Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Energy and Carbon Footprint Report

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Thames Tideway Tunnel

Creating a cleaner, healthier River Thames

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Energy and Carbon Footprint Report

Errata

Section	Paragraph No.	Page No.	Errata / Clarification
Section 3.5 Project design evolution and carbon footprint	3.5.1	14	Incorrect reference to Section 6.2. Text should read "Preliminary work on the project carbon footprint was undertaken in 2009 and was based on three route options (see Section 5.3)."
Section 4.5 Alternative scenarios	4.5.1 (i)	20	Incorrect reference to Section 8.1. Text should read "All Road' scenario where 100% of the excavated and construction materials are transported by road; and a 'Preferred' scenario', that which is proposed for the project, where river transport is used at 11 worksites. This is as set out in the Transport Strategy which accompanies the application (see Section 7)."
Section 4.5 Alternative scenarios	4.5.1 (ii)	20	Incorrect reference to Section 10.4 Text should read "UK grid projections: in order to illustrate the impact that decarbonisation of the grid has on the overall carbon footprint of the project, an alternate non-decarbonised model of each scenario has been quantified. This was calculated by assuming the 2012 UK electricity emission factor for the entire 120 year operational phase of the project (see Appendix A)."

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Energy and Carbon Footprint Report

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Abbreviations

CCC – Committee on Climate Change

CO_2e – Carbon Dioxide Equivalent

CSO – Combined Sewage Overflow

DECC – Department of Energy and Climate Change

Defra – Department for Environment, Food and Rural Affairs

DWF – Dry Weather Flow

EA – Environment Agency

GHG – Green House Gas

GLA – Greater London Authority

ICE – Inventory of Carbon and Energy (Bath)

NIP – National Infrastructure Plan

NPS – National Policy Statement

NSIP – Nationally Significant Infrastructure Project

PFA – Pulverised Fuel Ash

STW – Sewage Treatment Works

tCO_2e – metric tonne of Carbon Dioxide Equivalent (measurement unit of emissions)

UPS – Uninterruptible Power Supply

UWWTD – EU Urban Waste Water Treatment Directive

Glossary

Carbon Footprint – a measure of the total amount of carbon dioxide (CO_2) and methane (CH4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_{2e}) using the relevant 100-year global warming potential (GWP100).

Decarbonisation – to decarbonise is to minimise the emission of greenhouse gases by the economy into the biosphere. By reducing the consumption of fossil fuels and increasing the use of renewable energy.

De minimis – '*de minimis'* emissions are emissions from one or more sources and of one or more greenhouse gases that, in aggregate, are less than or equal to 3% of the total annual CO_2 equivalent emissions of a reporting entity.

Embodied Carbon – refers to carbon dioxide emitted during the manufacture, transport and construction of building materials, together with end of life emissions.

Embodied Energy - is the sum of all the energy required to produce goods or services, considered as if that energy was incorporated or 'embodied' in the product itself.

Greenhouse Gas - a gas that contributes to the natural greenhouse effect. The Kyoto Protocol covers a basket of six greenhouse gases (GHGs) produced by human activities: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, all measured as carbon dioxide equivalents on the basis of the gases' global warming potential

Greenhouse Gas Protocol – The Greenhouse Gas Protocol (GHG Protocol) is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions.

Life Cycle Analysis - a process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities. LCA is commonly referred to as a "cradle-to-grave" analysis. LCA's key elements are: (1) identify and quantify the environmental loads involved; e.g. the energy and raw materials consumed, the emissions and wastes generated; (2) evaluate the potential environmental impacts of these loads; and (3) assess the options available for reducing these environmental impacts

Radiative Forcing - Radiative forcing is the perturbation to the energy balance of the earth-atmosphere system following, for example, a change in the concentration of carbon dioxide or a change in the output of the sun; the climate system responds to the radiative forcing so as to re-establish the energy balance. A positive radiative forcing tends to warm the surface and a negative radiative forcing tends to cool the surface.

Renewable Energy – energy that comes from natural sources, not fossil fuels. Renewable resources include wind, waves, tide, sunlight and geothermal heat.

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Executive Summary

EX 1.1 The Thames Tideway Tunnel project (the ‘project’) is a nationally significant infrastructure project aiming to improve the condition of the water in the Thames and ensuring it complies with relevant wastewater legislation by reducing the overflow of untreated sewage discharge.

EX 1.2 The purpose of this report is to describe to relevant stakeholders how the Thames Tideway Tunnel project would comply with the National Policy Statement for Waste Water (Defra, March 2012)[1] main Government objective for ‘sustainable development’. This report evaluates the Thames Tideway Tunnel’s carbon footprint over its 120 year design life and records where interventions have been made during the design stage to reduce Greenhouse Gas emissions.

EX 1.3 As part of assessing the environmental impacts of the project, the overall energy demands and Greenhouse Gas emissions have been modelled and evaluated, using two linked models. One model deals with electrical and diesel energy demands from the construction and operational phases of the project; this is referred to as the Energy Model. The other is more detailed and synthesises the outputs of the Energy Model and other significant project activities into Greenhouse Gas emissions. This is known as the Carbon Model.

EX 1.4 The different aspects of the project modelled and evaluated in this report are: the route, materials, logistics, construction activities at each worksite and operational phase activities.

EX 1.5 The results show that out of a total carbon footprint, in the decarbonised scenario, of some 840,000 tCO_2e (tonnes of carbon dioxide equivalent) the principal impact from the project is the GHG emissions caused by construction of the infrastructure, in particular embodied carbon in materials, being approximately 84% of the total emissions, with emissions from construction plant and machinery (construction worksite activities eg tunnel boring and emissions from plant and machinery) being around 10% of the total emissions. Emissions during the 120 year operational life of the tunnel represent approximately 2.5% of the total GHG emissions. The transport of excavated material and construction materials represents approximately 3.5% of the total carbon footprint of the project.

EX 1.6 In order to determine the order of magnitude of the potential carbon saving realised from constructing a shorter tunnel, the GHG emissions arising from the three alternative alignments, as presented at Phase One consultation were considered. The results indicate that as a shorter tunnel alignment uses less material, it would have less embodied Greenhouse Gas emissions. Reducing the length of the tunnel has the greatest benefit in avoiding environmental impact.

EX 1.7 The modelling results for materials highlight the embodied carbon in different materials and the associated Greenhouse Gas emissions. Two scenarios are described in the logistics section, one using road transport alone to move excavated material from and deliver construction materials to the project worksites, the other using a combination of river and road transport, as proposed by the project in the *Transport Strategy*. The results show that Greenhouse Gas emissions would be reduced when using barges as they can carry more materials and use less fuel. The modelling of construction activities examined the energy intensity of the different machinery that would be used in construction; showing the tunnel boring machines to be most energy intensive. The modelling results for the operational phase show Greenhouse Gas emissions under two potential scenarios, one where the national grid becomes decarbonised and a scenario where it remains as it is in 2012. Applying decarbonisation results in a 38% overall reduction in the footprint, realised in the operational phase of the project.

EX 1.8 The report concludes that overall GHG emissions due to the construction of the Thames Tideway Tunnel have been significantly reduced following the adoption of the Abbey Mills Route in place of earlier, longer alignments. In addition, measures incorporated in the design, for example use of lower carbon materials and transport modes and passive design features, have sought to minimise the overall carbon footprint of the project.

EX 1.9 There are opportunities to further reduce the overall project carbon footprint, albeit modestly, and, as the project moves into the next phases, the objectives set out in the *Sustainability Strategy* will be further developed and will guide this in the detailed design, procurement and construction phases.

1 Introduction

1.1 Project overview

Purpose

1.1.1 At present, untreated sewage mixed with rainwater (combined sewage) regularly overflows into the River Thames from London's Victorian sewerage system via combined sewer overflows (CSOs).

1.1.2 Combined sewage discharges must be reduced in order to comply with relevant wastewater legislation. The primary objective of the proposed Thames Tideway Tunnel project (the 'project') is to control discharges from CSOs in order to meet the requirements of the European Union's Urban Waste Water Treatment Directive (91/271/EEC) (EU, 1991)[2] (UWWTD) and the related United Kingdom (UK) Urban Waste Water Treatment Regulations. Other European Union and UK legislation also forms part of the legal framework within which the project is to be designed and delivered. The Water Framework Directive, and the regulations that transpose it into UK law, set out various 'environmental objectives' to be achieved in relation to surface water quality.

1.1.3 The Thames Tideway Tunnel would control CSO discharges by intercepting and diverting combined sewage flows into a new storage and transfer tunnel between Thames Water's operational sites at Acton Storm Tanks and Abbey Mills Pumping Station. It would intercept identified CSOs that frequently discharge into the tidal River Thames. The flows of combined sewage would be captured, stored and pumped out for treatment at Beckon Sewage Treatment Works (STW). A total of 24 sites are required in London to construct and operate the project.

1.1.4 The new infrastructure would protect the tidal Thames from increasing pollution for over 100 years. It is envisaged that construction would commence in 2016 and be completed by 2022.

Main tunnel

1.1.5 The main tunnel would capture and store combined sewage from the unsatisfactory CSOs along its route and transfer it to Beckton Sewage Treatment Works.

1.1.6 The horizontal alignment of the main tunnel would generally follow the River Thames, where possible and practical, in order to:

a. ensure the most efficient route to connect the CSOs located on both banks of the river

b. enable river transport during construction to supply and remove materials, where practicable and economic

c. minimise the number of structures the tunnel would pass beneath in order to reduce the number of third parties affected.

1.1.7 The main tunnel route would take the shortest line from Acton Storm Tanks to the River Thames and stay beneath the river from west London to Rotherhithe. It would then divert from beneath the River Thames to the northeast via the Limehouse Cut and terminate at Abbey Mills Pumping Station, where it would connect to the Lee Tunnel.

1.1.8 The main tunnel would be approximately 25km long with an approximate internal diameter of 6.5m in the west increasing to 7.2m through central and east London. The approximate depth of the tunnel would be between 30m in west London and 65m in the east in order to provide sufficient clearance to existing tunnels and facilities under the city and meet the hydraulic requirements.

Connection tunnels

1.1.9 Two long connection tunnels would be required in order to connect five remote CSOs to the main tunnel. The tunnels are known as:

a. the Frogmore connection tunnel (approximately 3m internal diameter and approximately 1.1km long), which would be situated in the London Borough of Wandsworth

b. the Greenwich connection tunnel (approximately 5m internal diameter and approximately 4.6km long), which would pass through the London boroughs of Southwark and Lewisham and the Royal Borough of Greenwich.

1.1.10 A series of shorter connection tunnels would also be necessary to connect various CSOs that are close to the proposed main tunnel route.

Above-ground worksites

1.1.11 The Environment Agency has identified 34 ‘unsatisfactory’ CSOs that the project needs to address. CSO control studies and design development have established that 14 of these CSOs could be controlled indirectly, which reduces the number of worksites required.

1.1.12 A detailed site selection process has been carried out, having regard to engineering, planning, environment, socio-economic, community and property constraints. Twenty-four worksites were selected in total, which can be categorised by function as follows:

a. five ‘main tunnel sites’: These sites would be used to construct the main tunnel and can be further classified as ‘drive sites’ and/or ‘reception sites’. Shafts would be excavated to the appropriate depth and the tunnel boring machines would start at ‘drive shafts’ and be removed via ‘reception shafts’. A shaft may serve as both a drive and a reception shaft.

b. sixteen ‘CSO sites’: These sites would be used to construct the CSO drop shafts and interception structures and to drive or receive connection tunnels.

c. two ‘system modification sites’: These sites would be used to control CSOs locally rather than connecting them to the main tunnel.

d. Beckton Sewage Treatment Works: At this site the combined sewage flows would be lifted from the main tunnel system and transferred for treatment. This site also requires a siphon tunnel to bypass the pumping mechanism when the tunnel system is full.

