Sustainability and the Tunnelling Industry

Philip DUARTE, Mott MacDonald, United Kingdom, Philip.Duarte@mottmac.com
Alun THOMAS, Mott MacDonald, Hungary, Alun.Thomas@mottmac.com
Matthew COOKE, Mott MacDonald, United Kingdom, Matthew.Cooke@mottmac.com

Summary

To a greater or lesser extent, the need for sustainability has been accepted. In some ways civil engineering has been slow to embrace this challenge, although one could argue that many tunnelling projects are inherently sustainable. Because this field is in a nascent phase, there is a lack of established tools but in some areas standardised approaches have been developed – such as the CEEQUAL assessment system for sustainability. Technological advances are filtering through into the construction industry – such as hydrogen fuelled trains. This paper will explain how the challenges of sustainability apply to tunnels. Through some case studies such as the award-winning Thames Water Ring Main Extension and the A3 Hindhead projects in the UK, examples will be shared of how tunnels can minimise their environmental footprint at all stages of their lives.

Keywords: Sustainability, Carbon footprint, CEEQUAL, Operational / Embodied Carbon

1. Introduction

“The world must learn to work together, or finally it will not work at all” [1]

Sustainability was once believed and perceived to be the job of the environmentalist or perhaps something that got in the way of good engineering. Today it is generally recognised as an essential consideration to ensure survival of mankind as we know it. The statistics offered are bleak, and more often than not, the scenarios that face us in the next 100 years and which we deem unacceptable, are actually the best cases.

To ensure we understand the goal of this paper, it is worth defining what is meant by “sustainability”. “Global warming” refers to an increase in the Earth’s average surface air temperature. Global warming and cooling in themselves are not necessarily bad, since the Earth has gone through cycles of temperature change many times in its 4.5 billion years. However, as used today, global warming means a fast, unnatural increase that is enough to cause the expected climate conditions to change rapidly and often cataclysmically. [2] To be regarded as sustainable, a development has been widely defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. That is to say to, not unduly compromise the ability of our heirs to this planet to live unrestrained by our actions today. This paper will present how this is possible within the constraints of the tunnelling industry and where it has been applied successfully.

It is not the intention of this paper to list and debate statistics or which scenarios are most likely, since this tends to divide opinion on who or what is correct. What is clear and widely agreed is that the planet is heading for an extremely challenging future if human impact is not brought back to a level which is globally acceptable. In the interests of the reader and to illustrate key points, some generally agreed trends are summarised to address the urgency and need for change. While the exact numbers are not set in stone or necessarily important, the trends and repercussions are.

Generally speaking, as we continue on current trends, the more likely scenarios see London, Florida and New York (amongst other “key” cities) submerged in water by 2100. [3] Whilst you may not have noticed, the planet has seen a change of 0.5°C over the last 30 years (refer to Figure 1), this average increase has contributed to more extreme weather events. It must be understood that the construction industry contributes to this in many ways. A lot of the processes that we facilitate either generate carbon in use, so called “operational carbon”, as well through the construction process, known as “embodied carbon”.

1.1 Key Contributors

The key contributory gases to global warming can be found in Figure 2, and those that could be directly and indirectly attributable or controllable by the construction industry are highlighted in green. Looking at the graphic in more detail, almost 80% of global warming gases are attributable to carbon dioxide (CO₂). Of that 80%, as highlighted, approximately a third are areas relevant to tunnelling to a greater or smaller degree. It is clear that the whole life cycle of a tunnel contributes to this percentage, however, the challenge is to appreciate that even small changes early on, such as choosing from where materials are sourced for example, can impact the amount of carbon produced. Therefore it is from this base that this paper will look how the issues can be tackled through good design and by harnessing the technological advances available to the industry.

Today’s financial crises present an added obstacle which could derail progress or commitments from key polluters around the globe, particularly in developing nations (such as China and India) whose first priority is to stabilise their countries and eliminate poverty. As engineers we should see
this as a challenge rather than an obstacle to provide smarter designs that can fulfil the objectives of a sustainable tunnel over one which may, in the short term, seem more economically attractive.

1.2 What is different now?

Today it is widely accepted that the planet is being irreversibly damaged by our activities and agreed that collectively something must be done. The Kyoto protocol is almost 15 years old and although it was the first summit to produce legally binding targets for greenhouse gas emissions, it was clear that the major obstacle to international agreement was economic interest, especially in the developing nations like China, India, and Brazil. [6] Indeed, this has not changed and is arguably worse today. Those concerns ultimately hamstrung the Kyoto Protocol with the treaty only responsible for 33% of world emissions (after 2012, many nations will let their commitments expire and this will reduce to 15%). Even though it included comprehensive goals that set binding targets to reduce emissions an average of 5% against 1990 levels by 2012, it fell short in signatories. Only 37 industrialised nations signed the Protocol, committing to stabilise emissions. [6] Later on, the USA withdrew from the treaty saying it was “…fatally flawed in many ways...”.

