise from:

- Development and operation of infrastructure for energy generation (e.g. dam, reservoir and turbine halls for hydropower, fossil fuel power stations);
- Development of renewable energy installations (e.g. organic waste-to-energy digesters, photovoltaic panels), albeit with low (or zero) operational emissions;
- Development and operation of energy transmission infrastructure plus local substations and distribution.

Other carbon impacts arise from:

- Road/rail infrastructure for transportation of fuels (e.g. coal, biomass, waste), including vehicle fuelling stations;
- Displacement of local off-grid energy production;
- Expected increase in energy use (for example as people purchase more electrical appliances and spend more time using technology) as a result of cheaper, more accessible energy supply – the rebound effect;
- Landfills may also serve as a secondary source of energy from landfill gas.

The approach set out in Section 3 relating to assessing the carbon emissions arising from the construction, operation and maintenance of engineering infrastructure generally apply to energy projects. Typical sources of carbon emissions arising from the construction, operation and maintenance of energy projects are shown in Table 4.

Project Phase	Source of emissions	Relative significance
Planning and design	Site investigations, design office utilities use, travel	**Very low** (but *high influence* on future emissions).
Construction	• General site utilities use, enabling and temporary works • Extraction and processing of construction materials and transport to site • Off-site manufacture and transport of generating equipment and other components. This could range from large complex process trains for fossil fuel plants (furnace, boilers, steam turbines, generators) to smaller pre-assembled generating units • Excavation, on-site construction of foundations, concrete and steel structures, and buildings • Emissions from sub-contracted works • Removal and disposal of construction waste	**Low** (for carbon-intensive energy supply solutions – e.g. fossil fuel generating stations) **Medium/high** (for low-carbon, renewables or energy efficiency schemes)
Operation and maintenance	• Emissions arising from the process of energy generation (e.g. combustion of fossil fuels) including process emissions of methane and nitrous oxide[14] • Transport of fuel and other consumables to site, transport of waste from site, and subsequent recycling/disposal • Transmission and distribution losses • Equipment repair and replacement	**High** (for carbon-intensive energy supply solutions – e.g. fossil fuel generating stations)
Use	Change (increase) in energy use by consumers (including increased numbers of first-time connections) as a result of project implementation	Potentially **High/ very high** (requires assessment within scope of project)
End of life	Decommissioning/demolition transport of waste/material, disposal/recycling of waste	**Uncertain**
Other	Displacement of other existing generating capacity with higher (or lower) carbon intensity, flooded woodland for hydro power resulting in double carbon impacts due to of loss of carbon sequestration and addition of rotting biomass	**Uncertain** (but important to assess)

Table 4 Typical sources of emissions by energy project phase

4.3 Selecting the appropriate level of carbon accounting

Inputs into the carbon accounting of an energy project depend on the level at which such an assessment is to be carried out, in conjunction with the amount of accessible information and time constraints.

Four levels are show in Table 5. In general, a high-level top-down assessment requires less analysis, but is more dependent on the availability of sector-specific data. A top-down assessment is most appropriate at the early stages of programme or project decision making, where choices between alternative options are required. A lower-level bottom-up assessment is more data intensive, but can be built up from generic emissions factors applied to known quantities. Bottom-up assessments may be applied at later stages where

[14] Although considered not to be applicable to current energy generation in LDCs, these emissions would need to be adjusted to account for any carbon capture and storage technology, if applicable in future.

validation of earlier estimates is desired. A combination of top-down and bottom-up assessment is similar to approaches used for cost estimation.

Level	Carbon metric	Comments
1. Work item	kg CO_2e/kg or /m^3 of material or work item	Common to all infrastructure sectors. Thus, comments made in Section 3 relating to construction generally apply to the construction of energy projects.
2. Component of works	kg CO_2e /unit of an equipment item, or kg CO_2e = function [item size yardstick]	Typical components include: tank, pipeline, pump, boiler, turbine, and transformer; e.g. kg CO_2e/kW turbine/photo voltaic cell, kg CO_2e/m^3 of water pumped.
3. Process or project	kg CO_2e/unit of capacity or throughput, or kg CO_2e = function [capacity or throughput yardstick]	Typical processes include: power station, cooling system, bio-digester, substation, CHP engine, PV generator, transmission line; e.g. kg CO_2e/kWh of energy generated, kg CO_2e/tonne of organic waste digested.
4. Overall investment	kg CO_2e/ person served kg CO_2e/£ spent	Carbon emissions of providing energy to a given population, or carbon saved through an energy efficiency programme; e.g. kg CO_2e/per consumer (average) supplied, kg CO_2e saved/kWh of energy. Allows comparison between different types and sizes of energy infrastructure.

Table 5 Levels of carbon estimating and associated metrics

4.4 Reducing carbon emissions from energy infrastructure

Of all the sectors, the greatest activity for low-carbon infrastructure, unsurprisingly, occurs in the energy sector, since this is usually the largest source of infrastructure-related emissions. For instance, in a Low Emissions Development Strategies Special Edition of its newsletter, the Climate Development Knowledge Network (CDKN, 2013) highlights work with its partners to:

- Transition Central America onto a more sustainable energy pathway;
- Assess the sustainability of Togo’s and Cameroon’s energy sectors;
- Promote green tourism and local jobs in iconic Southeast Asian cities;
- Support energy-efficient buildings for a greener India.

As discussed in Section 3, it is important to set appropriate boundaries for assessing and delivering carbon efficiency. In cases where the energy project is one of a suite of projects or where the project will affect other assets or operational activities, it is important to consider the overall opportunities for carbon reduction. It is also best to avoid taking action to reduce emissions from one asset that leads to an increase to emissions elsewhere. Instead, it is best to scope integrated projects, perhaps covering multiple facilities, to maximise overall energy, water and resource efficiency, and minimise waste.

Opportunities for low-carbon energy developments are diverse but include:

- Improving the operational efficiency of existing fossil fuel power stations and transmission networks;
- Carefully scoping new energy supply projects so that the balance of centralised energy supply to local distributed supplies (particularly in rural or remote areas) delivers the most carbon-efficient (as well cost-efficient) solutions overall;
- Improving the thermal insulation of residential and commercial properties (to minimise requirements for mechanical heating and/or cooling);
- Assisting households to switch from wood- or oil-burning stoves to cleaner gas or mains electricity alternative, where these are more carbon efficient;
- Promoting the installation of more energy-efficient appliances, building heating and cooling systems;
- Implementing programmes of small-scale organic waste-to-energy digesters where the availability of suitable food and other organic waste is high enough to make such installations cost beneficial;
- Implementing programmes of solar thermal heat systems and solar photovoltaic panels on public buildings, where seasonal insolation is high enough to make such installations cost beneficial;
- Implementing small-scale or larger-scale hydropower schemes where there are water courses with sufficient hydraulic head and flow, and such developments are overall socially, environmentally and cost beneficial.

SECTION 5

Carbon management: water and sanitation

5.1 Carbon impacts of water and sanitation infrastructure

The demand for water and sanitation services in urban areas is expected to increase with population growth, and growing industrialisation and migration to cities. In general, the carbon intensity of water supply and sanitation services is lower than those in developed countries due to lower levels of treatment, together with the use of lower technology and less energy-intensive systems. Increased demand will lead to the development of new water systems with the potential for greater centralisation and pumping, particularly in urban areas.

The need to improve public health and safeguard city environments will call for large expansions in conveyance systems and technological leaps in treatment processes. Although there is increasing appetite in developed countries to retrofit decentralised systems (such as sustainable drainage systems), the reality is that large urban areas will rely on trunk mains and trunk sewers. However, this brings potential risks, since the climate variability in many LDCs with long dry periods followed by flash floods increases the stress on such infrastructure and its failure (e.g. high flood exceedance flows) can undermine public health and safety. The adoption of Integrated Surface Water Management Plans alongside the development of water and sanitation services will help mitigate such risks and maximise the benefits of investment.