Above-ground permanent works

1.1.13 Some permanent above-ground infrastructure would be required, which would vary according to the type of site. This infrastructure might include:

a. air management facilities including ventilation structures and ventilation columns

b. a kiosk structure to house electrical and control equipment

c. a means of access

d. areas of hardstanding adjacent to shafts and structures to enable periodic inspection and maintenance.

1.1.14 Maintenance visits would be required approximately every three to six months for above-ground equipment inspections and every ten years for tunnel system and shaft inspections.

1.1.15 Construction sites would be restored on completion of the works by means of levelling, in-filling, landscaping and making good.

1.2 The applicant

1.2.1 Thames Water is a statutory water and sewerage undertaker. It is the UK's largest water and wastewater services company, serving around 13 million customers across London and the South East of England.

1.2.2 By virtue of its location, purpose and storage capacity, the Thames Tideway Tunnel project is a nationally significant infrastructure project (NSIP), under the Planning Act 2008 (the 2008 Act).

1.2.3 In accordance with the 2008 Act, Thames Water is making an application for development consent which would contain the consents and powers necessary for the construction, operation and maintenance of the project. The project has evolved through a robust site selection process, in response to extensive consultation and engagement with stakeholders, and through on-going design development.

1.3 The application documents

1.3.1 This Energy and Carbon Footprint Report is part of a suite of documents which accompany the application for development consent. A full description of all the application documents is provided in the *Guide to the Application* which also accompanies the application for development consent. Appendix H provides a visual representation of the application documents.

1.4 Purpose of this document

1.4.1 This Energy and Carbon Footprint Report has been prepared by Thames Water, as part of the application for development consent for the project.

1.4.2 A 'Carbon Footprint' is the commonly used way of referring to the emissions of Greenhouse Gases arising from an activity or set of activities, and the terms carbon and GHG emissions can be used interchangeably (see para 2.2.1 for a full definition).

1.4.3 This report evaluates the Thames Tideway Tunnel's carbon footprint over its 120 year design life and records where interventions have been made during design to reduce Greenhouse Gas (GHG) emissions. Thames Water believes it is important to manage and control emissions as far as practicable and possible whilst delivering the project.

1.4.4 The quantification of the life cycle carbon of the project has followed a detailed bottom up approach, one of the most detailed carbon footprints for an infrastructure project on this scale and this document intends to capture and communicate these findings.

1.5 Structure of this document

1.5.1 This document first provides some context to the project in the form of an 'Energy policy and wider context' chapter before defining the purpose and detailed scope of the assessment in the 'purpose and scope' chapter.

1.5.2 The report provides an overview of the methodology and approach undertaken, then presents an analysis of the results for each of the individual life cycle stages (i.e. materials, logistics, worksite construction activities, operational etc). The report ends with a discussion of measures to reduce GHG emissions, both those already incorporated in the project together with opportunities at the detailed design stage, and conclusions.

2 Energy policy and wider context

2.1 Energy Statement requirements

2.1.1 The National Policy Statement for Waste Water (the NPS) was published in February 2012 by the Department for Environment, Food and Rural Affairs (Defra). It establishes the need for the Thames Tideway Tunnel project and identifies this as the preferred infrastructure solution to address the problem with CSOs.

2.1.2 The Government's key policy objectives are set out in paragraph 2.3.3 of that document. This includes objectives relevant to this report, as:

a. Climate change mitigation and adaptation – in line with the objectives of Defra's mitigation and adaptation plans to help deliver the UK's obligation to reduce greenhouse gas emissions by 80% by 2050 and work to carbon budgets stemming from the Climate Change Act 2008, within the context of the EU Emissions Trading System.

b. Waste hierarchy – to apply the waste hierarchy in terms of seeking to first reduce waste water production, to seek opportunities to re-use and recycle resources and to recover energy and raw materials where possible.

2.1.3 Whilst the NPS sets out its policy position on climate change and emissions, there is no statutory requirement to produce an Energy and Carbon Footprint Report in support of the application for Development Consent. Thames Water regards this as good practice, however, and has produced this document in line with available precedents and guidance.

2.1.4 There is currently no specific guidance relating to the production of an energy and carbon assessment for large infrastructure projects, such as the Thames Tideway Tunnel project. The GLA guidance note 'Energy Planning – GLA Guidance on Preparing Energy Assessments' (GLA, 2011)[3] is intended for assessments to accompany 'strategic' planning applications (i.e. those referred to by the Mayor of London), though the use of the guidance is recommended for other applications made in London.

2.1.5 The International Standard on Life Cycle Analysis (ISO14044)[4] has been used to develop the methodology for this assessment and the accounting principles defined by the GHG Protocol and the assumptions and methodologies used by Defra were also used for guidance.

2.1.6 The London Plan 2011 makes specific references to preparing energy statements in Policy 5.2. Whereas the production of an Energy Statement is mentioned in the London Plan, the requirements therein are often underpinned by Part L of the Building Regulations which have been developed by the government to drive energy and carbon efficiency of domestic and non-domestic building stock. The Thames Tideway Tunnel project clearly falls outside of these Regulations, but the spirit of the London Plan guidance is clear in its intentions to promote reduction in demand and offsetting greenhouse gas emissions with renewable energy technology.

2.1.7 The energy hierarchy, described in the Mayor of London's guidance for Energy Planning and in policy documents from the Institute of Mechanical Engineers has up to five steps which follow the basic structure below, in descending order of preference:

a. reduce the fundamental need for energy and thereby GHG emissions

b. increase efficiency through measures to decrease energy consumption and GHG emissions

c. introduce zero-GHG renewable energy

d. introduce lower-GHG renewable energy

e. continue with business as usual

2.1.8 The Mayor's Guidance does not distinguish between zero- and lower-GHG renewable energy but is otherwise comparable.

2.1.9 This hierarchy has been adopted in the Energy and Carbon Report as a framework for examination of each lifecycle stage.

2.1.10 Due to the nature of this infrastructure project, there are unlikely to be many significant opportunities at every stage of the energy hierarchy in relation to efficiencies in supply and usage of equipment. The project is considered to be an infrastructure scheme of national significance with a 120-year structural design life and a purpose which cannot be compromised.

National Infrastructure Plan 2011 and update 2012

2.1.11 The *National Infrastructure Plan* (NIP) contains the Government's major commitments for meeting the infrastructure needs of the UK. It sets out a new strategy for coordinating public and private investment in critical UK infrastructure projects and a particular focus on delivery. The NIP demonstrates an active role by the Government, to ensure barriers to infrastructure delivery are resolved and that the projects identified in the plan are realised.

2.1.12 Section 2.8 of the 2011 NIP explains that the Government has identified a top 40 priority infrastructure projects, representing both major programmes and significant individual projects. The Thames Tideway Tunnel is a named project within Table 2.B which identifies priority infrastructure investment.

2.1.13 Section 3.114 of the NIP states that: "*the Government wants to ensure fair and affordable water and sewerage services while maintaining excellent drinking water quality and protecting and enhancing the ecological status of water bodies such as lakes and rivers*".

2.1.14 One of the key ambitions of the NIP is "*maintaining the security and performance of the water and sewerage system while reducing its environmental impacts'.* This ambition translates to the following three key areas for water and sewerage infrastructure identified at Section 3.122;

a. *“maintain the water industry’s good performance (in terms of security of supply, water quality and the effective removal of waste water) in the face of rising demand and climate change pressures;*

b. *“improve the quality of England’s water environment, through reduced pollution and sustainable abstraction, improving the status of water bodies in line with the objectives contained within the EU Water Framework Directive; and*

c. *“support the water regulator and industry in delivering a greater level and quality of customer service, and ensuring water and sewerage services are provided at prices households can afford.”*

2.1.15 In Section 3.125, the NIP states that: *“…the increasing level of sewage overflowing into the River Thames is an example of where the capacity of the drainage system to cope with an increasing population and increasing urbanisation has been exceeded and there is now a need to build new infrastructure to meet both current and future needs. The proposed Thames Tunnel will, in combination with other measures, also provide resilience to likely increased intensity of rainfall as a result of climate change and help prevent the ecological status of the Thames Tideway from deteriorating after decades of improvement”.*

2.1.16 In December 2012 a progress report was issued and this noted progress with the Thames Tideway Tunnel project and the intention to submit this application for Development Consent early in 2013.

2.2 Defining carbon

2.2.1 The Carbon Dioxide Equivalent (CO_{2e}), more often referred to as ‘Carbon’ or ‘Greenhouse Gas’ or ‘GHG’ emissions’ is a metric used for communicating the six greenhouse gases covered by the Kyoto Protocol in terms of their CO_2 equivalence – i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Each GHG defined by the Kyoto Protocol has a Global Warming Potential (GWP) relative to that of Carbon Dioxide which is used to calculate the CO_{2e} value.

2.2.2 The GHG Protocol (GHG, 2005)[5] defines direct and indirect emissions as follows:

a. Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity.

b. Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity.

2.2.3 The GHG Protocol further categorises these direct and indirect emissions into three broad scopes:

a. Scope 1: All direct GHG emissions

b. Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam

c. Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

2.3 UK grid decarbonisation

2.3.1 The nature of the UK grid electrical supply is such that currently, the majority of electricity generation is via the combustion of fossil fuels. Consequently, the consumption of electrical energy results in the emission of GHG, principally CO_2 from the generation process.

2.3.2 The Climate Change Act sets out a number of seriously challenging targets for the decarbonisation of the United Kingdom such that by 2050, total annual emissions of CO_2 will be reduced to 80% of the mass emitted in 1990.

2.3.3 The emission factor published by Defra as part of the DUKES dataset for UK electricity generation in 1990 was 858 grams of carbon dioxide equivalent per kilowatt hour generated (858 g CO_2e / kWh). This factor had reduced to 594 g CO_2e / kWh by 2009. The majority of this reduction can be explained by the widespread uptake of North Sea gas which emits less CO_2 per kWh generated than the coal it partially replaced.

2.3.4 In estimating CO_2e emissions from the operational Thames Tideway Tunnel project, two works have been consulted:

a. the first report of the Committee on Climate Change (2008 – Chapter 5)[6] which includes a trajectory for the decarbonisation of the UK economy (hereafter referred to as the CCC Report), and

b. AEA's Pathways to 2050 report for DECC (2011)[7], hereafter referred to as the DECC Report.

2.3.5 Both reports assume a degree of decarbonisation of supply in the years to 2023, at a rate of around 25g CO_2e/kWh per year. 2023 is the expected opening year of the Thames Tideway Tunnel project.

2.3.6 The CCC Report estimated that the grid electricity emission factor would be 310g CO_2e/kWh in 2020 and the AEA Forecast for DECC estimated 340g CO_2e/kWh. These are assumed to be "All Scope" emissions in the context of the Greenhouse Gas Protocol, that is to say including indirect emissions. Assuming a linear rate of decrease from 2009 until 2030, when both reports suggest an emission factor of 69g CO_2e/kWh, the factor for 2020 would be 319g CO_2e/kWh.