Despite the best efforts of the nations that signed up (who reduced their carbon emissions), global emissions have soared by 35% since 1997 and this was directly attributable to those who did not sign up to the treaty. The top three largest emitters are China, USA and India in that order. [6]

The summit in Durban attempted to succeed where others have failed, to get more nations on board and crucially the big emitters, thereby addressing the urgency required, at the very least, to abate current trends that form the basis of these bleak predictions. By many observers this was deemed a success and this “high-ambition coalition” eventually included more than 120 nations, and what can be rightly described as momentous it also included the big three. It is intended that this treaty will be signed by 2015 and come into force in 2020, and to help soften the blow to developing nations, include a $100 billion per year fund overseen by the World Bank, to help them fight and adapt to climate change (noting that this was one of the reasons the Kyoto protocol was not acceptable to them in 1997). [6]

So based on this renewed global enthusiasm, and the very real prospect of a global effort, we must move forward to honour this commitment, and as engineers we are best placed to lead.

1.3 What is a Sustainable Tunnel?

It is worth at this point clearly distinguishing the two types of carbon that a project will be faced with from its conception to operation:

- **Embodied Carbon** - “the sum of energy inputs (fuels/power, materials, human resources, etc.) that was used in the work to make any product, from the point of extraction and refining of materials, bringing it to market, and disposal / re-purposing of it”.[1] This usually encompasses inter alia:
  - Extraction of raw materials (e.g. clay, sand, limestone, aggregates and metal ores), and associated transport.
  - Processing raw materials into products (e.g. limestone into cement, metal ores into steel or aluminium).
  - Transport of product to site.
  - Installation of material / product into building.
  - Maintenance of material / product.
  - End-of-life disposal of material. [7] [8]

- **Operational Carbon** - this is simply the carbon that is used during operation of the tunnel (i.e. when it is built)

Both these allow one to anticipate, calculate and modify how much carbon a tunnelling project can use, with the appropriate software or tools (discussed in a later section).

Based on the definitions above, the broad process required to achieve a sustainable tunnel can be summarised as follows:
1. A tunnel that considers the full project life cycle from the outset and seeks to have “feedback loops” at certain stages of design;
2. A tunnel that seeks to use the minimum amount of embodied carbon possible;
3. A tunnel that seeks to minimise the amount of operational carbon (i.e. future emissions);
4. A tunnel that complies with current sustainable initiatives;
5. A tunnel that represents a holistic collaborative effort between the client, designer and contractor.

The benefits of designing, building and operating a sustainable tunnel are both financial and socially rewarding. Currently the construction industry is not directly regulated by the EU Carbon Emissions Trading, but other industries which can be considered as the constituent parts of the industry are, so for example, both cement and steel are subject to scrutiny. The airline industry will also be regulated by this same system in 2012 which at first glance may not seem to affect the tunnelling community, but that is where the whole lifecycle of a project begins to rear its head; air travel to meetings for example. This really is a cradle to grave mindset which needs to be considered from the very beginning.

1.4 Key challenges

1.4.1 Financial

As alluded to earlier in the paper, a key challenge to the success and consideration of sustainability in a project is usually the financial one, and indeed there are elements which may cause the capital cost to increase. However, there are many incentives that can be realised without costing the project any more money, and even save money in the long run. Although a tunnel, or any project for that matter, may not be currently regulated or subject to strict performance criteria, that is not to say that in the future this will not happen.

A simple exercise such as that outlined in Figure 3 can quickly give a feel for the options available from the outset, and some of which are very easy to implement. The aim here is to establish “easy wins” with high benefit / low cost through to the high benefit / high cost. The latter options however would require buy in from other parties to continue (namely the Client) when this will substantially increase the capital cost – use of Ground Source Heat pumps or energy segments will cause the capital cost to increase but with potential benefits in the long run. It is a common misconception to discard sustainability as a “nice but expensive” exercise when, with even the smallest of efforts from the inception of a project, major strides can be made. All that is required is a mindset to do so.

![Figure 3 - Cost Benefit analysis](image-url)
1.4.2 Mindset

It is fair to say this could well be the greatest challenge facing us in the present day and future. Without a will there is no way. The older generation of engineers may not have seen this as one of the key challenges during their tenure and therefore this mindset has been inherited by the younger generation. Thinking back to when you joined your current employer, do you remember any form of induction or briefing that included sustainability? It is true that this is changing and some companies are further ahead than others, but the challenge remains. Given the recent commitments made in South Africa, it will certainly become a key part of our working lives, and to that end, changes are inevitable.