As discussed in Section 3, a whole life approach to carbon accounting and management should be adopted to ensure the carbon efficiency of water and sanitation infrastructure. While the carbon emissions arising from construction activity can be significant, particularly for large urban water systems, infrastructure should be planned to ensure that annual operational emissions are well managed. Two examples are:

1. Once a pumping-reliant system is installed, it is very difficult to take it out again! Therefore, systems that minimise the need for pumping will be carbon beneficial.
2. The increasing energy demand of more complex treatment systems can be offset by recovering energy through sludge digestion and combined heat and power schemes. Extending the process stream in this way also produces biosolids that can be put to beneficial use (for example as a local land fertiliser).

UKWIR's (2012) framework for accounting for embodied carbon sets out a step-by-step approach for accounting for the whole life carbon emissions of water projects. Although developed for the UK water industry, the principles will generally be applicable within a developing country context. The framework is supplemented by a meta-database of emission factors, which can be obtained directly from UKWIR along with the report.

5.2 Identifying significant sources of emissions

The comments made in Section 3 relating to emissions from construction activities, operation and maintenance generally apply to the development of water and sanitation projects.

Key carbon impacts associated with water and sanitation infrastructure arise from:

- Construction of water abstraction works, raw water mains, treatment works, pumping and distribution systems;
- Construction of urban sewers, centralised sewage treatment plants, septic tanks or other local works;
- Operation of pumping and treatment systems;
- Operation of wastewater pumping, wastewater treatment (particularly secondary treatment).

Other carbon impacts can arise from:

- The transport of chemicals to treatment plant sites;
- The transport and recycling/disposal of sludge and waste from treatment plant sites;
- Displacement of existing water supply sources;
- Increases in water use as a result of cheaper, more accessible water supply – the rebound effect;
- Energy generated from sludge treatment (from on-site digestion), which displaces energy demand (and carbon emissions) elsewhere.

Typical sources of emissions arising from the different phases of water projects are set out in Table 6, together with the significance of each phase relative to the overall whole emissions.

Project Phase	Source of emissions	Relative significance
Planning and design	Site investigations, surveying, design office utilities use, travel.	**Very low** (but *high influence* on future emissions)
Construction	• Excavations, general site utilities use, enabling and temporary works • Extraction and processing of construction materials and transport to site • Off-site manufacture and transport of pipes, M&E equipment ranging from large complex kit such as a sludge press, to pre-fabricated tanks, to cabling, MCC kits, pipes to valves • Excavation, on-site construction of foundations, concrete and steel structures tanks and buildings • Installation of pipelines • Emissions from sub-contracted works • Removal and disposal of construction waste	**Low** (for solutions with significant operational energy use – e.g. pumping systems or energy-intensive treatment processes) **Medium/high** (for low-energy, gravity solutions)
Operation and maintenance	• Energy used for pumping, filtration, aeration and other processes • Fugitive process emissions • Manufacture of chemicals and transport of chemicals and other consumables to site • Transport of sludge from site and subsequent recycling/disposal, offset by any sludge digestion and combined heat and power (as discussed above) • Equipment repair and replacement	**High** (for solutions with significant operational energy use – e.g. pumping systems or energy-intensive treatment processes) **Low** (for low-energy, gravity solutions)

Project Phase	Source of emissions	Relative significance
Use	Change (increase) in water by consumers (including increased numbers of first-time connections) plus the resulting changes in the amount of wastewater to be treated, leading to greater energy use and greater CH_4 and NO_2 emissions from treatment processes	Potentially **High/ very high** (requires assessment within scope of project)
End of life	Decommissioning/demolition activities, transport of waste/material, disposal/recycling of waste	**Uncertain**
Other	Displacement of already existing water supply or sanitation operations (including methane generated from local septic tanks and cesspits) with higher (or lower) carbon intensity.	**Uncertain** (but important to assess)

Table 6 Typical sources of emissions by water/sanitation project phase

5.3 Selecting the appropriate level of carbon accounting

The inputs into a carbon emissions assessment of a water project depends on the level at which such an assessment is carried out, in conjunction with the level of accessible information and time constraints. Four levels are shown in Table 7. In general, a high-level top-down assessment requires less analysis but is more dependent on the availability of sector-specific data. A top-down assessment is most appropriate at the early stages of programme or project decision making, where choices between alternative options are required. A lower-level bottom-up assessment is more data intensive but can be built up from generic emissions factors applied to known quantities. Bottom-up assessments may be applied at later stages where validation of earlier estimates is desired. The combination of top-down and bottom-up assessment is similar to approaches used for cost estimation.

Level	Carbon metric	Comments
1. Work item	kg CO_2e/kg or m^3 or kg CO_2e/of material or work item	Common to all infrastructure sectors. Thus, comments made in Section 3 relating to construction, generally apply to the construction of water and sanitation projects.
2. Component of works	kg CO2e/unit of an equipment item or kg CO_2e = function [item size yardstick]	Typical components include: tank, pipeline, pump, blower, building unit; e.g. kg CO_2e/m^3 of reinforced concrete tank, e.g. kg CO_2e/m of MDPE pipe laid in road, e.g. kg CO_2e/per pump, mixer, blower, UV disinfection lamp, etc.
3. Process or project	kg CO_2e/unit of capacity or throughput kg CO_2e = function [capacity or throughput yardstick]	Typical processes include: pumping station, sedimentation tank, aeration tank, filter bed; e.g. kg CO_2e/m^2 (sedimentation) tank, e.g. kg CO_2e/m^3 of water, pumped or treated, e.g. kg CO_2e/kg biological oxygen demand (BOD) treated.

Level	Carbon metric	Comments
4. Overall investment	kg CO_2e/person served kg CO_2e/£ spent	Carbon emissions of providing drinking water to a given population, for treating sewage of a given population, of leakage reduction programme or pipeline rehabilitation programme; e.g. kg CO_2e/potable water per consumer (average), e.g. kg CO_2e/population equivalent (PE), e.g. kg CO_2e/km of mains rehabilitation programme. Allows comparison between different types and sizes of water/sanitation infrastructure within/between programmes.

Table 7 Levels of carbon estimating and associated metrics

5.4 Reducing carbon emissions from water and sanitation infrastructure

As discussed in Section 3, it is important to set appropriate boundaries for assessing and delivering carbon efficiency. In cases where the water/sanitation project is one of a suite of projects or where the project will affect other assets or operational activities, it is important to consider the overall opportunities for carbon reduction. It is also best to avoid taking action to reduce emissions from one asset that leads to an increase to emissions elsewhere. Instead, it is best to scope integrated projects, perhaps covering multiple facilities, to maximise overall energy, water and resource efficiency, and minimise waste.

Over the last decade, energy consumption by the water sector in developed countries has increased considerably as a result of implementing new works to meet new standards. Significant efforts are now being made in many countries to identify and implement energy efficiency improvements in these systems. The Global Water Coalition and UKWIR have published a compendium of energy efficiency best practice and case studies covering a number of priority areas: demand management, pumping, treatment, sludge management and energy generation (Brandt et al, 2010). Energy efficiency gains of 5-25% are considered realistic, with pumping systems and aerobic sewage treatment assessed as the areas of greatest opportunity. While focused on the developed world water and sanitation facilities, the best practice set out in this compendium is likely to be relevant to the development of urban water and sanitation systems in LDCs, as well as older systems which would benefit from an overhaul.

There are various opportunities for developing carbon-efficient water and sanitation treatments:

- Most emissions associated with water are not the result of supply or treatment, but from its use by consumers (such as boiling hot water and general use for cleaning, washing, cooking, etc.). Hence, consideration of community-based education initiatives regarding water-efficient practices within the home, and the control of water-efficient equipment will help curb emissions and education on the acceptable materials to discharge to sewers to prevent blockages and pump failures. The increasing application of local potable water solutions (such as the LifeStraw water filters discussed in Box 7) which reduce the need to boil water are important initiatives that can significantly assist in the provision of low-carbon water supplies.