2.3.7 In the CCC Report the grid electricity emission factor falls annually until the UK electricity generating network is effectively supplying zero carbon electricity by 2035. This is achieved through a combination of technology switching, capture and offsetting. .

2.3.8 If these assumptions prove accurate, the operational Thames Tideway Tunnel project will only give rise to net GHG emissions during the first 14 years of operation.

2.3.9 The decarbonisation trajectory is illustrated in more detail in Appendix A. To illustrate the significant impact that decarbonisation has in terms of carbon reduction, a worst case scenario for the Thames Tideway Tunnel project assuming the 2012 electricity emission factor for the full 120 year operational phase has also been produced. The findings from this worst case scenario can be seen in the 'Results – Operational' section.

2.4 Other project objectives and targets

2.4.1 Thames Water's commitment to tackling climate change is set out in its Climate Change Policy (2011), which is taken into account across all its business operations, including new projects like the Thames Tideway Tunnel project.

2.4.2 Thames Water has adopted a series of sustainability objectives with which it aspires to work towards in delivering the project. This includes an objective for climate change mitigation, which is to – '*Maximise energy efficiency and minimise the carbon footprint of the project'*. This Energy and Carbon Footprint Report helps to explain how this objective would be achieved for this project.

2.4.3 Thames Water's (TW) Corporate Responsibility and Sustainability Report 2011/12 (Thames Water, 2011/12)[8] sets a voluntary target of cutting greenhouse emissions (CO2e) by 20% by 2015 compared with 1990 levels for the emissions associated with its operations and electricity and natural gas use. This relates to operational energy and as such is consistent with the London Plan.

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3 The energy and carbon footprint assessment

3.1 Purpose of the energy and carbon footprint assessment

3.1.1 The principal purpose of the assessment is to evaluate the Thames Tideway Tunnel's carbon footprint over its 120 year design life and record where interventions have been made during design to reduce GHG emissions. The report presents the key findings, describes the methodology used to model the carbon and energy demand of the project and discuss the mitigation opportunities available.

3.1.2 The energy and carbon footprint assessment:

a. seeks to be accurate, verifiable, complete, consistent, relevant, transparent and not misleading

b. uses a methodology that is sufficiently thorough and comprehensive to support the energy demand claim with reproducible results

c. uses a 'bottom up' approach aggregating energy demands from the lowest practicable level as sourced from the large amount of information prepared by the project design team.

3.1.3 The report summarises and interprets the outputs of two technically-linked models which have been produced. One model deals with electrical and diesel energy demands from the construction and operational phases of the project; this is referred to as the Energy Model. The other is in more detail and synthesises the outputs of the Energy Model and other project activities into GHG emissions. This is known as the Carbon Model.

3.1.4 The Energy Model has been constructed in Microsoft Office Excel® while the Carbon Model has been constructed in Atkins' Carbon Critical Knowledgebase software package (referred to as the 'Carbon Knowledgebase').

3.1.5 The Carbon Knowledgebase relies on a database of emission factors (carbon factors), which have been used in the Carbon Model. As the quality of these data evolves and understanding of carbon improves, so the variety of elementary carbon data will increase. It is recognised that carbon-related decisions, including the calculation and analysis of carbon, are only as good as the data that underpin them and as such the efficacy, accuracy and quality of these data is fundamental. For this reason the Carbon Knowledgebase was created to store, manage and control fundamental carbon factor information. The Carbon Knowledgebase forms the centralised body of knowledge upon which all carbon calculations and decisions are based.

3.1.6 The overall energy demands and GHG emissions from the Thames Tideway Tunnel's construction and operation have been modelled in as much detail as the information emerging from the detailed design of the Thames Tideway Tunnel allowed. This has not been simply undertaken as an accounting exercise – the real value in undertaking such a detailed modelling exercise is found in the analysis of the model outputs. These outputs have been examined to identify the activities which are the most GHG-intensive, with a view to targeting suitable interventions for mitigation at these areas of greatest significance.

3.1.7 This report is intended to meet the needs of a conventional Energy Statement, as required by the London Plan and associated guidance and includes a detailed treatment of the operational phase of the project: the 120 years (minimum) in which the Thames Tideway Tunnel project is in operation.

3.1.8 In accordance with the London Plan, this report has broadly been based upon the GLA 'Energy Planning' approach for assessment of projects. However, as there is no specific guidance on the treatment of large infrastructure projects, the approach adopted is necessarily bespoke.

3.1.9 Any assessment of energy requirements requires completeness of data within the scope; in a project of this size the assessment's scope boundaries have been clearly and carefully defined.

3.2 Energy and carbon requirements

3.2.1 It is inevitable that there will be a 'carbon cost', associated with the project, which is a net increase in global GHG emissions beyond a business- as-usual scenario. This is unavoidable for any infrastructure project of this kind – particularly due to the large upfront GHG emissions associated with the production of the necessary materials and the construction process itself. Due to the order of magnitude and nature of this project it is difficult to directly quantify a carbon payback period; however, the environmental benefits of the project are numerous, and well-documented in both the NPS and the *Needs Report*.

3.2.2 Thames Water believes it important to manage and control emissions as far as practical and possible whilst delivering the Thames Tideway Tunnel project. The project must therefore make full use of the most up-to-date energy and carbon model (Appendix B) to identify carbon hotspots and potentially mitigate carbon through the following key measures:

a. reduce the fundamental need for materials

b. investigate alternative low carbon materials

c. reduce energy consumption; e.g. through the introduction of measures to decrease consumption and ultimately to explore zero- and low-carbon energy generation to meet a proportion of the project's needs.

3.3 Scope of the assessment

3.3.1 This report represents part of the work that the project is committed to undertaking to optimise the sustainability of the project during both construction and operation.

3.3.2 This report identifies the main aspects of the project's construction and operational phases that result in the release of GHGs. This is a wider scope than a conventional energy statement, which focuses solely on the energy demand of a building or asset in operation. The life cycle analysis was therefore carried out on a 'cradle to built-asset' basis with the addition of the operational phase.

3.3.3 To solely focus on operational energy would underestimate the project's impacts. It is the total GHG emissions associated with the project that are more representative. GHG emissions are produced during energy generation from fossil fuels but also emitted directly from project activities (such as the operation of vehicles and machinery) and indirectly from the project's demand for materials, which require energy during their production and therefore emit GHGs when produced and supplied.

3.3.4 The scope of the assessment hence evaluated GHG emissions from the following source types:

a. Materials – the project will increase demand for materials, particularly concrete and steel, the production of which have a high energy demand and significant GHG emissions.

b. Logistics – the project will increase the overall number of vehicle journeys in and around construction sites to deliver and remove materials from the active work sites

c. Construction worksite activities – the project will increase energy demand and emissions from electrically and diesel-powered plant and machinery during construction

d. Operation – the project will require electrical energy to operate over its 120 year life.

3.3.5 In relation to emissions associated with the supply chain (e.g. embodied carbon of concrete), whilst mitigation in this area is considered out of scope of this assessment, there are measures included in the *Code of Construction Practice* which seek to reduce such emissions. The contractor will be required to produce a Materials Management Plan which will include measures to manage materials usage during construction and for the contractor to consider the carbon footprint of construction activities. The plan will include ways to: use sustainably sourced materials (eg FSC or PFEC certified timber); use recycled or secondary materials; minimise use of unhealthy materials, which have the potential to harm human health or the natural environment.

3.4 Key assumptions

3.4.1 The following is a set of assumptions used in undertaking the assessment:

a. The Lee Tunnel, currently under construction, will share some common infrastructure with the Thames Tideway Tunnel project. For example the combined Thames and Lee Tunnel flow received at the Tideway Pumping Station will be lifted by a common set of pumps. Where possible, the energy consumption of the shared infrastructure that is specific to the operation of Thames Tideway Tunnel project has been included in this assessment.

b. The CSO volume pumped out in the typical year by the Thames Tideway and the Lee Tunnels combined is estimated at 22.3 million cubic metres per annum. Of this, the Lee Tunnel alone will pump out approximately 6.1 million cubic metres and the Thames Tideway Tunnel will pump out the remainder (approximately 16.1 million cubic metres per annum or around 72% of the total combined sewage volume).

c. The Thames Tideway Tunnel design does not include additional wastewater treatment capacity at Beckton, except for supplementary inlet flow screening. The preceding Lee Tunnel Project provided additional wastewater and sludge treatment capacity at the Beckton and Riverside treatment plants. There is however capacity planned at the treatment plants to manage the extra waste water collected by the Thames Tideway Tunnel – not just that collected by the Lee Tunnel.

d. The expected duty for the Tideway pumping station is 300 hours of operation per year over the years 2023 to 2143, around 3.5% of the time.

e. The energy demand of the Thames Tideway Tunnel hence includes a background energy consumption component for maintaining the capacity and integrity of the empty tunnel during dry weather conditions, as well as with the intermittent energy consumptions required to deliver the tunnel functions under filled or partially-filled conditions.

f. The energy demand is therefore projected on the basis of annualised data whilst recognising that, in reality, operational conditions will be characterised by short-term fluctuations.

g. Operating the tunnel consumes only electrical power; there are no heating or cooling requirements. This power may be sourced from the supply grid, local generation capacity, a decentralised private generation network, or indeed any combination of these sources.

h. The scenario which includes some barge transport (ie the proposed logistics scenario) excludes the GHG emissions associated with the construction of any materials handling facilities which would be required for barge shipment.

3.4.2 The detailed assumptions, exclusions and justifications are discussed in the results chapters for each of the different lifecycle stages (i.e. Materials, Logistics, Worksite construction activities and Operation).

3.5 Project design evolution and carbon footprint

3.5.1 Preliminary work on the project carbon footprint was undertaken in 2009 and was based on three route options (see Section 6.2 below). Similar to the carbon modelling exercise presented in this report, this work examined the proposed construction of the Thames Tideway Tunnel as well as the operational phase.

3.5.2 Although these design changes cannot be accounted for as planned carbon reductions, it is still important to highlight the effect they have had on the overall carbon footprint. The most notable change between the early designs and the current proposed route is the length of the tunnel. This has a direct impact on the amount of construction materials needed (i.e. concrete), the quantity of excavated material which needs to be transported away from the sites and the amount of tunnelling required by the energy intensive Tunnel Boring Machines (TBMs).

3.5.3 The longest alignment, the River Thames Route (see Plate 6.1, Section 6.2), cannot be considered the official baseline as it was an early concept and not a realistic design to put forward as a proposed route; therefore the baseline for the purposes of this assessment is the proposed Abbey Mills route.

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4 Methodology

4.1 Standards

4.1.1 At the time of publishing this report, there is no formal standard methodology for the quantification of GHG emissions over the lifetime of a capital infrastructure project. Guidance does exist but is largely focussed on discrete products or commercial entities. Nonetheless, the principles of the ISO Standard 14044:2006 on Lifecycle Analysis have been applied; namely:

a. define the goal of the study

b. define the scope and boundaries

c. produce a lifecycle inventory , with documentation on data sources

d. undertake interpretative analysis on the inventory

4.1.2 In addition to ISO14044, the accounting principles defined by the GHG Protocol (Corporate Standard) (GHG, 2004)[9] and the assumptions and methodologies used within Defra's 2012 Conversion Factor document were also used for guidance. When additional direction was needed, the GHG Protocol 'Product Life Cycle Accounting and Reporting Standard 'and' Scope 3 standards were also consulted.