1.4.3 Tunnelling

Unfortunately, in many ways tunnelling can be considered quite an onerous form of construction with respect to the materials used, spoil excavated and components required. Cement and steel are very energy intensive materials and fundamental to construction, but with the development of admixtures and the reduction of steel (in the form of synthetic fibres in sprayed concrete linings, for example) this can be substantially reduced. Impact on local communities can be particularly onerous where large sites are required but that is true of any construction project. The main problem with a tunnel is the footprint cannot be utilised due to safety and space constraints (for example you cannot store flammable materials in a tunnel which means putting it all outside). In greenfield sites or outside of major cities this is less of an issue than when compared to a project in, say, central London or New York.

1.4.4 Implementation

The stage (design, construction or operation) at which a sustainable initiative is implemented will have a large bearing on its success and cost. Figure 4 is a simple illustration that highlights that in the design stage (and before) the options are great and the cost of implementation low (however, this is also dependent on the outcome of a cost benefit exercise as shown in Figure 3). The earlier an initiative is considered the better chance it has to be fully co-ordinated and incorporated into the lifetime of the project and therefore less costly to implement. For this to work well, all relevant parties need to be on board with the concepts, and buy into the idea – this means the Client, designer and contractor are all on the same page from the beginning.

There are many ways that tunnelling can be a far more sustainable method of construction if it is designed intelligently and this will be described in more detail in later sections.

![Figure 4 - Illustration highlighting cost versus options at each project stage](image)

1.5 Inherent sustainability

We should not forget that many tunnelling projects are inherently sustainable. For example, mass transit systems like metros or renewable energy projects like hydropower plants all help reduce carbon emissions. The Crossrail project under construction in London has estimated that it will produce a total 1.7 million tonnes of CO₂ during construction. During operation it will save between
70,000 to 225,000 tonnes per year, through replacement of journeys by car and diesel train, essentially offsetting the projects carbon emissions in 7 to 26 years [9]. Such statistics are important in promoting the tunnel industry and the benefits that underground construction offer.

Other projects are dealing with the consequences of urbanisation and global warming, for example the Mott MacDonald designed the SMART (Stormwater Management and Road Tunnel) project in Malaysia. In Kuala Lumpur recurring floods and traffic congestion had an adverse economic impact on Kuala Lumpur's central business district. A single solution to both problems has taken shape in the form of an ingenious dual-purpose tunnel carrying both vehicles and storm water. This world-first tunnel provides a cost-effective and environmentally economical solution to the dual problems of flash flooding and traffic congestion and since opening in 2008 SMART has prevented major flooding 10 times in the city centre.[10]

2. Project Preparation

2.1 Holistic Design

As noted in section 1, changing the mindset of stakeholders is a key challenge in progression towards sustainable design and needs to be addressed at the earliest stage possible, starting with the Client and progressing through to the contractors. It cannot be over stated that the role of the Client is fundamental to a sustainable project.

The period from project conception to construction normally accounts for a small proportion of a tunnels lifetime and so the principles employed should respect the full lifetime of the tunnel, not just the project.

Referring to Figure 4 it is clear that a good design will put the project on the right track from the outset, setting the tone. However, the influence pre-dates the design, starting with the Client. If the client signals his/her intentions from the outset, at the bidding stage, the project stands a far higher chance of success. Much like the safety legislation in the UK, the Client must be more responsible and accountable for the success of a project, where success here is being gauged on its sustainable credentials. The criteria for weighting a successful bid should be based on the viability of a sustainable project and only by doing this will the industry mindset begin to change; that is not to say that some clients are not already doing this, just simply not enough. At this very early stage it is possible to set carbon targets at separate stages of a project, say feasibility, concept and detailed design. Again with each design stage the opportunity for change becomes less whilst change becomes more expensive.

The fundamental approach to a successful project is as follows and shown in Figure 5:

- Clear direction from the Client;
- Clear communication between parties;
- Clear objectives for key stages of the project;
- Transparency;
- Early contractor involvement;
- Feedback (very important to ensure the hard work is not wasted in later stages of the project).
Figure 5 - Setting clear framework for a successful project

Many client organisations commissioning tunnel projects now have well developed sustainable development policies. Transport for London for example has committed itself to “help the Mayor [of London] achieve his target to reduce CO₂ emissions by 60 per cent in 2025 (from 1990 levels)”. How such ambitious targets filter down through a client organisation to individual projects is less clear. Understanding of such targets though is essential for a project team so they can then be developed into individual targets for a project.