Where new larger-scale water or sanitation projects are to be developed:

- On water projects, give consideration to the carbon emissions from the various abstraction works, treatment, pumping and distribution systems that make up a water resource zone and take action to ensure that the current project contributes to the maximum possible reduction across that zone.

- On wastewater projects, give consideration to the carbon emissions from the various treatment works, urban drainage systems and land-management practices within a catchment, and take action to ensure that the current project contributes to the maximum possible carbon reduction across that catchment. In some cases, it may be appropriate to recommend a review of proposed licences/consents on the basis of catchment-level carbon impacts to avoid over-treatment.

In general, ensure that, where different development options are being considered, the boundary for assessing carbon efficiency is the same for each option.

Box 7 Case Study – Carbon reduction through the provision of clean water

The 'carbon for water' programme is a campaign using carbon financing to provide sustainable access to safe drinking water, and is expected to reduce two million tonnes of carbon emissions. In April and May 2011 more than 877,500 *LifeStraw®* water filters were distributed to approximately 90% of all households in Western Province, Kenya. This programme is providing safe access to clean drinking water for a community of 4.5 million residents.

The programme is led and financed by Vestergaard Frandsen (VF), a Swiss-based company, in partnership with the Kenyan Ministry of Public Health and Sanitation. VF's expenses are being reimbursed by carbon financing. The carbon for water programme generates carbon credits for VF and, in turn, once they are sold, revenue. Carbon credits are earned because residents in Kenya who receive *LifeStraw®* filters no longer have to treat water by boiling it using wood, which generates greenhouse gases. This behavioural change is expected to produce more than two million tonnes of carbon emission reduction annually.

As the supplier of the water filters and implementer of the programme, Vestergaard Frandsen earns the carbon credits. Since the company only gets paid for performance (i.e. emissions reduced) it has a strong incentive to invest the revenue it earns back into the programme – to maintain and replenish the *LifeStraw®* family water filters and to educate residents on proper and consistent usage. The programme is ambitious and visionary. It is eight times larger than any other registered project in the Gold Standard voluntary market. It is also the first that directly links low-carbon development with access to safe drinking water and positively impacting health outcomes.
(Source: *Vestergaard Frandsen, 2012*)

SECTION 6

Carbon management: surface transport

6.1 Carbon impacts of surface transport infrastructure

Transportation is the fastest growing major contributor to global climate change, accounting for 23% of energy-related CO_2 emissions. In parts of the world where the transport sector is expected to grow, related CO_2e emissions are expected to increase significantly if no changes are made to transport investment strategies (Replogle et al, 2010). This section focuses on DFID's main areas of transport interest: roads and some aspects of rail transport.

Bowen and Fankhauser (2011) state that, as it was imperative for LDCs to develop and overcome poverty, the Kyoto Protocol allowed poor countries to bypass adopting emission reduction targets. However, rapidly industrialising countries such as India and China have been far more emission-intensive than typical LDCs, emitting 505 and 1052 tonnes CO_2/per million dollars of GDP respectively. UNEP states that India is now the world's fourth largest GHG emitter and the second largest contributor to this is its transport sector. Bowen and Fankhauser (ibid) advise that low-carbon transportation is as imperative as tackling poverty because of its potential major contribution to the growth of carbon emissions from LDCs.

A major factor influencing growth in the demand for transport infrastructure is increasing wealth; this is leading to increasing car ownership and freight traffic, which in turn requires greater transport infrastructure, fuelling stations and support service industries.

At the individual project level, it is important that proper consideration is given to the carbon impact of new transportation projects – applying the principles set out in Section 3.2 – to supplement an overall Climate and Environment Assessment prepared in support of the business case (as discussed in Box 8).

Box 8 Case Study – Road development in the Democratic Republic of Congo

As part of MONUSCO (the United Nations Organisation Stabilization Mission in the Democratic Republic of the Congo), the UK will provide £19.5m over 10 years to build and maintain roads in eastern Democratic Republic of Congo (DRC). It is an imperative initiative and critical to the DRC; with only 5-10% of its 152,400km road network in fair-to-good condition (the remainder is impassable), this is restricting DRC's efforts to achieve its MDG goals and take itself out of poverty.

The project is to build/upgrade 628km of roads, the construction of which will support employment and trade, and help to reduce basic household living costs. Owing to the heavily forested nature of topography in the eastern provinces, sustainable road maintenance will be critical, without which roads quickly deteriorate; an investment of US$1 in maintenance in sub-Saharan Africa saves a further US$4 in rehabilitation costs.

As part of its Climate and Environment Assessment, DFID intends to undertake a carbon assessment of the project and include staff travel, the embodied carbon of construction materials, and the increased emissions that will result from higher traffic volume on the roads. Consideration will be given to opportunities for emission reduction, including reduced

air lifts, which will be weighed against the benefits for DRC's development and stabilisation. While road construction is vital, there is a risk that the social, environmental and carbon cost may outweigh the benefits unless great care, management and rigorous policing is undertaken following road construction.
(Source: *DFID, 2013b*)

6.2 Identifying significant sources of emissions

Carbon emissions from the transport sector arise predominately from the construction, use and maintenance of highways, rural roads and railways.[15]

Akin to water and sanitation projects, construction-related emissions from most transport projects are usually small in proportion to their in-use emissions. A study by the ADB (2010) (see Box 9 in Section 6.4) of four highway projects in India showed that the road use phase has the highest contribution to a road's carbon footprint (more than 93% in all sampled roads); the construction and maintenance aspects account for only 7% of the total.

Even with a sensitivity analysis (with a 10%-20% increase and decrease in traffic flows) the construction and maintenance emissions amounted to no more than 10% of the total life cycle emissions (ibid). Possible exceptions to this could be projects that involve extensive tunnelling or elevated structures, which require significantly more construction materials and energy per kilometre.

The mode of transportation infrastructure is also a factor. Emissions from highways and trucks are higher than those from railways and public transport (high capacity buses in particular); of course, cycling emissions are lower than private motorised road transport (Replogle et al, 2010).

In addition, the carbon assessment of transport projects must take account of induced travel impacts, particularly where an increase in transportation capacity leads to changes in vehicle use. The emissions arising from changes in land use as a result of building roads can be very significant.

A carbon stock assessment conducted by the ADB for the East West Economic Corridor (EWEC) in Laos showed that annual carbon emissions, due to loss of carbon stocks, were 10 times the annual emissions from traffic using the EWEC road in Savannakhet (Crishna-Morgado et al, 2012).

Typical sources of carbon emissions arising from the construction, operation and maintenance of transport projects are shown in Table 8, together with the significance of each phase relative to the overall whole emissions.

Project Phase	Source of emissions	Relative significance
Planning and design	Site investigations, surveying, design office utilities use, travel	**Very low** (but <u>*high influence*</u> on future emissions)
Construction	• Excavations, site utilities use, enabling and temporary	**Low**

15 Of course, the development and operation of airports, and the growth in aviation traffic these generate, also lead to significant increases in carbon emissions; however, airport infrastructure is not addressed in this guide.