4.2 Project Boundary

4.2.1 The goal of the study is to quantify, as accurately as possible, the lifecycle GHG emissions resulting from the construction and operation of the Thames Tideway Tunnel with a view to targeting interventions to mitigate.

4.2.2 The various emission sources were identified using the recommended life cycle stages as per ISO 14044 and if there was any uncertainty regarding the inclusion or exclusion of any emission sources in the boundary, the wider guidance was referred to. The following are the life cycle stages considered:

a. **Raw materials (Procurement)** – this considers the embodied carbon in the construction materials and the transport emissions arising due to the various site deliveries of bulk materials.

b. **Construction** – this stage considers the diesel and electricity (i.e. energy) consumed during the construction phase as a result of plant activity and also the transport emissions arising due to the removal of excavated material.

c. **Operational** – this considers the emission sources throughout the full 120 year operational phase of the project. Table 10.5 sets out the scope of the operational phase demand

d. **End of Life** – due to the uncertainty of data and the fact that the tunnel may operate beyond its 120 year design life, this life cycle stage has not been considered within the boundary of the energy and carbon assessment.

4.3 Emissions sources

4.3.1 Based on the defined scope and boundaries of the assessment, the main emission sources can be summarised as follows.

a. **Materials**: indirect (embodied) GHGs from the bulk construction materials

b. **Worksite construction activities:** direct emissions of GHGs from construction plant and machinery and indirect emissions from remote (grid) electrical energy generation. This excludes construction traffic (road and river) which is considered below

c. **Transport:** direct emissions of GHGs from petrol and diesel-fuelled vehicles transferring materials, during the construction phase, to and from construction worksites

d. **Operation:** indirect emissions of GHGs from electrical energy generation required during the operational lifetime of the Thames Tideway Tunnel. Maintenance has been considered out of scope at this stage in the design.

4.3.2 As is consistent with the guidance reviewed, decommissioning has been excluded from the boundary. It is likely that the Thames Tideway Tunnel will continue to serve well in excess of its operational design life of 120 years. Even if not, a scenario whereby the Thames Tideway Tunnel is removed and its component parts and materials disposed of is unlikely – if it ever became genuinely obsolete it is likely to remain in situ. The technologies for removal and disposal in the mid-22nd century cannot be evaluated with any certainty; therefore the overall uncertainty about whether decommissioning would even take place, and how it would be achieved if so, is too great to be included in the scope of the report. Decommissioning is therefore not discussed further.

4.3.3 Using these emission sources as a starting point, the data gathering process could start. This was achieved by utilising the full range of site specific construction report documents, logistic strategy documents and by data sharing and regular communication with the project team.

4.3.4 Energy data (ie. consumption of electricity and fuel) were calculated in terms of kilowatt hours (kWh) using a bespoke Microsoft Office Excel® spread sheet as part of the Energy Model. Logistics and material data (ie. transport of materials and material quantities) were input directly into the Carbon Model and calculated directly into CO_{2e}.

4.3.5 Essentially the requirements of a typical Energy Statement were covered by the Energy Model and the additional items such as embodied carbon and transport emissions were calculated using the Carbon Model. Once complete, the results from the Energy Model were entered as kWh electricity and litres of fuel consumed into the Carbon Model so that the carbon footprint could be analysed and communicated in its entirety.

4.3.6 The Carbon Model is an active tool and any factors used or assumptions made are all clearly documented within the model. Should any changes be required (eg. an increase in Pulverised Fuel Ash (PFA) composition of the concrete) then this can be quickly applied to the model to create an additional scenario.

4.4 Data requirements

4.4.1 The Carbon Model was generated by gathering the required data for materials, worksite construction activities, transport, and operation. Each lifecycle stage had specific data requirements and data was received from a range of different sources.

Materials

4.4.2 Quantities of materials are summarised in Appendix C. Materials are organised by construction site for ease of understanding; there is no actual emission of GHG from materials at any site since these are historical emissions from the material's production processes. As the principal effects of GHGs on radiative forcing, enhanced greenhouse effect and climate change are in any case a global rather than local issue so the exact location of any emission point is immaterial.

Logistics

4.4.3 The summary requirements expected for the transportation of materials to and from the project worksites form part of the *Transport Strategy* and the *Transport Assessment* which are submitted as part of the application. A breakdown of estimated deliveries to and from all worksites is given in Appendix C.

Worksite construction activities

4.4.4 A breakdown of anticipated worksite construction activities is given in Appendix D, including the estimated operational durations of the TBMs and the quantity and operational hours of all other diesel-fuelled or electrically operated plant, machinery and tool used in the Thames Tideway Tunnel construction phase.

Operational phase

4.4.5 The aim of the operational lifecycle stage is to present the outputs of the operational phase energy model and discuss the consequent GHG emissions arising from the supply of the necessary electrical power.

4.4.6 The energy modelling takes the lowest denominator energy loads available for each active site (such as pumps or fans) and multiplies them by activity intensity and efficiency factors to generate a daily demand. For small power loads (such as local heating, lighting, stand-by power supply and mechanical actuation of valves and penstocks) estimations are made of daily consumption and efficiencies.

4.4.7 The annual composite energy demands for each site are aggregated on a daily and annual timescale basis to give the overall project demand projection. This annual demand is multiplied by the operational lifetime to give the projected whole life energy demand for the Thames Tideway Tunnel.

4.4.8 As the site demands presented in the results section are ‘best available’ normalised projections, the aggregated demands should be treated as indicative, with the attendant uncertainty that any modelling exercise brings.

4.5 Alternative scenarios

4.5.1 Two sets of alternative scenarios have been considered - one based on alternative transport scenarios, the other on UK grid projections - in order to consider potential variation in impacts:

i **Transport**: two scenarios were developed to allow consideration of the effect of using river transport: an ‘All Road’ scenario where 100% of the excavated and construction materials are transported by road; and a ‘Preferred’ scenario’, that which is proposed for the project, where river transport is used at 11 worksites. This is as set out in the *Transport Strategy* which accompanies the application (see Section 8.1).

ii **UK grid projections**: in order to illustrate the impact that decarbonisation of the grid has on the overall carbon footprint of the project, an alternate non-decarbonised model of each scenario has been quantified. This was calculated by assuming the 2012 UK electricity emission factor for the entire 120 year operational phase of the project (see Section 10.4).

4.6 Data analysis

4.6.1 The model was analysed using the functionality in the Carbon Knowledgebase itself. This allowed graphs or tables to be constructed for any level or section of the Carbon Model. High level analysis could be carried out on a site by site basis, lifecycle stages could be analysed or the tool allowed analysis on the level of individual carbon factor types (i.e. concrete, steel, electricity etc).

4.6.2 The Carbon Model results could be exported as data trees in either PDF format or into an Excel workbook for more detailed analysis if required.

All four of the carbon models (ie. ‘All Road’ & ‘Preferred Scenario’, decarbonised and non-decarbonised) are available within the tool for further analysis or modification as the Thames Tideway Tunnel team move into the more detailed design and potentially procurement phases of the project.

5 Assessment results – overall project

5.1 Introduction

5.1.1 This section presents the findings of the assessment for the overall project. In order to gauge the effectiveness of proposed interventions and design improvements, it includes comparisons with the logistics and grid carbonisation scenarios which have been tested.

5.2 Overview

'All Road' vs 'Preferred' scenario

5.2.1 The aggregated results for the 'All Road' and 'Preferred' scenarios are contained presented in Table 5.2.1 and Table 5.2.2 below. Data have been rounded to the nearest tCO_2e.

5.2.2 Table 5.2.2 also shows the potential GHG emissions avoided due to various design and construction interventions.

Table 5.2.1 – All Road Scenario (Decarbonised)

Project phase	GHG emissions (tCO_2e)
Materials (2016-2023)	702,882
Transport and logistics (2016 – 2023)	35,818
Worksite construction activities - plant and machinery (2016 – 2023)	87,182
Operation (2023-2140)	19,133
Total:	**845,015**

Table 5.2.2 – Preferred Scenario (Decarbonised, with Barge)

Project phase	GHG emissions (tCO_2e)	% of Total	Potential carbon avoided (tCO_2e)
Materials (2016-2023)	702, 882	83.9	Up to 199,000t from decrease in tunnel length
Transport and logistics (2016 – 2023)	28,837	3.4	Up to 7,000 t from partial barge transportation
Worksite construction	87,182	10.4	Marginal

Project phase	GHG emissions (tCO_2e)	% of Total	Potential carbon avoided (tCO_2e)
activities - plant and machinery (2016 – 2023)			
Operation (2023-2143)	19,133	2.3	Up to 3,800t from renewables if achieved
Total:	**838,034**	**100**	**Up to 210,000**

5.2.3 Table 5.2.1 and Table 5.2.2 show that the 'Preferred' scenario has the lower carbon impact on the basis that some construction materials and excavated materials would be transported by barge. The tables also highlight that the key impact from the project is the GHG emissions caused by construction of the infrastructure, in particular materials, being approximately 84% of the total emissions, with construction plant and machinery being around 10% of the total emissions. An analysis of the information presented in the tables follows.

Materials

5.2.4 Table 5.2.3 provides a detailed breakdown of the baseline information presented in Table 5.2.1. As can be seen in Table 5.2.3, concrete accounts for a significant proportion of the total carbon footprint; 48% when all concrete/cement materials are taken into account. This is based on the 'All Road – Decarbonised' baseline model and would be a similar percentage for the 'Preferred' scenario and would therefore be a lower percentage if the grid decarbonisation was not accounted for. Using this same model, steel accounts for another 25% of the total carbon footprint.

5.2.5 The electricity consumed during the construction phase (ie. plant and equipment) accounts for 9% of the total footprint (see Table 5.2.3) and the TBMs alone are responsible for 51% of this figure.

Table 5.2.3 – All Road (Decarbonised) Baseline - Summary of GHG emissions

Carbon Factor	Total tCO_2e	% of Total	Notes
Concrete – Fibre Reinforced	291,252	34	Construction Material
Steel – Bar & Rod – World Average Recycled Content	212,989	25	Construction Material
Concrete – RC50 – C50 MPa – Cement Replacement – PFA – 25%	119,388	14	Construction Material

Carbon Factor	Total tCO_2e	% of Total	Notes
Cement – General (UK Weighted Average)	73,288	9	Construction Material
Aggregate – General	4,776	1	Construction Material
Sand – General	1,190	0	Construction Material
Electricity – used in construction phase	74,158	9	Electricity consumption during construction phase; does not include the project's operational life.
Diesel	13,024	2	Diesel consumption during construction phase; does not include the projects operational life.
Freight – HGV – Rigid (> 17t) – Average UK Load – Diesel	28,911	3	Transport of Construction Materials/Excavated Material
Freight – HGV – Articulated (> 3.5-33t) – Average UK Load – Diesel	6,906	1	Transport of Construction Materials/Excavated Material
TTT Electricity 2023-2027	11,387	1	Operational phase electricity
TTT Electricity 2028-2032	6,096	1	Operational phase electricity
TTT Electricity 2033-2038	1,651	<1	Operational phase electricity
TOTAL	**845,015**	**100**	Project total (including all sites)

Transport and logistics

5.2.6 In relation to the emissions arising from transport and logistics strategy, comparing

5.2.7 Table 5.2.1 and Table 5.2.2, there were some instances where short distances by road were replaced by long barge journeys which actually resulted in an increase in GHG emissions; however overall there is still an approximate 20% reduction in emissions associated with the introduction of barge transport. On this basis, the proposed transport strategy is endorsed.