2.1.1 Design Stage

In the design stage of a project more options are available and the cost of implementation minimised (there are “easy wins” and the more capital intensive options such as ground source heat pumps (GSHP) – see Figure 3). Either way, if they are chosen early on, then the design can cater for them through construction sequences and lining thicknesses to even surrounding developments (capitalising on perhaps ground source heat pumps for example). “Fail to prepare, prepare to fail” is applicable in many walks of life and not devoid of meaning in this context. Planning out the project life cycle can set an invaluable framework for evaluation at key stages, ensuring opportunities for “feedback” of the design. As noted earlier, it is possible to set carbon targets at each stage of design, then provide feedback on these targets – bearing in mind there are still many options available at this stage if action needs to be taken to further reduce the carbon generated.

If design organisations are committed to delivering best value for their client they must be proactive in developing sustainable projects at all stages. The following summary expands on incentives and activities which can be implemented successfully in the early stages of a project to increase the chance of success.

Bid/ response and scoping:
• Understand sector and client specific needs
Client/ stakeholder engagement:
- Understand a clients’ sustainability objectives
- Set and agree targets with the client for reduction of embodied energy (requires benchmarking at various stages of a project)
- Seek information from clients on how they operate tunnels, i.e. where they use most energy (if available)
- Identify the ‘big ticket’ wins, the areas which have greatest magnitude of impact
- Seek to achieve a recognised industry award, such as CEEQUAL or BREEAM as way of galvanising the team towards the goal

Tender:
- Assist the client in developing a contract that allows for inclusion of specific clauses relating to energy performance
- Evaluate tenderers based on their environmental performance (e.g. as was done for Thames Water Ring Main, see later) – in a similar way to the evaluation of quality and safety.
- Seek inclusion of low energy materials in the finished product
- Require a contractor to measure the embodied energy in the materials he purchases as well as the fuel and energy used.

Delivery:
- Work with material suppliers to gain an understanding of the relative embodied carbon in various construction materials (used at various design stages for carbon estimates)
- Educate the design team to increase their level of understanding and breadth of knowledge on sustainability issues
- Identify where a project can reduce waste and increase use of recycled materials
- Develop designs that minimise energy use and material wastage
- Civil, mechanical and electrical engineers must collaborate fully to develop integrated and efficient designs that fully utilise the most up to date technology, such as ground source heat (GSHP) and LED lighting
- Carry out whole life cost and carbon analysis
- Work with the client to specify materials and products which although possibly not lowest value, have a low embodied carbon or in the case of plant have a low energy usage. This will benefit the client in the long term.

2.1.2 Construction Stage

During the construction stage, and with the benefit of Early Contractor Involvement (ECI), the contractor will have a clear idea of what the goals are and how best to achieve them. [11] During the ECI period the contractor can bring some extremely valuable feedback on proposals but also can go further. For example suggestions could be made with the designer and client during the ECI period on alternative construction methods, materials, etc (see Table 1). If this can be made to work on the design front and the client is happy to proceed, this will save a lot of time in the construction phase. Beyond the design stage the contractor still has many options available which would further reduce the carbon demand; such as considering modes of transport, renewable fuel sources, involving the community etc. These can and should be considered in the design stage but correct implementation is pivotal to its success.
### List of areas to improve

<table>
<thead>
<tr>
<th>Community impact</th>
<th>Areas to be managed/ Improved</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Engage the Community</td>
<td></td>
</tr>
<tr>
<td>Large storage areas for materials</td>
<td>Off site storage (though note transportation)</td>
<td></td>
</tr>
<tr>
<td>Noise pollution</td>
<td>Working hours</td>
<td></td>
</tr>
<tr>
<td>Waste (dust, pollutants)</td>
<td>Waste management (site bins)</td>
<td></td>
</tr>
<tr>
<td>Traffic</td>
<td>Traffic management (cyclists at risk)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Materials used</td>
<td>Use less energy intensive alternatives</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>Use of steel or synthetic fibres</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>Use recycled aggregate</td>
<td></td>
</tr>
<tr>
<td>Aggregates</td>
<td>Use of sprayed membranes</td>
<td></td>
</tr>
<tr>
<td>Waterproofing</td>
<td>Use renewable fuels for plant</td>
<td></td>
</tr>
<tr>
<td>Natural Resources</td>
<td></td>
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</tr>
</tbody>
</table>

### Table 1 - Example process for reducing carbon / environmental impact

#### 2.1.3 Operation and Maintenance

This phase of the project is actually where the majority of carbon is used and also the stage where retro-fitting is extremely difficult and expensive. For new builds this should not be considered as the time to implement sustainability as it will be unduly expensive while options available limited. However, that is not to say that retro-fitting should be discouraged or considered impossible. There are many projects today that would benefit from retro-fitting but, in opinion of this paper, that is the only time retro-fitting should be debated – past projects, not future projects.