Project Phase	Source of emissions	Relative significance
	works • Extraction/processing of construction materials and transport to site • Import of road building equipment such as rollers • On-site construction of foundations, bridges • Off-site manufacture and transport of geotextiles, culverts, drains, barriers and other components • On-site activities, e.g. traffic diversions, earthworks, aggregate extraction/crushing and concrete batching • Use of mobile construction plant to lay foundations and roadways • Emissions from sub-contracted works • Removal and disposal of construction waste	(construction and maintenance probably less than 10% of whole life emissions – see Box 9)
Maintenance	• Fuel (diesel) used for road cleaning/sweeping/gritting/painting • Electricity used for lighting, signalling equipment and control systems • Gully cleaning, maintenance of verges and embankments, winter maintenance • Repairs and renewals of roadway and ancillaries	**Low** (construction and maintenance probably less than 10% of whole life emissions – see Box 9)
Use	• Energy consumed by traffic using highway, and changes in traffic flows elsewhere attributable to the project • (Increase) Energy consumed by traffic using highway, and changes in traffic flows elsewhere attributable to the project, increases in population, resulting in higher volume of vehicles, and households owning, more than one vehicle. Increased road freight transport, and vehicular accidents, particularly those involving flammable products. Car parking, both at residences and at industrial sites and retail sites, is likely to result in concrete-paved driveways, multi-storey car parks, and oil leaks.	**High** (probably more than 90% of whole life emissions – see Box 9)
End of life	Decommissioning, demolition activities, disposal of wastes and landscaping	**Uncertain**
Other	Loss of forested areas leading to reduction in carbon sequestration and burning of resulting wood fuel	**Uncertain** (but important to assess)

Table 8 Typical sources of emissions by transport project phase

6.3 Selecting the appropriate level of carbon accounting

The inputs into a carbon emissions assessment of a transport project depend on the level at which such an assessment is carried out, in conjunction with the level of accessible information and time constraints. Four levels are shown in Table 9. In general, a high-level top-down assessment requires less analysis but is more dependent on the availability of sector-specific data. A top-down assessment is most appropriate at the early stages of programme or project decision making, where choices between alternative options are required. A lower bottom-up level assessment is more data intensive, but can be built up from generic emissions factors applied to known quantities. Bottom-up assessments may be applied at later stages where validation of earlier estimates is desired. The combination of top-down and bottom-up assessment is similar to approaches used for cost estimation.

Level	Carbon metric	Comments
1. Work item	kg CO_2e/kg or m^3 of material or work item	Common to all infrastructure sectors. Thus, comments made in Section 3 relating to construction generally apply to the construction of transportation projects.
2. Component of works	kg CO_2e /unit of an equipment item, or kg CO_2e = function [item size yardstick]	Typical components for roads could include: section of road pavement, bridge deck, street light, signalling, signage, drain and soak away. Similar components could be derived for railways; e.g. kg CO_2e/m^2 of road pavement, kg CO_2e/street light.
3. Process or project	kg CO_2e/unit of capacity or throughput, or kg CO_2e = function [capacity or throughput yardstick]	E.g. kg CO_2e/km of 2-lane highway constructed (based on aggregated quantities of cement, steel, bitumen, etc. per m^2 of road surface), kg CO_2e/km of railway laid, kg CO_2e/km of bicycle path, kg CO_2e/ha of forested land lost due to new highway.
4. Overall investment	kg CO_2e/person served kg CO_2e/£ spent	Allows comparison between different types and sizes of transport infrastructure within/between programmes; e.g. kgCO_2e/passenger-km or /freight tonne km.

Table 9 Levels of carbon estimating and associated metrics

6.4 Reducing carbon emissions from surface transport infrastructure

As discussed in Section 3, it is important to set appropriate boundaries for assessing and delivering carbon efficiency. In cases where the transport project is one of a suite of projects or where the project will affect other assets or operational activities, it is important to consider the overall opportunities for carbon reduction. It is also best to avoid taking action to reduce emissions from one asset that leads to an increase to emissions elsewhere. Instead, it is best to scope integrated transport projects, perhaps covering multiple facilities, to maximise overall energy, water and resource efficiency, and minimise waste.

Opportunities for reducing the carbon impacts of transportation projects include:

- Promoting integrated transport investment strategies that encourage shifts to lower carbon modes including light rail, public transport, and cycling;
- Carefully selecting and scoping the type and extent of new transport infrastructure based on the results of multi-modal studies. This may involve prioritising the development of public transport and railways over highways, where this delivers lower carbon solutions;
- Improving traffic operations – including upgrading national fleets, deploying cleaner fuels, retrofitting vehicles with green technologies, and improving driver behaviour;
- Pursuing intermodal freight initiatives to improve supply chain efficiencies, maximising the proportion of freight km by low-carbon modes ;
- Improving road maintenance practices to reduce rates of deterioration and thereby improve travel efficiencies;
- Implementing safe, well-lit cycle routes to encourage those travelling short distances to avoid use of the highways – this will also help improve accessibility for the poorest and more vulnerable members of society;

- Improving sequestration through reforestation – plantations on slopes should be managed for soil protection, water conservation and biodiversity;
- Investing in biofuel alternatives (where there is no conflict with agriculture, forestry or other more beneficial land uses) to reduce reliance on fossil fuels.

Box 9 Case Study − India

In 2010, the Asian Development Bank (ADB) developed a robust carbon footprint model for road projects in LDCs. The report which followed sets out a carbon emission calculation methodology to assist in future project evaluation. It determined that the carbon footprint of a road can be defined as the total amount of CO_2 and other GHGs (direct and indirect) emitted over the full life cycle of a road, including construction, operation and maintenance and end-of-life rehabilitation or abandonment.

The carbon emissions from roads, according to the ADB methodology, can be assessed under three categories:

1) Construction phase
    a. Embodied carbon in construction materials
    b. Fossil fuels (direct emissions from combustion, embodied carbon from upstream life cycle)
    c. Removal of vegetation (lost carbon sequestration, emissions from wood fuel combustion)
    d. Machinery and vehicles (embodied carbon in machinery and vehicles)
2) Operation/use emissions
    a. Fossil fuels (direct emissions from combustion, embodied carbon from upstream life cycle)
    b. Vehicles (embodied carbon in vehicles)
3) Maintenance emissions
    a. Embodied carbon in construction materials
    b. Fossil fuels (direct emissions from combustion, embodied carbon from upstream life cycle)

The phases and calculation approach is closely aligned with the methodology set out in this guide, including the life-cycle emissions of materials and fossil fuel use, as well as the exclusion of emissions from construction machines/vehicles on the basis that the same machines/vehicles are used on multiple projects.

Four ADB-funded road projects were selected, covering different types of road project, location and stage of construction. Data were then collected against a range of metrics covering all the activities involved in constructing, operating and using these roads. Assumptions were made on the expected fuel mix and fuel efficiency of traffic using the roads up to 2030, using references on mileage for different modes of transport.

The various quantities were converted to CO_2e using emission factors obtained from Indian sources – such as ARAI (2007) and Smith et al (2000) – as well as international references. Overall metrics were calculated for each case study project for the construction and operational/use and maintenance phases, all expressed in tCO_2e/km.

The study found that the road use phase has the highest contribution to a road's carbon footprint (more than 93% in all sampled roads), such that the construction and maintenance aspects account for only 7% of the total. Even with a sensitivity analysis (with a 10-20%

increase and decrease in traffic flows) the construction and maintenance emissions amount to no more than 10% of the total life-cycle emissions. Thus, the construction and maintenance phases are small when compared with emissions from vehicular movement on Indian roads over their total life. This leads to the conclusion that future work on estimating carbon footprints of ADB road projects should focus on the operational/use phases and opportunities for mitigating this most significant source of emissions from road projects. However, it is emphasised that this does not mean that efforts to reduce GHG emissions at the construction phase should be abandoned.
(Source: *ADB, 2010*)

SECTION 7

Carbon management: solid waste

7.1 Carbon impacts of solid waste infrastructure

In many cities in LDCs, municipal waste is either simply not collected or collected infrequently. This often results in the uncontrolled disposal of waste, leading to significant emissions of methane (arising from rotting organics) as well as other problems. Since methane has a global warming potential 21 times that of carbon dioxide (see Appendix 1), such practices contribute significantly to a country's GHG emissions, in addition to causing obvious health risks. In such circumstances, even the provision of a simple sanitary landfill would provide significant improvement. In other cities, waste-picking (informal collection, separation and recycling) is commonly undertaken by some of the local population. Besides the useful income that can be derived from this, it is a low-carbon, albeit informal, practice.