Operation

5.2.8 The operational GHG emissions for both scenarios are defined assuming decarbonisation. The GHG emissions for non-decarbonised operation (2023-2143) are 532,970 tCO_2e. This is discussed in more detail in the presentation of the assessment results for the operational phase (see Section 10).

5.2.9 The effect of decarbonisation can be seen from Table 5.2.2 as the operational phase amounts to under 3% (19,133 tCO_2e) of the total carbon footprint. When the decarbonisation assumption is removed and the 2012 electricity emission factor is assumed for the full 120 years, the operational phase accounts for approximately 40% of the total carbon footprint. See Section 10 for more detail on the effect of grid decarbonisation.

5.3 Comparison against alternative tunnel alignments

5.3.1 This report has been produced in part to analyse the requirements of the project and evaluate interventions into the design such as substitutions of materials and modal shift of deliveries. Interpretation of the overall energy requirements and GHG emissions is problematic as:

a. no formal methodology exists

b. no benchmark information is available as there are no other comparable projects that have been evaluated in the same way

c. assessing the relative performance of the Thames Tideway Tunnel compared to other tunnelling projects is not currently possible.

5.3.2 As a starting point, in order to determine the order of magnitude of the potential carbon saving realised from constructing a shorter tunnel, the GHG emissions arising from the three alternative alignments, as presented at Phase One consultation were considered. The alignments, shown in Plate 6.1, are as follows:

a. the River Thames alignment, which follows the Thames from Hammersmith to Beckton, cutting across the Greenwich peninsula

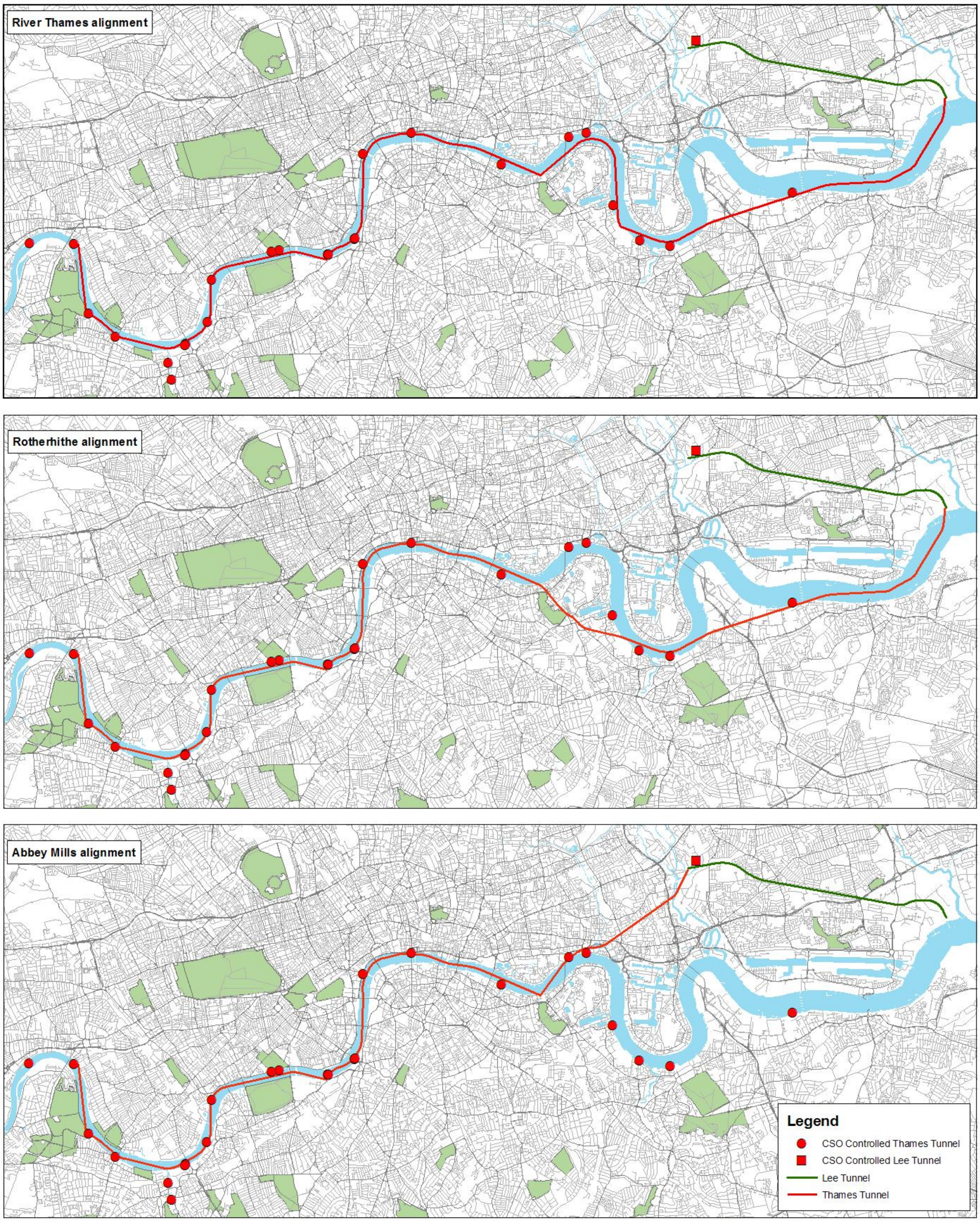
b. the Rotherhithe alignment, which is similar to the River Thames route also cutting across the Rotherhithe peninsula

c. the preferred Abbey Mills alignment, which follows the Thames as far as the Rotherhithe peninsula and then follows the Limehouse Cut canal to the Abbey Mills pumping station in Newham where the Thames Tideway Tunnel meets the Lee Tunnel.

5.3.3 On the basis of engineering, planning and environmental factors, the Abbey Mills alignment was selected and, following further design and assessment work, a slightly longer variant of it is that now proposed. The proposed alignment is shorter than the other alternative alignments (approximately 25 kilometres compared with approximately 29 for the Rotherhithe Route and 31 for the River Thames Route) and will as such require the least materials for construction.

5.3.4 The Carbon Model has been used to produce an approximate per-kilometre GHG emissions figure for the materials usage and construction phase of the Thames Tideway Tunnel of 33 kilotonnes CO_2e to the nearest kilotonne. Comparing the River Thames and Rotherhithe alignments with the Abbey Mills alignment now proposed gives a reduction in length of approximately 4 and 6 kilometres and means the GHG emissions avoided are approximately 133 kilotonnes (14% reduction) and 199 kilotonnes (19% reduction) respectively.

Plate 5.3.1 – Alternative tunnel alignments presented at Phase One consultation



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5.3.5 It was therefore possible to investigate the magnitude of the change between the alignments using ktCO2e/km as a key performance indicator. Table 5.3.1 shows the estimated ktCO_2e/km for the main tunnel for each of the alternative tunnel alignments. Table 5.3.1 uses the high level calculations undertaken at the early stages of the project to indicate the level of change in carbon emissions from the original design through to that now proposed.

Table 5.3.1 – Alternative tunnel alignments and GHG emissions

Route	Length (km)	$ktCO_2e$	Main Tunnel ($ktCO_2e/km$)	% Change
River Thames Alignment (Original Design)*	31.3	1358.85	43.41	0%
Rotherhithe Alignment (Alternative 1)*	29.6	1315.92	44.45	2.4%
Abbey Mills Alignment (Alternative 2)*	22.3	1043.17	46.78	7.8%
Abbey Mills Alignment (Proposed Alignment - Baseline)**	25	826	33.1	-23.8%

*Note: * GHG emissions based on high level assessment for main tunnel*
*** GHG emissions for main tunnel based on Carbon Model*

5.3.6 As can be seen from Table 5.3.1, the proposed alignment has a significantly lower impact in terms of carbon than the earlier alternatives. Further to this, despite the clear reductions in the overall carbon footprint from the early alignments, it was encouraging to see that the original and current carbon footprints were still of a similar order of magnitude.

5.3.7 Often when carrying out a high level carbon assessment the worst case scenario is assumed as the desired level of granularity is not often available; therefore it is not surprising that the original carbon footprints are higher than the one calculated for the official baseline. Further to this there have been numerous design and material improvements (including shortening of the tunnel) which also would have reduced the carbon footprint.

6 Assessment results - materials

6.1 Introduction

6.1.1 This section presents the analysis of the findings of the assessment in relation to the quantity and type of bulk construction materials for the project.

6.2 Analysis

6.2.1 The report assumes a basic familiarity with the concepts of embodied energy and embodied carbon. These are commonly expressed as factors describing the amount of energy required or quantity of GHG emissions associated with the production of a quantity of material, commonly expressed as kWh/kg or $kgCO_2e/kg$. These have been included in the scope of the report as building materials like concrete and steel – which the Thames Tideway Tunnel will require in large quantities – have appreciable energy and carbon factors and were hence likely to have a significant effect on the overall Thames Tideway Tunnel lifetime GHG emissions.

6.2.2 The embodied GHG emissions from the production of the materials required to build the Thames Tideway Tunnel project are summarised in Table 6.2.1.

6.2.3 The sites are ordered from west to east along the route. A more detailed breakdown can be found in Appendix B which shows the fully expanded Carbon Model.

6.2.4 As could be expected, the main tunnel drive sites (i.e. Kirtling Street, Carnwath Road and Chambers Wharf) were responsible for the bulk of the constriction material imports into the project boundary and as a result were the hotspots for embodied carbon. Of the three main tunnel drive sites, Kirtling Street imports the highest quantity of construction materials resulting in 192,551 tCO_2e, which is just over 27% of the entire projects embodied carbon.

Table 6.2.1 – Materials GHG breakdown by site

Site Name	Name	Project tCO_2e
Acton Storm Tanks	Materials (site subtotal)	19,731
	Imported Fill	5
	Concrete - Ready Mix	2,081
	Concrete - Batched - Cement	6,589
	Concrete - Batched - Sand	85
	Concrete Batched 10/20mm	116
	Grout Batched Cement	3
	Grout Batched Sand	<1

Site Name	Name	Project tCO_2e
	Rebar	10,853
Hammersmith Pumping Station	Materials (site subtotal)	6,710
	Concrete - Ready Mix	3,247
	Grout Batched Cement	3
	Grout Batched Sand	<1
	Rebar	3,460
Barn Elms	Materials (site subtotal)	3,005
	Imported Fill	30
	Concrete - Ready Mix	1,273
	Rebar	1,702
Putney Embankment Foreshore	Materials (site subtotal)	4,277
	Imported Fill	160
	Concrete - Ready Mix	1,830
	Rebar	2,288
Dormay Street	Materials (site subtotal)	3,635
	Imported Fill	6
	Concrete - Ready Mix	1,628
	Grout Batched Cement	101
	Grout Batched Sand	3
	Rebar	1,897
King George's Park	Materials (site subtotal)	20,658
	Imported Fill	396
	Concrete - Ready Mix	10,136
	Grout Batched Cement	25
	Grout Batched Sand	<1
	Rebar	10,100
Carnwath Road Riverside	Materials (site subtotal)	110,115
	Tunnel/ Shaft Rings	66,919
	Concrete - Ready Mix	6,105
	Concrete - Batched - Cement	11,817
	Concrete - Batched - Sand	153
	Concrete - Batched 10/20mm	208
	Grout - Batched - Cement	3,855
	Grout - Batched - Sand	106
	Rebar	20,953
Falconbrook Pumping Station	Materials (site subtotal)	4,688
	Imported Fill	5