#### 2.1.4 Holistic design case study: A3 Hindhead

The theme of this section is the adoption of an integrated approach to sustainable design. A good example of this is the A3 Hindhead Scheme, which completes the final 6.7km of dual carriageway between Portsmouth and London. It was clear that sustainability should underpin the design and construction of the project. To help achieve this goal a sustainability register was used from the early stages of design. The key aspects of it were:

- To raise awareness
- To identify sustainability goals
- Implementation during design & construction phases
- It was reviewed & audited
- There were regular meetings about it

The scheme will not only improve journey times and road safety but will also deliver environmental benefits, reducing traffic emissions and noise pollution. Its recent completion will allow a sustainable community to be built in Hindhead by removing a major highway and 28,000 vehicles a day from the village. The scheme will have a positive impact on the natural environment with the National Trust-owned Devil’s Punch Bowl, a Site of Special Scientific Interest, returned to peace and quiet through the closure of the existing road.

The Mott MacDonald team developed a design which:

- Includes two 1.8km long tunnels under environmentally sensitive areas.
- Reduced the scheme footprint by up to 50% in places compared to the tender design
- Utilised lime/cement stabilisation to improve the quality of the exiting material
- Maximised use of on-site materials considerably reducing importation of materials
- Optimised the tunnel profile to minimise excavation and allow balance of cut and fill
- Used an innovative sprayed concrete lining design to minimise lining thickness and save up to 33% of concrete compared to a traditional approach.
This project demonstrates what is possible when there is a will and collective understanding to do so.

2.2 Lifecycle considerations

It is clear therefore that sustainability must be improved as, not only is the construction industry going to have to play a significant role in reducing its carbon output, but it will also play a significant role in “de-carbonising” the economy as a whole through the buildings and infrastructure it produces. Therefore, not only must the environmental impact of a project be understood at the construction phase, but a designer and contractor must have a full understanding of the entire project lifecycle. This is typically now 120 years for a tunnel and realistically even longer based on the fact that parts of London’s sewer and metro system are over 150 years old and still in use.

2.2.1 The project lifecycle

Understanding the lifecycle of how a tunnel is operated, maintained and refurbished is as important for any designer and constructor as the ability to build it in the first place. Tunnels are energy intensive pieces of infrastructure once they are in operation. They require continual maintenance, periodic major refurbishments and upgrades, while lighting, cameras, public address, ventilation and a multitude of additional systems use energy 24 hours a day.

Take for example a typical highway tunnel and compare it to a section of “at grade” highway. Ignoring the fuel used by the vehicles travelling along a section of road, the energy used to build and maintain the tunnelled section is significantly more from the outset and the gap widens as the asset ages (Figure 6). There are three distinct stages of life that must be considered from the inception:

- Construction - around 5 years duration (typically easiest to understand for a designer or contractor, it is the most imminent and controllable stage)
- Operation – 20 year cycles (systems have been installed and operational parameters are essentially set)
- Refurbishment – minor (some M&E systems are replaced, the tunnel lining painted, road resurfaced) & major (- internal fittings renewed inc doors, crown cable management systems, all M&E systems, fans, pumps, internal cladding systems replaced) every 20 & 40 years respectively.

The graph in Figure 6 shows an indicative energy use profile for a tunnel in a 40-year cycle. The energy at year 0 is the embodied energy in the asset, i.e. the energy used to build the tunnel. Although significant (a relatively large amount of energy is used in a short period) it is small in magnitude compared to the lifecycle energy. Now compare the values to that of an at-grade road. Once built a road uses very little energy and has a low material consumption, it will be resurfaced every so often and may be lit at night, but compared to a similar length of tunnel it is small.

This indicative graph aims to demonstrate that in terms of energy usage a tunnel should be treated like a building, not a piece of infrastructure. It also shows that as with commercial and domestic buildings in the design phase it is important that the whole life energy usage is considered early on, as it will have the greatest impact over the life span of a structure. This is generally not so crucial with other pieces of fixed infrastructure.
It is clear that the energy used in the life of a tunnel is dependent of how well it is designed and built and then how well it is operated. But they are not mutually exclusive activities and to a great extent the ability of an operator to manage his assets energy consumption efficiently is governed by the quality of the product with which he is supplied.

If the industry is to improve its environmental performance and produce more energy efficient assets there must be an established, agreed and comparable measure of performance for a whole project lifecycle. If we do not know how we are performing today, how will it be possible to demonstrate that we have improved tomorrow?