On the assumption that improved waste collection would be an important first objective in many LDCs (with opportunities for carbon reduction), municipal solid waste (MSW) infrastructure projects can perhaps be divided into four broad types: landfills, composting facilities, incineration, and waste-to-energy plants, the latter supplemented by various forms of mechanical or biological treatment. A standard landfill produces large quantities of methane emissions from decaying wastes (albeit at a lower rate than uncontrolled disposal). This can be mitigated by capturing the methane and using it to generate electricity (or, if necessary, flaring). Although not yet commonly practised in LDCs, this should increasingly be considered as a sustainable solution.

Composting of organic waste has many benefits. The findings of a case study by Snyman (2011) in the city of Tshwane in South Africa revealed that composting practices can significantly reduce MSW volumes and thereby extend the lifespan of current landfills (see Box 10). Furthermore, composting creates new jobs for residents and produces marketable products (e.g. good replacement for artificial fertiliser) and a more cost-effective alternative to standard landfills. Composting as a MSW management technology could expand and play a much greater role in developing countries. Informal methods of composting cost almost nothing, aside from the manual labour and the gathering of readily available materials. However, a strong policy is often needed to introduce composting activities in order to reach MSW minimisation goals. Importantly, such policies seek to ensure composting is carried out under aerobic conditions, to avoid the methane generation that occurs under when composting operations become anaerobic.

While burning waste in an incinerator reduces methane emissions, this generates significant CO_2 emissions. Conventional waste incineration entails little or no separation or pre-treatment and so much of the waste that could be recycled is lost. In addition, in countries where legislation is weak, emissions to air can have adverse health impacts for the local population. By contrast, more advanced energy-from-waste plants, incorporating waste separation, pre-treatment and, importantly, energy recovery, can provide much better waste-management solutions. While it is recognised that these solutions are expensive and not yet appropriate for many LDCs, the potential carbon savings and revenue from energy recovery could make waste-to-energy approaches viable for larger cities.

Box 10 Case Study – Composting in the city of Tshwane in South Africa

The findings of a case study in the city of Tshwane in South Africa reveal that composting practices can be financially viable, using an accelerated composting method using dome aeration technology (DAT). Whatever method is used, composting will reduce MSW volume by at least 42.5%, and thereby extend the lifespan of current landfills. Furthermore, composting creates new jobs for residents and produces marketable products and a more cost-effective alternative to standard landfill cover. It is also a good replacement for artificial fertiliser, which is more expensive and has a greater impact on the environment. The demand for compost is increasing and more companies are starting to produce and sell compost. Both windrows studied produced good quality compost. However, with the DAT method the turnaround frequency proved to be more than double that of the conventional windrow method, thus making it a more viable composting alternative. Snyman (2011) proposes that composting as a MSW management technology could expand and play a much greater role in Tshwane and other developing countries. The growth of MSW composting facilities will, however, depend on the development of good facilities and the economics of MSW management. Composting costs almost nothing, aside from the manual labour and the gathering of readily available materials. The costs are inconsequential in comparison with the returns composting can bring to residents and the natural environment. (Source: *Snyman, 2011*)

Gurung and Polprasert (2007) investigated the potential for waste to energy as a CDM project in the MSW management sector in Bangkok, Thailand. Waste minimisation is possible through a combination of the '3Rs' (reduce, reuse, recycle) and waste-to-energy processing. If the 3R path is followed, Gurung and Polprasert (ibid) have shown that the pre-treatment of wastes by MBT (mechanical-biological waste treatment) can reduce waste volumes by 40-60%, with minimal or no methane emissions.

Of course, the success of waste-minimisation approaches depends on the success of efforts to encourage the public and other waste producers to sort waste prior to disposal, as well as the logistics of waste collection from urban conurbations. There may also be induced effects on waste-picking activities, which in some cities are an important source of income for poorer households.

7.2 Identifying significant sources of carbon emissions

Carbon emissions from the waste sector depend on the method of waste management and technologies employed.

Carbon impacts associated with waste management projects arise from:

- Waste collection (where motorised vehicles are used) and transportation of waste to landfill or treatment sites;
- Development and operation of landfills and composting facilities;
- Development and operation of waste incineration or waste-to-energy plants;
- Waste separation and recycling activities. Of course, high technology MBT processes will require significant energy inputs relative to manual sorting operations.

In addition, the changes in emissions arising from the displacement of existing waste practices (including informal dumping by waste producers and decomposition) by new infrastructure projects should be included in the analysis. Of course, separation and recycling at source (by the waste producer) will reduce the amount of process and waste treatment and, hence, carbon emissions. Typical sources of carbon emissions arising from the construction, operation and maintenance of waste projects are shown in Table 10.

Project Phase	Source of emissions	Relative significance
Planning & design	Site investigations, surveying, design office utilities use, travel	**Very low** (but *high influence* on future emissions)
Construction	• Excavations, general site utilities use, enabling and temporary works • Extraction and processing of construction materials and transport to site • Excavation, on-site construction of foundations • Off-site manufacture and transport of geotextiles and liners for landfills • Specialist storage/composting equipment for MBT • Retrofitting old landfills with bio-filter liners and caps/pipes for methane capture • Emissions from sub-contracted works • Removal and disposal of construction waste	**Low** (for energy-from-waste schemes depending on scale and efficiency) **Medium/high** (for capital-intensive solutions with low operational emissions)

Operation and maintenance	• Methane emissions from landfill (where not collected)
	• MSW Combustion produces CO2 and N2O emissions
	    ◦ CO2 emissions can be calculated by estimating the total carbon content of waste from default data (see Table 5.6 in IPCC, 2000)
	    ◦ N2O emissions depend on facility and type of waste. Emission factors for fluidised-bed plants are higher than from plants with grate firing systems. If site-specific factors are not available, use default values (see Table 5.7, ibid)
	• Fossil fuel combustion and electricity used for waste processing
	• Materials for bio-filter (coconut shells/eucalyptus) and filters (geotextile)
	• Repairs and renewals of roadways and ancillaries
	• Transportation of municipal waste to landfill or processing centre
		Medium/high (for carbon-intensive waste solutions – e.g. landfill without gas capture)
		Medium/low (for energy-from-waste schemes depending on scale and efficiency)

Use	• Collection and transportation of sorted and unsorted MSW by local population • Provision of bins and skips for residents and businesses	**Low**
End of life	Disposal of wastes, landscaping and flaring of excessive gas	**Uncertain**
Other	Loss of forested areas due to land requirements for waste management, leading to reduction in carbon sequestration	**Uncertain** (but important to assess)

Table 10 Typical sources of emissions by waste project phase

7.3 Selecting the appropriate level of carbon accounting

The inputs into a carbon emissions assessment of a waste project depend on the level at which such an assessment is carried out, in conjunction with the amount of accessible information and time constraints. Four levels are shown in Table 11.

Level	Carbon metric	Comments
1. Work item	kg CO_2e/kg or /m^3 of material or work item	Common to all infrastructure sectors. Comments made in Section 3 relating to construction generally apply to solid waste projects.
2. Component of works	kg CO_2e /unit of an equipment item, or kg CO_2e = function [item size yardstick]	Typical components could include: tank, pipeline, pump, building unit, landfill lining; e.g. kg CO_2e/m^2 landfill area, kg CO_2e/m^3 composting volume, kg CO_2e/m^3 methane flared, kg CO_2e/tonne km waste transported.
3. Process or project	kg CO_2e/unit of capacity or throughput, or kg CO_2e = function [capacity or throughput yardstick]	Typical processes include: transportation and sorting of municipal waste, MBWT process, incineration, compost production, gas flaring/energy generation at landfill; e.g. kg CO_2e/m^2 landfill (based on methane production, etc.), kg CO_2e/tonne organic waste composted, kg CO_2e/tonne waste processed by MBT, kg CO_2e/kWh of electricity generated (based on kWh per m^3 of methane captured/landfill m^2).
4. Overall investment	kg CO_2e/person served kg CO_2e/£ spent	Allows comparison between different types and sizes of waste management approaches within/between programmes; e.g. kg CO_2e/person served by waste facility.