Site Name	Name	Project tCO_2e
	Concrete - Ready Mix	2,116
	Rebar	2,567
Cremorne Wharf Depot	Materials (site subtotal)	7,380
	Imported Fill	12
	Concrete - Ready Mix	2,234
	Rebar	5,134
Chelsea Embankment Foreshore	Materials (site subtotal)	6,882
	Tunnel / Shaft Rings	1,530
	Imported Fill	406
	Concrete - Ready Mix	2,287
	Grout Batched Cement	9
	Grout Batched Sand	<1
	Rebar	2,651
Kirtling Street	Materials (site subtotal)	192,551
	Tunnel/ Shaft Rings	133,545
	Concrete - Ready Mix (2.45 T/m³)	10,708
	Concrete-Batched-Cement	13,257
	Concrete-Batched-Sand	171
	Concrete-Batched-10/20mm Aggregate	233
	Grout Batched Sand	211
	Grout-Batched-Cement	7,669
	Rebar	26,756
Heathwall Pumping Station	Materials (site subtotal)	9,507
	Tunnel Shaft Rings	2,320
	Imported Fill	61
	Concrete - Ready Mix	3,214
	Grout Batched Cement	6
	Grout Batched Sand	<1
	Rebar	3,906
Albert Embankment Foreshore	Materials (site subtotal)	8,993
	Tunnel / Shaft Rings	279
	Imported Fill	442
	Concrete - Ready Mix	4,036
	Grout Batched Cement	23
	Grout Batched Sand	<1

Site Name	Name	Project tCO_2e
	Rebar	4,213
Victoria Embankment Foreshore	Materials (site subtotal)	7,955
	Tunnel/ Shaft Rings	1,750
	Imported Fill	275
	Concrete - Ready Mix	2,821
	Grout Batched Cement	12
	Grout Batched Sand	<1
	Rebar	3,097
Blackfriars Bridge Foreshore	Materials (site subtotal)	45,174
	Imported Fill	776
	Concrete - Ready Mix	14,186
	Grout Batched Cement	24
	Grout Batched Sand	<1
	Rebar	30,188
Shad Thames Pumping Station	Materials (site subtotal)	912
	Tunnel/ Shaft Rings	63
	Concrete - Ready Mix	236
	Rebar	614
Chambers Wharf	Materials (site subtotal)	115,665
	Tunnel/ Shaft Rings	58,205
	Imported Fill	769
	Concrete - Ready Mix	10,645
	Concrete - Batched - Cement	14,131
	Concrete - Batched - Sand	183
	Concrete Batched 10/20mm	248
	Grout Batched Cement	3,353
	Grout - Batched - Sand	92
	Rebar	28,040
Earl Pumping Station	Materials (site subtotal)	10,288
	Imported Fill	22
	Concrete - Ready Mix	5,114
	Grout Batched Cement	17
	Grout Batched Sand	<1
	Rebar	5,134
Deptford Church Street	Materials (site subtotal)	10,497
	Imported Fill	15
	Concrete - Ready Mix	5,220

Site Name	Name	Project tCO_2e
	Grout Batched Cement	16
	Grout Batched Sand	<1
	Rebar	5,245
Greenwich Pumping Station	Materials (site subtotal)	41,327
	Tunnel/ Shaft Rings	24,217
	Imported Fill	4
	Concrete - Ready Mix	4,728
	Concrete Batched Cement	2,742
	Concrete Batched Sand	35
	Concrete Batched 10/20mm	48
	Grout Batched Cement	1,313
	Grout Batched Sand	36
	Rebar	8,203
King Edward Memorial Park Foreshore	Materials (site subtotal)	20,658
	Imported Fill	396
	Concrete - Ready Mix	10,136
	Grout Batched Cement	25
	Grout Batched Sand	<1
	Rebar	10,100
Abbey Mills Pumping Station	Materials (site subtotal)	39,770
	Concrete - Ready Mix	10,730
	Concrete - Batched - Cement	8,183
	Concrete - Batched - San	106
	Concrete Batched 10/20mm	144
	Grout - Batched - Cement	17
	Grout - Batched - Sand	<1
	Rebar	20,590
Beckton Sewage Treatment Works	Materials (site subtotal)	12,501
	Tunnel/ Shaft Ring	2,424
	Concrete - Ready Mix	4,675
	Grout Batched Cement	98
	Grout Batched Sand	3
	Rebar	5,301
Grand total (rounded)	Materials	702,900

6.3 Exclusions & justifications

6.3.1 The scope of the materials GHG assessment covered all bulk materials used in the construction of the Thames Tideway Tunnel project, primarily the ready mixed and batched concrete used in tunnel and shaft segments, grout and steel rebar. Imported fill was included where required at certain sites. Temporary and permanent above ground structures were considered de minimis emissions given the relatively small requirements for these structures.

Table 6.3.1 – Master List of Material Weights

Materials Imported to / from Site	Weight of Total Material (tonnes)
Tunnel / Shaft Rings (various sizes)	613,127
Imported Fill (2 t/m^3)	650,808
Demolition Material (2 t/m^3)	137,155
Excavated Material (2 t/m^3)	4,708,469
Concrete - Ready mix (2.45 t/m^3)	669,659
Concrete - Batched – Cement	76,648
Concrete - Batched – Sand	143,715
Concrete - Batched - 10/20mm Aggregate	191,619
Grout - Batched – Cement	22,360
Grout - Batched – PFA	22,360
Grout - Batched – Sand	89,445
Grout - Batched – Bentonite	1,119
Formwork/ Pipe/ Track/ Oils etc (15 t/delivery)	318,495
Rebar (15 t/delivery)	99,645
Plant Deliveries (15 t/delivery)	165,930
Site Supplies (1 t/delivery)	40,473
Total:	**7,951,027**

6.3.2 Formwork, pipe and track and plant deliveries are noted in the overall quantities above but the carbon footprint of these items was excluded as these were deemed to be outside the boundary of the project's lifecycle. Similarly the site supplies were considered to be too diverse and uncertain in nature and therefore disproportionately difficult to quantify given the relatively small quantities involved.

6.3.3 The justification for the above exclusions can best be illustrated using the site fencing as an example. The installation of site fences (i.e. excavation/sawing equipment etc) has been included as part of the construction phase plant emissions of the project as the project is directly responsible for any fuel consumption on site; however the embodied carbon in the fences (hoarding) has not been considered. The main reason for this is that the fences will likely enter the boundary of the project at the beginning and will be collected by the relevant supplier upon project completion to either be re-used or re-cycled. Therefore the fences will not form part of the permanent infrastructure of the Thames Tideway Tunnel but the project will have been responsible for the energy consumed whilst installing them for use in the construction phase.

6.3.4 To provide added justification of the immateriality of the fences; assuming Kirtling Street's site boundary (estimated at approximately 600m based on site drawings) and fences (made of plywood held in place by concrete blocks and steel poles); the total embodied carbon in the fences would be approximately 121,032 kgCO_2e. This figure is less than 0.06% of the embodied carbon figure for construction materials at Kirtling Street alone and even less when looking at the total GHG emissions resulting from Kirtling Street. In the same way, plant equipment and site buildings were not included in the scope in terms of embodied carbon.

6.3.5 Similar to the above exclusions from the boundary; the embodied carbon in the pumps (including the replacement of any spare parts) can also be considered as immaterial. To put this into perspective, a large waste water pump has approximately 400kg of steel (e.g. ABS 201G-CB2); this is less than 0.003% of the steel used at just Kirtling Street. If compared to the project as a whole then the immateriality of the pumps (especially compared to the non-decarbonised model) becomes evident.

6.3.6 The above exclusions and justifications are considered in line with the guidance followed for this assessment.

6.4 Carbon mitigation

6.4.1 Were the Thames Tideway Tunnel to be constructed from completely virgin aggregate materials rather than 25% pulverised fuel ash, as currently assumed as part of the performance specifications, the overall increase in the project carbon budget would be around 51 kilotonnes (over 5% of the overall project total). It would be misleading to claim this as a targeted intervention but illustrates the continued importance of challenging the project's ultimate supply chain on the carbon performance of the materials supplied.

6.4.2 The construction contractors appointed to build the Thames Tideway Tunnel will be challenged on the embodied carbon of their supply chain's products. However, there will not be a carbon budget which must be met. It is important to note that the Carbon Model presented as part of this report has been calculated at a particular point in time using emission factors from 2012 and activity data based on the most recent design iteration. It is therefore possible that by the time the construction phase is underway that the total carbon figure may be different and the weighting could also change; for example a higher percentage of PFA may be selected as the actual concrete composition. The hot spots the delivery team will need to target for carbon mitigation may therefore vary to those identified in these reports.

6.4.3 The final, most fundamental aspect of the Thames Tideway Tunnel's GHG performance is its durability. Construction materials account for over 83% of the project's GHG emissions over 120 years (assuming the decarbonised scenario). The approach adopted will be to specify materials to last without appreciable maintenance. The ready-mix concrete specified throughout has a maximum percentage of cement clinker replaced with PFA, a lower embodied carbon material, of 25%. Replacing this with 50% PFA would give a saving over the project lifetime of a further 50 kilotonnes of CO_2e but may not have the requisite engineering properties. This saving would be offset by the materials required to replace around only 1.3 kilometres (6%) of the tunnel in the event of a failure.

6.4.4 There is little influence that the project can exert over lower-carbon energy usage in the supply chain (e.g. at cement production facilities). The drive to decarbonise these industrial sectors will come from cap and trade legislation such as the EU Emissions Trading Scheme, the Carbon Reduction Commitment Energy Efficiency scheme and most significantly the projected decarbonisation of the UK grid from which the supplier industries import electrical energy.

7 Assessment results - logistics

7.1 Introduction

7.1.1 This section covers the GHG emissions associated with the transportation of bulk materials from their point of production to the relevant construction site on the Thames Tideway Tunnel alignment. Also included is the removal of excavated materials from certain construction sites to remote waste handling facilities.

7.2 Analysis

7.2.1 Table 7.2.1 demonstrates the GHG emissions avoided by the introduction of barge transportation at certain sites. It should be noted that these figures exclude the GHG emissions associated with the construction of any materials handling facilities which would be required for barge shipment.

7.2.2 The impact that the main drive sites have on transport emissions can also be clearly seen from the table below; this is due to the significant amount of construction materials imported into these three sites and the large amount of excavated material transported away from the sites. These are the hotspots to target for carbon mitigation should a more substantial alternative transport scenario be possible.

Table 7.2.1 – Summary of GHG emissions for logistics

Site	tCO_2e road only	tCO_2e road and barge
Acton Storm Tanks	116	116
Hammersmith Pumping Station	236	236
Barn Elms	153	153
Putney Embankment Foreshore	303	208
Dormay Street	344	344
King George's Park	58	58
Carnwath Road Riverside	6,206	4,946
Falconbrook Pumping Station	152	152
Cremorne Wharf Depot	201	178
Chelsea Embankment Foreshore	818	558
Kirtling Street	12,267	9,858
Heathwall Pumping Station	359	377
Albert Embankment Foreshore	1,042	660
Victoria Embankment Foreshore	662	379

Site	tCO_2e road only	tCO_2e road and barge
Blackfriars Bridge Foreshore	1,645	1,017
Shad Thames Pumping Station	40	40
Chambers Wharf	6,972	5,483
Earl Pumping Station	366	366
Deptford Church Street	285	285
Greenwich Pumping Station	1,999	1,999
King Edward Memorial Park Foreshore	809	637
Abbey Mills Pumping Station	554	554
Beckton Sewage Treatment Works	233	233
Totals (rounded)	**35,820**	**28,835**

7.3 Exclusions and justifications

7.3.1 The scope of this section includes the GHG emissions arising directly from the operation of vehicles transporting materials to and from work sites; effectively tailpipe emissions.