### 2.2.2 Carbon and the project lifecycle

Whole life costing is an established method of helping an asset owner to understand the long term financial implications of choosing to build and operate an asset (in this case a tunnel). The tools are well understood and based on published financial data and models, which are readily comparable. Despite this, the accuracy of any projections made 40, 60 or even 120 years into the future are limited; there are just too many uncertainties.

Whole life carbon costing is essentially the same process, but counting carbon emissions rather than financial liabilities, although it is inevitable that at some point in the near-future the two will become inexorably linked as carbon emissions taxes and quotas are expanded throughout additional aspects of commercial and domestic activity. The tools for carbon costing, however, are far from established and the process itself is open to a wide variety of complications, assumptions and interpretations.

Take for example counting the cost of a simple concrete pour. Financially, there is the cost of the concrete and reinforcement, site labour to carry out the pour and the cost of the plant and formwork. The challenge comes when trying to carry out the same calculation for the carbon associated with that pour. Unless your material supplier provides the designer with a value of the embodied carbon in that particular concrete mix, he would be forced to estimate the carbon associated with mining of the aggregate, production of the cement, additive manufacture, mixing at the concrete plant and transport to site, calculations for steel, plant and labour complicate the process even more greatly. The value is also subject to a wide degree of variability for the same material, for example, was the cement manufactured and transported 6000 miles, 10 miles down the road, or in France where 80% of electricity is produced using nuclear power?

It is therefore evident that even a routine site procedure, with an easily and accurately predictable financial cost has a carbon cost that at a project level that is currently very difficult to calculate without making large assumptions. Escalating the whole life carbon calculation to take account of
a whole project lifecycle requires even greater assumptions. However, this should not discourage
engineers from building this into a project at an early stage as making these assumptions from the
outset can give the Client/ Designer an understanding as to what is required to make the project
more sustainable (i.e. perhaps cement is more sustainable from France than 10 miles down the
road?). Earlier we saw how the Crossrail project has estimated the carbon it will produce, but
ultimately more importantly what it saves. Such statistics highlight the need for a standard tool in
order to enable comparison of projects and to add weight to the figures. However, the ability for
many tunnel projects to offset carbon should not be seen as an excuse for not attempting to
reduce the carbon footprint during construction and operation.

3. Design Stage

3.1 Barriers to carbon reduction

The lack of an established tool for measuring carbon performance was identified above as one
reason why the industry has been slow to fully embrace sustainability. New software integrating
carbon and financial calculations along with an increasing awareness by suppliers of their carbon
footprint will ensure that this does not persist.

In 2009 the Carbon Trust, a UK government funded company tasked with accelerating the move to
a low carbon economy, published the results of a study interviewing more than 70 industry
directors and managers looking at barriers to reducing emissions from non-domestic buildings. [12]
Unsurprisingly many of the factors mentioned would be recognised in the civil engineering industry
and are summarised here.

Lack of demand - both end user and within supply chain

- Immaterial savings;
- Lack of clarity and direction from Government;
- Lack of perceived material value in development of low carbon buildings [tunnels];
- Lack of capital;
- High transaction costs;
- Misinformed on cost-benefit;
- Lack of motivation;
- Separate capital and operational expenditure budgets/no lifecycle costing;
- Lack of client management skill to procure/operate low carbon building [tunnel];

Awareness and information

- Lack of post-occupancy evaluation and feedback;
- Information unavailable on buildings’ [tunnels’] energy use and emissions;
- Information unavailable on buildings’ cost-benefit of measures to improve building [tunnel]
  performance.

Design/construction team alignment

- Lack of skills and knowledge to design and construct low carbon buildings [tunnels];
- Lack of coordination/collaboration across supply chain;
- Poor commissioning and handover;
- Lack of compliance;
- Liability issues;
- Perverse incentives in fee structures.

Breaking down the complex set of factors is outside the scope of this paper and any one single
factor could form a study in its own right, but it is important to recognise the underlying theme
which is essentially a lack of an integrated framework and ethos allowing sustainability to be inte-
grated into design and construction processes.

3.2 Tools available

A key factor mentioned numerous times already is the measurement of performance. There are
various tools available for assessing the sustainability credentials of a tunnelling project and some
will be detailed here. As noted in earlier sections, the lack of a recognised sustainability measure in
the tunnelling world means that it is difficult to compare one project or option with another. This
will change in years to come, if only through projects that try to estimate how much carbon has
been used and benchmarking that against the next comparable project. That is not to say projects
have not already attempted this, and indeed as we saw earlier Crossrail has calculated that during
construction, 1.7m tonnes of carbon will be generated. The problem is, today, whether anyone
believes that to be a good figure or a bad figure; what can it be compared to? Is this in line with
government commitments to reduce CO₂ emissions?