Table 11 Levels of carbon estimating and associated metrics

In general, a high-level top-down assessment requires less analysis but is more dependent on the availability of sector-specific data. A lower-level assessment is more data intensive but can be built up from generic emissions factors applied to known quantities. A high-level top-down assessment is most appropriate at the early stages of programme or project decision making, where choices between alternative options are required. A lower-level bottom-up assessment is more data intensive but can be built up from generic emissions factors applied to known quantities. Bottom-up assessments may be applied at later stages where validation of earlier estimates is desired. The combination of top-down and bottom-up assessment is similar to approaches used for cost estimation.

7.4 Reducing carbon emissions from solid waste infrastructure

Opportunities for reducing the carbon impacts of waste management projects include:

- Improving waste collection practices and waste minimisation through the 3Rs;
- Increasing the amount of aerobic composting of organic waste;
- Landfill methane (and leachate) reduction and management through the use of bio-filters, linings and capture technology (see example in Box 11);
- Reusing leachate on composting windrows to increase production, and reducing contamination of arable and agricultural land;
- Increasing use of MBT technologies to remove recyclables and organic matter prior to reduce methane emissions and reduce waste volume to landfill (and therefore land area required);
- Increasing use of waste to energy (with pre-treatment) will provide alternative energy sources and reduce the requirement for fossil-fuel energy generation.

Box 11 Case Study – Landfill gas capture in Thailand

Gurung and Polprasert (2007) investigated the capture of landfill gas from two long-established landfills in Thailand (retrofitted with linings and pipes to enable methane capture, connection to export electricity to grid, and flues for flaring). Ratchathewa landfill captures landfill gas at 600m^3/hour and generates 1MW/h of electricity, and reduces nearly 47,000 tonnes CO_2e over a period of a year. Kampang Sean landfill captures gas at 300m^3/hour, which is flared, and reduces nearly 15,000 tonnes CO_2e over a period of a year. While direct comparison is difficult due to the landfill gas capture rate (600 vs 300m^3/hour) and the area of landfill used for gas capture (128,000 vs 20,000m^3), it is clear that methane emissions will be reduced by MBWT, energy from waste and even flaring (which is preferable to not taking any action at all).
(Source: *Gurung & Polprasert, 2007*)

Jowitt, P., Johnson, A., Moir, S. & Grenfell, R. (2012) *A Protocol for Carbon Accounting in Infrastructure*

The impacts of climate change have resulted in a need to address the whole life impact of infrastructure projects on carbon emissions. There is an increasing concern that carbon impacts need to be included as part of overall project appraisals. This leads to two fundamental issues: the first concerns setting the appropriate spatial and temporal boundaries for the carbon assessment; the second concerns the way carbon emissions are included in project decision making.

This paper addresses both these issues, establishing a protocol for carbon accounting based on best practice but questioning the simplistic concept of carbon pricing as an effective instrument of reducing carbon emissions. The protocol draws on the established standards for assessing life cycle emissions, such as PAS 2050, and reporting principles set out in the Greenhouse Gas Protocol.

While originally developed to provide guidance for low-carbon civil engineering infrastructure in the UK, it is considered that most of the principles and methodology set out within the protocol are also applicable to aid-funded infrastructure in less developed countries (LDCs). As such, the protocol set out in this paper has been adopted as the basis for the framework (principles and method) set out in Section 3 of the Topic Guide.

WRI & WBCSD. (2004) *Greenhouse Gas Protocol and ISO 14064: 2006 Greenhouse Gases*

The Greenhouse Gas Protocol (GHG Protocol) published by the World Resources Institute and the World Business Council for Sustainable Development is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. It is designed to allow GHG emissions reporting at the organisational level based on the principles of relevance, completeness, consistency, accuracy and transparency. In 2006, the International Organization for Standardisation adopted the Corporate Standard as the basis for its ISO 14064-1. WRI and WBCSD have since built on the GHG Protocol Corporate Standard by developing a suite of calculation tools to assist companies in calculating their greenhouse gas emissions, and produced additional guidance documents such as the GHG Protocol for Project Accounting.

The recently published ISO 14064 standards provide governments, businesses, regions and other organisations with an integrated set of tools for programmes aimed at measuring, quantifying and reducing greenhouse gas emissions. These standards allow organisations to take part in emissions-trading schemes using a globally recognised standard. ISO 14064 comprises three standards detailing specifications and guidance for: the organisational level; the project level; validation and verification.

These standards serve a number of purposes. They:

- Ensure the credibility, consistency and transparency of GHG accounting and reporting;
- Increase investor confidence;
- Facilitate the certification and trade of GHG emission reductions or removal enhancements;

- Facilitate the development and implementation of organisations' GHG management strategies and plans;
- Allow entities to track performance and progress in the reduction of GHG emissions and/or increase in GHG removals;
- Assist in the identification of GHG risks or liabilities;
- Facilitate the development and implementation of GHG projects.

Both the GHG Protocol and ISO 14064 standards provide solid foundations for carbon accounting. While the principles they contain, such as dividing emission sources into different scopes and setting appropriate boundaries, are fundamental to all types of carbon accounting, their applications are primarily intended for organisational-level reporting and formal verification of GHG reduction projects under schemes such as the Clean Development Mechanism (set up by the UN Framework Convention on Climate Change). Their methods are not directly applicable to assessing life-cycle emissions of infrastructure projects. For these reasons the methods set out in other references (Jowitt et al, 2012; BSI, 2011a) and sectoral guidance (such as UKWIR's framework for accounting for embodied carbon) are more directly used to inform the principles and method set out in this Topic Guide .

BSI. (2011(a)) *PAS 2050:2011 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*

PAS 2050 is a Publically Available Specification (PAS) prepared by the British Standards Institute with assistance from Carbon Trust and DEFRA. Building on existing life-cycle assessment methodologies established in BS EN ISO 14040 (BSI, 2006a) and BS EN ISO 14044 (BSI, 2006b), this PAS presents a consistent approach for assessing the life-cycle emissions associated with goods and services (termed 'products') and is based on the GHG Protocol Corporate Standard (WRI & WBCSD, 2004) principles of relevance, completeness, consistency, accuracy and transparency. PAS 2050 presents a rigorous approach for determining GHG emissions under the headings of scope, system boundary, and data and allocation of emissions, and is supported by a detailed document containing a fully developed whole life GHG assessment (BSI, 2011b).

For example, calculations carried out in accordance with this PAS should include all emissions and removals within the system boundary that have the potential to make a material contribution to the assessment of GHG emissions, i.e. all sources of emissions (and processes for removal) anticipated to make a material contribution to life-cycle GHG emissions of the 'functional unit', and at least 95% of anticipated life-cycle GHG emissions and removals associated with the functional unit.

Two types of assessment are identified: cradle-to-grave quantification and cradle-to-gate quantification. Cradle-to-grave quantification includes emissions from the full life cycle of the product, whereas cradle-to-gate quantification includes emissions arising up to the point at which the product leaves the organisation undertaking the assessment and is transferred to another party. The latter is a useful construct for the construction of engineering infrastructure and is broadly consistent with the concept of 'embodied carbon' used in this guide. Nevertheless, since the operational and use phases of engineering infrastructure can be material and, in some cases, dominant sources of emissions, a life-cycle approach is adopted. This is again broadly consistent with cradle-to-grave quantification, with the exception of end-of-life disposal, which is omitted because of the high level of uncertainty surrounding this stage of long-lived engineering infrastructure.

The processes to be covered in a PAS 2050-compliant assessment include: production of materials (their formation, extraction and transformation); energy use (including emissions at the point of consumption (e.g. combustion of oil and gas) and from the provision and transmission of energy (e.g. electricity generation and its transmission); chemical reactions; fugitive emissions; service provision; transport; storage of products; land use change; agricultural activities; waste management.

PAS 2050 is a rigorous approach best applied to the life-cycle processes of producing and distributing goods. The approach is not explicitly designed to suit the construction, operation and use of engineering infrastructure but, wherever practical, the principles and processes have been incorporated into the approach set out in this Topic Guide.