7.3.2 The construction materials under consideration are those tabulated in the previous section only (see Table 6.2.1). The removal of excavated materials from certain construction sites to remote waste handling facilities is included.

7.3.3 Transportation of temporary plant and machinery, general site waste and worker commuting are excluded. There will however be Travel Plans for each worksite which will seek to minimise the amount of private commuting to each construction site.

7.3.4 The single journey (i.e. delivery and collection) for plant equipment is not included in the boundary due to the significant additional accounting work required for a single lorry movement; this would again be significantly less than 1% and would therefore fall under de minimis emissions. In order to quantify this, the weight and origin of each individual piece of kit would need to be known so that the tonne kilometres could be determined.

7.3.5 The potential beneficial reuse of excavated materials has not been considered in this assessment however an *Excavated materials options assessment* (*EMOA*) has been developed which applies a sustainability appraisal type process, to develop a preferred list of suitable 'receptor sites' where this material could be disposed. The 'receptor sites' presented perform well against a series of environmental and socio-economic evaluation criteria, as well as specific technical and viability requirements. The preferred list of sites that are compliant to take this material, include:

a. former quarries undergoing restoration

b. former landfills undergoing restoration

c. habitat creation projects.

7.3.6 Information regarding the sustainability of the preferred receptor sites is available in the *Excavated material options suitability reports* (*EMOR*), appended to the *EMOA*.

7.4 Carbon mitigation

7.4.1 The energy requirements and therefore GHG emissions produced from fuel combustion to transport one tonne of materials over one kilometre by barge are lower than the equivalent tonne-kilometre journey by road vehicles. This reduction can be seen by looking at the carbon factors (kgCO_{2e}/tonne.km) which are available in the 2012 Defra GHG Conversion Factors for Company Reporting[10].

7.4.2 Though road transportation is not among the largest contributors to the overall Thames Tideway Tunnel project carbon footprint, it was examined for potential interventions at an early stage. Climate change and GHG emissions are only one element of the project's overall environmental sustainability performance – modal shift from road to river will bring benefits in terms of network congestion, emissions of air pollutants and noise. Hence, whilst GHG emissions were not the primary driver to investigate modal shift, there will undoubtedly be a positive effect on transport GHG emissions.

7.4.3 Further avoidance of GHG emissions will be explored as contracts for logistics are awarded. The Biofuels Directive (2003/30/EC)[11] has stipulated a minimum biofuel percentage in commercially available liquid fossil fuels since 2010, which will already be accounted for in the use of the Defra emissions factor data. Supply is still relatively constrained and the overall reduction in GHG emissions will be modest – the production and supply of biofuels is still a relatively energy (and fossil-derived GHG) intensive undertaking.

7.4.4 Biofuels for marine vessels are not in common use and are only in the early 2010s even being tested for long-term feasibility for use without major engine modifications. It is unlikely that a viable supply of suitable marine biofuel will be identified for use by the Thames Tideway Tunnel logistics barge fleet.

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8 Assessment results – worksite construction activities

8.1 Introduction

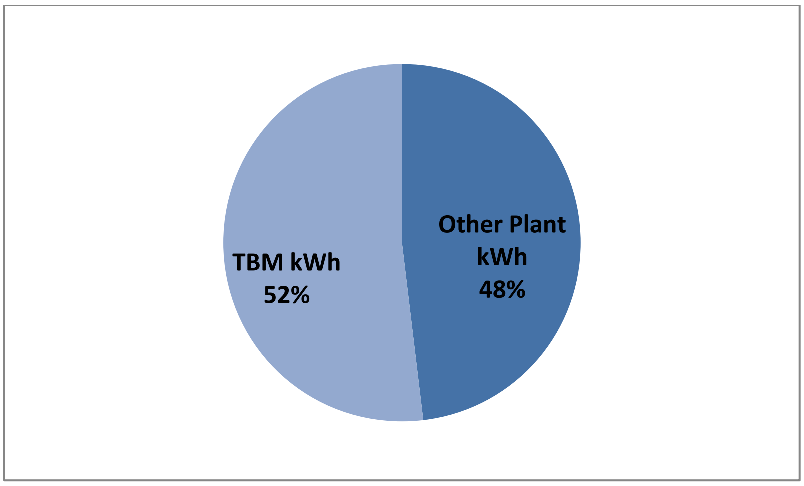
8.1.1 This section covers the GHG emissions from the construction activities at each worksite (excluding transport and logistics which are described in the above section). Construction phase emissions are rarely accounted for in major infrastructure carbon footprinting exercises, a presumption of insignificance and major challenges to obtaining expected construction activity data being the two main reasons for exclusion.

8.2 Analysis

8.2.1 Preliminary work suggested that at the very least, the effect of the TBM's would be significant in the context of overall project GHG emissions. These are heavy plant operating near-continuously for several years on a high-voltage power supply, thereby requiring additional fossil fuel combustion over 'business as usual'" by the electrical energy supplier. Their effect was considered likely to represent the vast majority of the construction phase emissions, though reasonable efforts were made to evaluate other activities.

8.2.2 The pie chart below demonstrates the percentage of the total construction phase electricity figure which is attributable to the TBMs. As can be seen the TBMs account for 52% of the electricity consumption during the construction phase. Therefore any reduction in TBM activity (shorter tunnel or more efficient operation) will have a significant effect on the construction phase electricity consumption.

Plates 8.2.1 – Percentage of kWh Attributable to TBM Activity



8.2.3 Table 8.2.1 shows the tCO_2e resulting from plant use (i.e. electricity and fuel consumption) during the construction phase.

As expected, the main drive sites are responsible for the largest impact in terms of carbon; this is mostly due to the TBM activity. The three main tunnel drive sites account for 65% of the emissions and with the drive site at Greenwich included over 76% of the GHG emissions. Therefore by focusing carbon mitigation activities on just these four sites there is potential to greatly reduce the carbon impact resulting from the construction phase of the project.

Table 8.2.1 – Construction phase worksite activities: GHG emissions by worksite

Construction site	GHG emissions, tCO_2e
Acton Storm Tanks	949
Hammersmith Pumping Station	801
Barn Elms	951
Putney Embankment Foreshore	819
Dormay Street	1,782
King George's Park	321
Carnwath Road Riverside	12,453
Falconbrook Pumping Station	544
Cremorne Wharf Depot	1,079
Chelsea Embankment Foreshore	755
Kirtling Street	25,759
Heathwall Pumping Station	1,086
Albert Embankment Foreshore	1,155
Victoria Embankment Foreshore	1,258
Blackfriars Bridge Foreshore	1,117
Chambers Wharf	18,610
Earl Pumping Station	727
Deptford Church Street	728
Greenwich Pumping Station	10,011
King Edward Memorial Park Foreshore	1,249
Abbey Mills Pumping Station	2,016
Beckton Sewage Treatment Works	3,013
Totals (rounded)	**87,180**

8.3 Exclusions and justifications

8.3.1 The areas included in the scope of the energy and carbon models for the construction phase comprise the principal energy consuming activities at the worksites, summarised as follows:

a. High-voltage electricity: the TBMs themselves

b. Low-voltage electricity: electrically operated plant and machinery in use at the construction sites, including tools, lighting and welfare facilities

c. Diesel-fuelled plant and machinery.

8.4 Carbon mitigation

8.4.1 The shorter, preferred alignment will have a commensurately lower need for plant and machinery, particularly tunnel boring machines, than previous design iterations. The carbon avoided has been discussed in chapter 7 on materials.

8.4.2 The expected run times of plant and machinery in the site-specific Construction Reports, from which the majority of the activity data evaluated is derived, are robust and likely to be overestimates in order to budget for a worst case scenario. Once contracts are let for the construction of the project, efficient operation of on-site plant and machinery may be specified in contract documentation or site environmental management plans. Specific measures may include keeping detailed records of fuel consumption and enforcing minimal idling of equipment.

8.4.3 Further avoidance of GHG emissions will be explored as contracts for construction are awarded. There will be limited opportunities for the installation of on-site renewable energy sources at the construction sites themselves. As with other project phases, the availability of biofuels for diesel-powered plant and the trajectory towards a greater proportion of renewable energy in the overall UK electricity generating grid represent the most realistic means of reducing construction-phase GHG emissions.

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9 Assessment results - operational phase

9.1 Introduction

9.1.1 This section covers the operational life of the Thames Tideway Tunnel – once construction is complete and the tunnel operational in 2023; the tunnel will operate until at least 2143. Throughout its lifetime it will require electrical energy to operate; and at least until such time as the UK's grid supply decarbonises, this requisite electrical energy will lead to indirect GHG emissions.

9.2 Analysis

9.2.1 The purpose of the Energy Model is to systematically present the energy demand expected during the operational phase of the project assuming no interventions from specifically-commissioned renewable or other offset.

9.2.2 For the purposes of this report energy demand and energy consumption are synonymous. The results of the assessment are presented as 'demand' on the basis that it is modelled, rather than using actual measured consumptions. The fundamental approach is the systematic presentation of itemised energy demands specified for the Tunnel; a 'bottom-up' strategy. This enables energy demand projections to be presented on both a site and category basis.

9.2.3 Applying the project's energy demand data results in an annual operational energy demand baseline of approximately 8.5 GWh. Over the design lifetime of the tunnel this equates to 1,016 GWh. To put this into context, Thames Water used 1,171 GWh of electricity to pump and treat water and sewage last year (2011/12) [i].

9.2.4 The disaggregated annual energy demands for each site (in kWh) are presented in Table 9.2.1.

Table 9.2.1 – Projected Annual Energy Demand by Site*

Site	Annual Energy Consumption		
	Total kWh	LV electric kWh	HV electric kWh
Acton Storm Tanks	337,670	337,670	-
Hammersmith Pumping Station	6,343	6,343	-
Barn Elms	9,665	9,665	-
Putney Embankment	9,666	9,666	-

[i] http://www.thameswater.co.uk/cr/Climatechange/Mitigatingclimatechange/Ourcarbonemissions/index.html

Site	Annual Energy Consumption		
	Total kWh	LV electric kWh	HV electric kWh
Foreshore			
Dormay Street	9,666	9,666	-
King Georges Park	9,665	9,665	-
Carnwath Road Riverside	642,106	642,106	-
Falconbrook Pumping Station	7,621	7,621	-
Cremorne Wharf Depot	8,347	8,347	-
Chelsea Embankment Foreshore	10,223	10,223	-
Kirtling Street	9,580	9,580	-
Heathwall Pumping Station	7,621	7,621	-
Albert Embankment Foreshore	19,481	19,481	-
Victoria Embankment Foreshore	9,901	9,901	-
Blackfriars Bridge Foreshore	19,481	19,481	-
Shad Thames Pumping Station	34,938	34,938	-
Chambers Wharf	9,580	9,580	-
Earl Pumping Station	355	355	-
Deptford Church Street	9,901	9,901	-
Greenwich Pumping Station	769	769	-
King Edward Memorial Park Foreshore	9,901	9,901	-
Beckton Sewage Treatment Works	7,281,770	2,383,333	4,898,438
Totals (rounded)	8,464,250	3,565,810	4,898,438

*Note: * Abbey Mills is excluded from this table as it forms part of the Lee Tunnel operation*

9.2.5 Further technical details of the model can be found in Appendix E.

9.2.6 The GHG emissions for the operational phase are complex as unlike the assessment of the other lifecycle stages, the effects of tunnel operation must be assessed over several decades during which time the UK national grid electricity supply is expected to steeply decarbonise. A full annual breakdown is provided in Appendix A.