3.2.1 CEEQUAL

Moving onto the tools currently available, CEEQUAL is “...the assessment and awards scheme for
improving sustainability in civil engineering, landscaping and the public realm, and celebrates the
achievement of high environmental and social performance...” and was launched in the UK in
2003[13]. The CEEQUAL scheme seeks to complement the statutory requirements, by operating
during design and construction, verifying what is built and how it is built, but not how it is actually
operated when complete. [13] Essentially the scheme sets out to score a project based on 12
areas that are weighted in terms of importance. Rather than a framework for sustainability, this
seeks to proactively or retrospectively assess a project. It certainly encourages choices to be made
regarding sustainability in the wider sense, but there is requirement to measure how much carbon
will be generated; it could be considered a subjective assessment of a project. This is not to say it
is not a valuable scheme which addresses the issue of sustainability, but it does not represent the
level of detail that is required to take us into the future. Before moving on, it is worth highlighting
that some tunnelling projects have been commended by this scheme. These include the Thames
Water Ring Main Tunnel Extensions and Crossrail.

To explain in more detail how CEEQUAL has been applied, we can consider an extension to
Thames Water Ring Main (TWRM). The TWRM forms a complete ring around the major water
supply zones within the Greater London area. The southern extension consists of a 4.9km tunnel
across south London from Brixton to Honor Oak, where it connects into one of the largest
underground reservoirs in London.

Mott MacDonald, working with the client's design team which included embedded staff,
coordinated the civil and MEICA design and provided planning input for the extension, leading to
delivery of the tender design and contract documentation for a design and build contract.

In 2007 the project was presented with an interim CEEQUAL award for environmental excellence in
civil engineering design. This project was awarded the 'Excellent' rating in the 'Interim
Client/Outline designer’ phase. The work required support from many of Mott MacDonald’s multi-
disciplinary teams.

Key actions undertaken by the Client-Design team during the Interim Award stage included:
- Reducing construction impact through careful consideration of worksite locations. The out-
  line design removed the need to construct an intermediate access shaft.
- An Environmental Management Plan (EMP) was prepared, including an environmental risk
  register.
- A Tender Assessment Scoring method was used which gave consideration to the contrac-
  tor’s environmental record.
- Environmental screening surveys were carried out to identify likely environmental impacts.
- A Project Communication Plan for liaising with all key stakeholders was prepared. Drop-in
  sessions were held on site for local residents.
- A firm of architects were appointed to design the site compound layout with a view to reducing the amount of land taken.
- A Landscape Plan was developed in collaboration with the London Borough of Southwark.

These two projects highlight the importance of project team integration and providing an environment which allows for sustainable initiatives to be taken forward.

### 3.2.2 Whole Life Carbon Assessment

As alluded to earlier in the paper, whole life carbon is a very useful financial and carbon estimating tool. From an early stage it is possible to set the tone for different stages of a project, and Mott MacDonald has developed a methodology called “LifeCYCLE” which allows one to consider carbon from start to finish (Figure 7). The key benefits of using this system (or equivalent) are as follows:

- Capital cost, life cycle cost and CO\textsubscript{2} in one calculation
- Model different lifespans of a structure
- Model new build and refurbishment
- Optimise specification based on whole life performance
- Model the impact of transporting resources

![Figure 7 - LifeCYCLE whole life assessment tool](image)

This tool has been used to good effect in Mott MacDonald and is currently being trialled for tunnelling projects. Once the database has been populated with a few projects the process will become more streamlined and easier to set up.

### 3.2.3 CapIT

“CapIT is the first online system of its kind in the world, allowing users to estimate cost and embodied carbon values for construction activities.”[15]

This tool provides a way of carrying out calculating in detail the embodied carbon in any construction activity, while also estimating the cost. It allows for assessment of how much carbon will be generated by various activities.
and thus where changes can be made to reduce this figure. It also is a powerful tool to track the
development of the design, measured against a projects’ targets for reducing embodied carbon,
should such a figure exist.

CapIT fits inside LifeCYCLE and allows one to use an online estimating system to control and audit
estimates. Again this has been used with some success in Mott MacDonald and is currently being
populated and trialled in the tunnelling division for widespread use. There are many advantages to
using this system which can be investigated further from the dedicated webpage. [15] However,
currently this system is in its infancy for the tunnelling sector, albeit with huge potential to provide
a one-stop shop with LifeCYCLE.