FFTF. (2009) *Forum for the Future – Carbon Management Framework for Major Infrastructure Projects – e21C Project Report*

The Carbon Management Framework for Major Infrastructure Projects from Forum for the Future (FFTF) arose from the UK Highways Agency's desire to extend the management of carbon across all its activities, with a particular interest in understanding the carbon implications of major projects. It has been informed, *inter alia*, by PAS 2050, the GHG Protocol Corporate Standard and DEFRA (DEFRA, 2009).

The FFTF framework accounts for GHG emissions over the whole life of an infrastructure asset (i.e. project and legacy, extending over the Pre-Design, Design, Construction, Use, Operation, Maintenance and Decommissioning phases), and recognises that, while all sources cannot be directly controlled, whole life carbon emissions can be influenced through effective design and management. Guidance is given on how to set boundaries and assess significant sources of emissions to be actively managed. General methods of calculation are provided along with tips for data collection and the level of accuracy requirements. The main details of the advocated methodology are expressed under four headings: understanding the role of project participants; boundaries; whole life carbon quantification and assessment; carbon management and reduction.

UKWIR. (2012) *A framework for accounting for embodied carbon in water industry assets, MWH*

Building upon a number of previously published sources, the UKWIR guidelines act upon the industry's intention to make carbon evident in investment decisions.

This guidance on embodied carbon and whole life carbon accounting for investment selection is based directly on DEFRA's (2009) authoritative guidance for companies to measure, report and reduce their carbon emissions; interpreting it for the water sector context, supplemented by authoritative international guidance provided in the new Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI & WBCSD, 2011) where relevant. The guidance is predicated on the DEFRA and DECC (2009) main recommendation (3) [emphasis added]: "Measure or calculate emissions that fall into your scopes 1 and 2 […] Discretionary: Measure or calculate your *significant scope 3 emissions* in addition to your scopes 1 and 2".

Two separate carbon emission boundaries are proposed:

1. Standard: based on the 'financial control' of emissions, covering a company's own assets, and including supply chain Scope 3 emissions. All companies should count their emissions within this boundary.
2. Discretionary: based on the test of other 'significant scope 3' emissions within the DEFRA guidelines. Companies may account, separately, emissions within this boundary, depending on their assessment of significance, ability to influence and relevance to their business case.

It is expected that there will be items identified as potentially significant contributors to the carbon emissions of a proposed solution and desirable to include within either the standard boundary or the discretionary boundary, but which are very difficult to count. This is likely to be because of a lack of information or a high level of uncertainty. In such cases these items may be omitted, or approximated, as long as a clear explanation is given.

Clear direction is provided regarding activity boundary and emission scope setting, together with guidelines for estimating the embodied carbon associated with the construction supply chain. Although the UKWIR document provides embodied emission values for some common construction items (e.g. below-ground pipeline installation), its primary focus is to set carbon embodied in construction within the context of a whole life carbon accounting approach and the application within economic appraisal. The UK water industry has been at the forefront of carbon accounting and the principles contained in the UKWIR Guidance are transferable to other infrastructure sectors.

DEFRA & DECC. (2009) *Guidance on How to Measure and Report your Greenhouse Gas Emissions*; DEFRA & DECC. (2012) *Guidelines to Defra/DECC's greenhouse gas Conversion Factors for Company Reporting*

The DEFRA (2009) guidance document provides step-by-step explanations on measuring GHG emissions as well as setting targets to reduce them. It is intended for all sizes of business and for public and voluntary sector organisations. It is based on the GHG Protocol (WRI & WBCSD, 2004), the internationally recognised standard for the corporate accounting and reporting of GHG emissions, and therefore is aligned with the most widely used national and international voluntary measuring and reporting schemes such as ISO 14064 and the UK's Carbon Trust Standard. The guidance also complements both PAS 2050 and ISO 14040, which can be used to measure the carbon footprint of products.

Although some organisations already report emissions for regulatory schemes such as the EU Emissions Trading Scheme, Climate Change Agreements or the UK's Carbon Reduction Commitment Energy Efficiency Scheme, these schemes only cover some of their GHG emissions. The DEFRA guidance covers an organisation's total GHG emissions, which encompasses all of the above, and recommends that all significant quantities of GHGs emitted as a result of its activities are measured.[16]

The guidance provides boundaries and recommends accounting for emissions that fall within the different scopes set out in the GHG Protocol, namely scope 1 (direct), scope 2 (indirect), and scope 3 (other) emissions where the latter are considered significant. Case studies are provided in order to illustrate key points. Of particular relevance to the Topic Guide is the fact that the emissions arising from the construction phase of infrastructure development fall under scope 3; these are significant and so need to be counted. In 2013, DEFRA published a new set of Environmental Reporting Guidelines (DEFRA, 2013) to help quoted companies to comply with the Companies Act 2006 (Strategic Report and Directors' Reports) Regulations 2013. The framework for reporting GHG emissions is broadly similar to that set out in the 2009 version and is based on the same references.

The DEFRA and DECC GHG Conversion Factors (annually updated excel spreadsheets with emissions factors) are provided to help organisations to calculate GHG emissions. While emission factors for non-UK based fuel use, freight transport, and passenger transport are not available, Annex 10 provides a useful list of overseas electricity conversion factors including factors for China, India, Pakistan, and Egypt, and generic factors for Africa, the Middle East and Latin America.

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16 The GHGs to be measured are the six gases that are covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), hydrofluorocarbons (HFCs), nitrous oxide (N_2O), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), measured in equivalent tonnes of CO_2 (tonnes CO_2e).

Automated spreadsheets (with pre-loaded emission factors' different activities) enable users to easily input activity data corresponding to the appropriate emissions factors. However, these are best suited to annual reporting of operational GHG emissions, rather than the life-cycle emissions of infrastructure development projects.

Nevertheless, when combined with relevant activity quantities, the conversion factors can be used to help assess the emissions from the various activities occurring during the life cycle of infrastructure projects in various sectors. These activities range from fossil fuel and biofuel use, passenger transport to freight transport, combined heat and power generation, industrial processes, water treatment and supply, refrigeration and air-conditioning, materials and waste.

Institution of Civil Engineers (ICE). (2011(a)) *Building a Sustainable Future: ICE Low-Carbon Infrastructure Trajectory 2050*

The ICE's infrastructure trajectory identifies changes required at all levels to ensure infrastructure is fit for a low-carbon future. The report takes a whole life view of infrastructure, looking at how benefits can be maximised and carbon minimised over the project life cycle. It also promotes a 'systems engineering' approach, considering the interaction between different networks, infrastructure assets and their users. It sets out five priority areas:

1. Establish a shared understanding of the purpose and performance requirements of UK infrastructure, taking into account UK's National Infrastructure Plan 2010 encompassing energy, transport, water, flood defences, digital communications and waste.
2. Establish an effective, transparent and predictable carbon price as the centrepiece of a package of incentives for developing low-carbon infrastructure. This will ensure that the potential harm and value of infrastructure decisions in terms of carbon is clear.
3. Systematically apply the concepts of Capital Carbon and Operational Carbon (as defined in the glossary) to infrastructure decision making.
4. Establish a high-level evaluation methodology for use at the appraisal stage of infrastructure project, ensuring that projects are geared towards lowest carbon solutions.
5. Make greater use of demand management, ensuring capacity where it is most needed without devaluing the infrastructure itself and without creating excess carbon emissions.

The report sets out actions that need to be undertaken within the next 5 years and provides supporting case studies covering water and road infrastructure, albeit with a UK focus.

DECC. (2013) *2050 Pathways: Exploring how the UK can meet the 2050 emission reduction target using the web-based 2050 Calculator*

The DECC (2013) Pathways project supports the UK's commitment to reduce GHG reductions by at least 80% by 2050. The 2050 Calculator, an excel-based tool at the heart of 2050 Pathways, combines live energy and emissions data and illustrates the benefits, costs and trade-offs of various future scenarios. Its aim is to enable users to understand and create a potential low-carbon future.