3.2.4 INDUS

INDUS can be considered an ethos or frame of mind as it lays out a framework on
how to approach a project from a sustainable point of view. This is used with the
client to define a roadmap for the project setting key objectives accounting for
economic, social and environmental sustainability over its whole life. Objectives
are weighted for importance at the outset providing a reference framework and
scoring system for decision making. By using this methodology it is possible to
benefit a project in a tangible way and has the flexibility to allow change as the project de-
velops.[16]

INDUS is can be considered the overarching process into which CapIT and LifeCYCLE contribute.
This too is being trialled currently in our tunnelling division to iron out any creases and begin pro-
viding a streamlined service for the tunnelling industry.

3.2.5 Cost benefit analysis

As noted in section 1.4, a tool that can be integrated within the main methodology - such as Life-
CYCLE - is a cost benefit analysis. This can be very high level to start with but extremely powerful
to illustrate what options are available to the designer and which may prove “easy wins” on the
embodied and operational carbon front. Each one of these can be taken further to assess in detail
the merit, where cost and viability are considered as well as carbon savings (for example using
GSHP may be an attractive proposal, but unless there is a building that can utilise the benefits it
brings, it may not viable in both an economic and environmental sense).

4. Construction

In the construction phase, the carbon becomes embodied in the project and the focus shifts to
minimising the energy consumption and waste. CEEQUAL represents a good framework for imple-
menting the drive towards sustainability and, in some places, the concepts have been embraced
so fully by the clients that sustainability initiatives have become integrated into the normal envi-
ronmental management plan. For example, waste minimisation is often promoted on sites, via
poster campaigns to boost awareness and selective waste containers, which is a big shift com-
pared to life on building sites 15 years ago. Recycling of spoil for use as aggregate in concrete is
an obvious opportunity on rock tunnelling projects (e.g. Lotschberg and St Gotthard). That said,
there is enormous scope for improvement. Consider spoil recycling, the subject is still in its infancy,
although there is a EC Waste Framework Directive and a Mining Waste Directive, However the lack
of coherent guidelines is hampering a more widespread adoption of this. [17]

As Figure 2 shows, transport is an important player in carbon emissions. Construction sites by their
very nature offer an excellent place to use hydrogen fuel cells. The transport is located within a
confined area so refuelling can be solved simply with a refuelling station on site. Often construc-
tion plant needs to be heavy – excavators, cranes, locomotives – so the large mass of the hydro-
gen fuel tanks is an asset rather than a hindrance. Finally, the main emission from a hydrogen fuel
cell is water vapour. This reduces the ventilation problems underground, in turn saving carbon by
reducing the need for forced ventilation. Pilot projects using hydrogen fuel cells for locomotives have already been successfully carried out in the mining industry. [18]

5. Operation and Maintenance

As discussed earlier, in the same way that people now talk about financial costs in terms of whole life costs, we need to consider the whole life carbon impact. Within the buildings sector in the UK a shift in the way energy is used during the operational life of a structure is taking place. Driven by legislation all new buildings must effectively be operationally carbon neutral by 2019 (2016 for domestic) [19], it is not unreasonable to assume that within the next few years, similar legislation will cover infrastructure, including tunnels. Currently around 60% of carbon emissions for buildings come during the operational phase [20], it is again not unreasonable to assume that for a typical tunnel these figures will be similar. Therefore designing out operational carbon emissions is clearly of great benefit.

Conventional approaches must be challenged to minimise the operational impact. For example, in tunnels that carry high voltage electrical cables, there has been a shift in the operational concept. Man-access for inspection and maintenance requires the installation of ventilation and lighting. Using remote controlled inspection vehicles and robots for maintenance obviates the need for these costly (in financial and carbon terms) installations.

Here we can consider two positive impacts from a tunnelling project – firstly, minimising the carbon consumption and, secondly, carbon offsetting. The use of geothermal energy in the form of ground source heat or energy segments represents a saving in carbon consumption. This technology has been used in the Vienna metro and various other pilots. The presence of district heating systems in Central European cities enhances the attractiveness of this since there is an existing customer and distribution system for the heat. In fact often metros face a problem of overheating (e.g. London Underground). Taking this model further, tunnelling projects could generate “carbon credits”. The carbon trading market has yet to mature but, if it does grow, selling the carbon credits could represent an additional income stream.

6. Conclusion

Sustainability represents a growing challenge for us all but it can also be seen as a great opportunity for engineers to help alleviate a great social problem through intelligent design and construction, in the same way that the development of sanitation and water supply tackled health problems such as cholera and typhoid. As a community, engineers including, regrettably tunnel engineers, have yet to fully embrace this opportunity and develop the tools to tackle this. However, there are notable exceptions and flagship projects that we can learn from. We look forward to this changing in the near future.
7. References

[1] General Eisenhower
[12] Carbon trust, Building the future, today. Transforming the economic and carbon performance of the buildings we work in, 2009