The scenarios are based on four trajectories, which cover supply (electricity generation), demand (transport, household and business) and other categories (geo-sequestration, balancing and storage, fossil fuel production). Users can select various options under the trajectories, down to quite granular levels. Using these selections, the model computes energy use and GHG emissions for the UK, based on the present time and 2050. The calculator is backed by a mine of information to assist users.

While a tool for the UK, the 2050 Pathways tool could be instructive for assessing the carbon emission implications of alternative infrastructure policies considered by developing nations. In fact, DECC is now working with countries around the world to help them develop their own calculators.

MacKay, D. (2009) *Sustainable Energy – Without the Hot Air*

This popular and authoritative text by Professor David MacKay addresses the present crisis facing the sustainable energy sector by objectively analysing the prevalent facts and figures. It provides a potential plan for change at the national and global scale. Using case studies, the text provides answers to conventional and non-conventional questions, as well as to the potential for sharing renewable energy between countries.

It also acknowledges the many predicaments and challenges relating to reducing consumption, but provides a much-needed positive reprise by addressing much of the misinformation that is in circulation.

Since many of the principles set out in this text are derived from the core science relating to energy generation and use, it will be a useful in helping DFID's practitioners develop a mature understanding of the issues and opportunities for sustainable energy infrastructure in developing countries.

HM Treasury. (2013) *Infrastructure Carbon Review*

The UK Government's Infrastructure Carbon Review, only recently published at the time of writing, sets out a series of actions for government, clients and suppliers to reduce carbon from the construction and operation of infrastructure assets, in line with the UK's climate change commitments. The purpose of the report is to realise the value of lower carbon solutions and to make carbon reduction routine practice in infrastructure development.

Using case study evidence, the report shows that reducing capital carbon and operational carbon (see glossary of key words and phrases in Section 10) makes good business sense because it: reduces costs; unlocks innovation and drives better solutions; drives resource efficiency; provides competitive advantage and export potential; contributes to climate change mitigation. Overall carbon reduction will deliver significant net benefit to the UK economy in the future.

Although aimed at leaders of organisations involved in the development, operation and maintenance of infrastructure assets across the UK Government's Strategy for National Infrastructure, the principles contained therein are applicable to all infrastructure development. Therefore, it is recommended that DFID practitioners familiarise themselves with this review and accompanying technical report to ensure the consistency of their approach to infrastructure carbon reduction overseas with government policy at home.

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Appendix 1 Global warming gases and selected databases of activity emission factors

The Kyoto 'six-pack' of global warming gases are shown in Table 12, together with their global warming potentials (GWP) relative to carbon dioxide.

Atmospheric gas	**GWP (global warming potential)** **tCO2e (carbon dioxide equivalent) over 100 years**
Carbon dioxide (CO2)	1
Methane (CH4)	21
Nitrous oxide (N2O)	310
Hydro fluorocarbons (HFCs) HFC-134a, HFC-23, HFC-152a , HCF-125	140-1170
Perfluorocarbons (PFCs) C2F6, C5F12, C6F14	7400-9200
Sulphur hexafluoride (SF6)	23,900

Table 12 IPPC Greenhouse gases and their GWPs

(Source: *IPCC, 2007a*, *Table 2.14*)

Some of the most commonly used activity emission datasets for operational and embodied carbon used for carbon assessment are listed in Table 13 and Table 14 respectively. The embodied carbon datasets have global application although some are country specific; an expanded list is available from the Greenhouse Gas Protocol website (WRI & WBCSD, 2012).

Parameter	**Suggested database**	**Comment**
Fuel combustion	(DEFRA & DECC, 2012)[17] Annex 1: fuel conversion factors	Emissions from fossil fuel use are a product of the carbon efficiency of fuel combustion and the amount of fuel used. Emissions per unit of fossil fuel combusted are primarily a function of thermodynamics. Hence, it is a fair approximation (and common practice) to use emission factors from standard suggested databases. These are single values that do not change with time.
Fuel combustion	(Smith et al, 2000)	Greenhouse gases from small-scale combustion devices in developing countries (Phase IIa): Household stoves in India. Although prepared using data for India, it is proposed this dataset could be used for similar calculations in other LDCs.
Transport fuel *(Transport emissions are further discussed in Section 6)*	(DEFRA & DECC, 2012) Annex 7: freight transport	Emissions from transport are a product of the carbon efficiency of the mode of transport used in country, the tonnage of goods transported and the distance travelled. In the absence of country-specific data, it is recommended that emission factors quoted from within the suggested database are applied, which are quoted in kg CO_2e/tonne km. Alternatively, fuel efficiency values (in litre/tonne km) may be determined from first principles using empirical information from the amount of fuel used to transport a known tonnage of goods over a known distance and then applying a standard value kg CO_2/litre of fuel from Annex 1 (DEFRA & DECC, 2012).
Transport fuel	(ARAI, 2007)	Draft report on Emission Factor Development for Indian Vehicles.
International	(DEFRA &	Emissions from electricity use are a product of the carbon intensity of

17 Produced by AEA.

Parameter	Suggested database	Comment
Grid Electricity Use *(Energy use emissions are discussed in Section 4)*	DECC, 2012) Annex 10: Overseas electricity transport	grid electricity provided in country and the amount of electricity used. International emission factors for a range of countries and regions are contained within the suggested database. For assessing the carbon emissions from energy used by consumers (e.g. construction activity) the values in Table 10c should be used. This table cites emission factors as kg CO_2 per kWh of electricity and it is recommended that the 5-year rolling average 'All Scopes – Grand Total GHG' values are used. These values are updated annually.

Table 13 Suggested databases for operational emissions factors

Parameter	Suggested database & citation ref	Comment
Construction materials, work items , pre-fabricated products	Inventory of Carbon and Energy (ICE V2) (Hammond & Jones, 2011)	Prepared by the University of Bath. Database of embodied energy and carbon of building materials. The database provides details of original references allowing users to verify sources. Widely used by the UK building, construction and wet infrastructure industry, it is presently the most widely used database in the UK.
Industrial Activities	CCaLC (Carbon Calculations over the Life cycle of Industrial Activities)	Prepared by the University of Manchester. The CCaLC tool calculates carbon footprints from cradle to grave. It enables identification of carbon 'hot spots' and carbon-reduction opportunities and also includes some data on other environmental and economic impacts as well as optioneering.
Construction materials, work items, pre-fabricated products	CESSM3 Carbon and Price Book	Published by the Institution of Civil Engineers. The *CESMM3 dataset* includes embodied carbon values for an extensive range of materials and work items, inclusive of labour, plant and temporary works in a manner that is similar to its dataset of unit financial costs.
A range of products across different industries	Ecoinvent	Ecoinvent is a Competence Centre of the Swiss Federal Institute of Technology Zürich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa), and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART). Ecoinvent was and is supported by Swiss Federal Offices. Ecoinvent provides scientifically sound and transparent international life cycle assessment (LCA) and life-cycle management (LCM) data and services to industry, consultancies, public authorities, and research institutions.
Industrial database dealing mainly with machinery and mechanical products	Environmental Product Declarations	There are also various other information sources on product groups provided by industry associations as well as an increasing number of Environmental Product Declarations on specific products, which are usually referenced on company websites. The BRE hold a store of certificates: http://www.greenbooklive.com/search/scheme.jsp?id=9 http://www.greenbooklive.com/search/scheme.jsp?id=153 The Environmental Product Declaration (EPD) also provides relevant, verified and comparable information about the environmental impact of goods and services.
Steel products	International Iron and Steel Institute (IISI)	The International Iron and Steel Institute (IISI) has produced a life-cycle inventory (LCI) study to quantify resource use and the energy and environmental emissions associated with the processing of 14 steel industry products from the extraction of raw materials in the group through to the steel factory gate.

Table 14 Suggested databases for embodied emissions