9.3 Detailed Scope, exclusions and justifications

9.3.1 This section presents the main technical specifications of the tunnel design preferred option relevant for inclusion in the modelling together with more detail on inclusions and exclusions from the demand estimation.

Site List

9.3.2 Tunnel-related energy consuming devices will be located in pumping stations, odour control towers, access chambers, ventilation shafts and other structures associated with the tunnel

9.3.3 These energy consuming devices will function at background low level associated with maintaining the tunnel capacity under dry weather conditions and at higher consumptions associated with flow reaching the main tunnel.

9.3.4 Table 9.3.1 summarises equipment installations at sites with significant energy loads directly associated with the operation of the Thames Tideway Tunnel. In some cases, these sites also house the pumps and equipment necessary to deliver the existing dry weather flow handling capacity, or used by the Lee Tunnel; the former components will be unaffected by the project and the latter have been assessed as part of the Lee Tunnel Energy Assessment.

Table 9.3.1 – Active sites with equipment necessary for project operation

Tunnel Site	Pumps + support systems	Active Ventilation/ Odour Control	UPS Power Supply	Small power (lighting & heating)	Hydraulic pumps	Other
Acton Storm Tanks	None	Yes	Yes	Yes	None	Actuators
Hammersmith Pumping Station	None	None	Yes	None	Yes	Actuators
Barn Elms	None	None	Yes	Yes	Yes	
Putney Embankment Foreshore	None	None	Yes	Yes	None	
Dormay Street	None	None	Yes	Yes	Yes	
King Georges Park	None	None	Yes	Yes	Yes	
Carnwath Road Riverside	None	Yes	Yes	Yes	None	
Falconbrook Pumping Station	None	None	Yes	None	Yes	Actuators
Cremorne Wharf Depot	None	None	Yes	Yes	Yes	

Tunnel Site	Pumps + support systems	Active Ventilation/ Odour Control	UPS Power Supply	Small power (lighting & heating)	Hydraulic pumps	Other
Chelsea Embankment Foreshore	None	None	Yes	Yes	Yes	
Kirtling Street	None	None	Yes	Yes	None	
Heathwall Pumping Station	None	None	Yes	None	Yes	
Albert Embankment Foreshore	None	None	Yes	Yes	Yes	
Victoria Embankment Foreshore	None	None	Yes	Yes	Yes	
Blackfriars Bridge Foreshore	None	None	Yes	Yes	Yes	
Shad Pumping Station	None	None	None	None	None	
Chambers Wharf	None	None	Yes	Yes	None	
Earl Pumping Station	None	None	Yes	None	Yes	Actuators
Deptford Church Street	None	None	Yes	Yes	Yes	
Greenwich Pumping Station	None	Yes	Yes	Yes	Yes	
King Edward Memorial Park Foreshore	None	None	Yes	Yes	Yes	
Abbey Mills Pumping Station	None	Yes	Yes	Yes	None	
Beckton Sewage Treatment Works	5 x VSD pumps	Yes	Yes	Yes	Yes	Sump pumping

Note: VSD = Variable Speed Drive

Hydraulic specifications

9.3.5 Combined sewage water volume exceeding the existing sewer network capacity will divert to the main tunnel. It will flow under gravity to Abbey Mills and then via the Lee Tunnel to the Tideway pumping station at Beckton. Here it will be lifted for full treatment or outfall discharge.

9.3.6 Together the Thames Tideway Tunnel and Lee Tunnel will capture an estimated 22.3 million cubic metres per year of flow to the Tideway pumping station (starting in year 2023) and deliver it to the Tideway pumping station. Of this 16.1 million cubic metres will be captured by the

Thames Tideway Tunnel and 6.2 million cubic metres by the Lee Tunnel project.

9.3.7 The tunnel lifetime spans 120 years during which environmental conditions will undoubtedly change. However in the absence of further information, the 2023 design flow is assumed to persist for all years of operation.

9.3.8 The Tunnel will be available for operation for 365 days per year, 24 hours per day with the projected pumping operations (for the Tideway pumping station) in the course of a year, as at 2023, being 300 hours.

9.3.9 This duty projects a nominal instantaneous flow rate of 15 cubic metres per second at the Tideway pumping station. The maximum pumping rate achievable by each of its six variable speed pumps installed is 3.05 cubic metres per second. These rates are assumed consistent for the lifetime of the project. This data is summarised in Table 9.3.2.

Table 9.3.2 – Tunnel Design Flow and Duration

Parameter	Annual Design Flow*	Annual Operational Period	Nominal Instantaneous Pumping Rate
Thames Tideway Tunnel	16.090 million cubic metres	300 hours	15 cubic metres per second

*Note: * - Period 2023 to 2143*

9.3.10 The Tideway pumping station pumps out the Thames Tideway Tunnel and Lee Tunnel combined gravity flow received via the Lee Tunnel. Its variable speed pumps will lift the contents for full treatment or discharge via the Tideway CSO according to the control strategy imposed.

9.3.11 Table 9.3.3 summarises the main physical characteristics of the pumping duty required.

Table 9.3.3 – Tideway Pumping Station Mechanical Design Parameters

Static Head	Dynamic Head	Pump Efficiency	VSD* Efficiency	Maximum Flow rate
79.0 metres	3.0 metres	0.75	1.0	15 cubic metres per second

*Note: * VSD - Variable speed drives*

Baseline energy assessment: caveats and boundaries

9.3.12 For the purposes of this assessment, energy demand is defined as:

"the projected energy consumption of fixed itemised equipment incurred during normal working conditions operations based on rated loads adjusted by loading, efficiency and activity factors persisting for the project duration".

9.3.13 Unless stated otherwise, the information and data used in the Energy Model have been sourced directly from the project design team and are current at the time of reporting.

9.3.14 At the project design and planning stage all information is 'best available estimate'. In the absence of appropriate information, factors and efficiencies have been estimated on best engineering judgement.

9.3.15 Applying the assessment rules presented, an estimate of the project's likely energy demand on a lifetime basis is provided by aggregating demand data from the lowest available level. As the demands are 'best available' projections the aggregated consumptions are indicative.

9.3.16 Only equipment directly attributed to the Thames Tideway Tunnel operation is recognised in the model. For example, pumping equipment at the Abbey Mills pumping station is concerned with dry weather flow (DWF) pumping and Lee Tunnel operation therefore is not included in the Thames Tideway Tunnel load schedule. In some cases electrical load may be common to both the Lee and the Thames Tideway Tunnels; for example UPS systems or drainage pumps; where this is the case 50% of the load is assumed attributable to Thames Tideway Tunnel.

9.3.17 Operational maintenance activities (eg cleaning, servicing and testing, small repairs, fan replacement etc) are excluded as being de minimis emissions.

9.3.18 Table 9.3.4 defines the model boundaries used in this assessment. A more detailed summary is to be found in Appendix C.

Table 9.3.4 – Operational Phase Demand Boundary Scope

Inclusions	Exclusions
Significant energy demand incurred by fixed assets as a result of directly operating the Tunnel as defined in Table 10.1, specifically: - Tideway pumping station including ancillary support systems - Fans at the Acton and Carnwath odour control towers - Odour control at Tideway pumping station	All existing pumping station operations under DWF conditions
The necessary small power consumption comprising heating, lighting, UPS and monitoring systems maintaining the operational capacity of the Tunnel.	All Lee Tunnel operational consumption
	Beckton STW operations post inlet works including odour control and screenings removal
	Maintenance, servicing and testing consumptions
Localised control systems including	Insignificant and incidental

Inclusions	Exclusions
hydraulic valve and penstock operation	consumptions and emissions.
	Any construction, testing and development works
	Embodied carbon from end-of-life equipment replacement.
	Other fuel types such as natural gas, LPG or diesel
	Personnel related emissions such as maintenance, travel, management and amenity
	Transmission grid losses and transformation losses

9.3.19 The major equipment components needed to operate the tunnel are few, with a design bias for reliability. These items are unlikely to develop significantly better energy efficiency over their lifetime, therefore no lifetime demand proportioning factors are applied in the model; ie. the 2023 energy demand is assumed constant throughout the Tunnel's operational lifetime.

9.3.20 The 2023 annual energy demand 'as commissioned' is hence considered to represent each year of operation until 2143. In reality, environmental conditions will change year to year, (and indeed decade to decade) but the impact of these changes on tunnel operations is currently highly uncertain.

9.3.21 It was concluded that the inclusion of pump maintenance and any cleaning of the tunnels would result in too high a degree of uncertainty. This is primarily due to a lack of data and the fact that very broad assumptions would need to be made for the maintenance frequency, requirements and amount of additional raw material in spare parts. Further to this, compared to the project as a whole the emissions associated with pump maintenance would be fall significantly below 1% and can therefore be considered *de-minimis*.

9.4 Carbon mitigation

9.4.1 The scope for demand reduction is very different to what might be achievable for a domestic or commercial building. The Thames Tideway Tunnel does not require heating, cooling or lighting, and many of the design interventions based on reducing energy consumption for these areas are as a result irrelevant.

9.4.2 The energy requirements of the operational tunnel are dominated by the need to pump liquid collected in the tunnel to the treatment works at Beckton. The need to specify energy efficient pumping equipment is understood, but it is not the overriding design consideration. The pumps must be reliable above all else and are specified as such. This has the following advantages with energy and GHG effects:

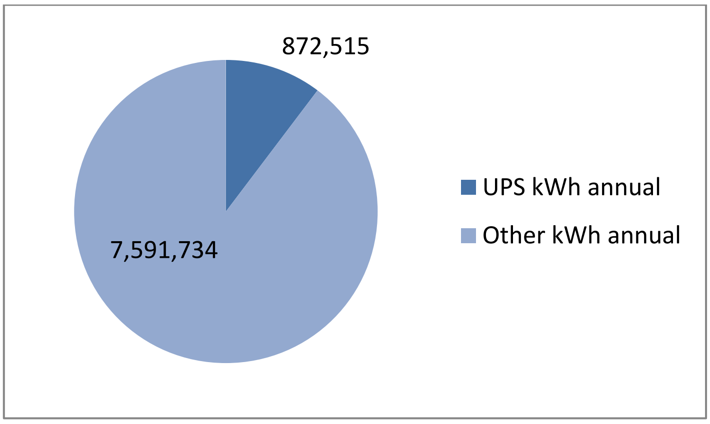
a. minimised overflow of untreated sewage with consequent fugitive GHG emissions, though this is a negligible effect in an uncontrolled environment;

b. minimised energy and materials used in maintenance and repair; and

c. embodied carbon from manufacture of replacement materials and pumps.

9.4.3 Plate 9.4.1 highlights the significance of the UPS energy demand compared to other operational phase equipment. As can be seen, the UPS accounts for 872,515kWh (10.3%) of the annual operation energy demand. This will largely be due to the assumptions provided by Thames Tideway Tunnel for the Energy Model; this therefore highlights the imports in refining the operational assumptions.

Plate 9.4.1 – UPS Annual Demand (kWh)



9.4.4 The project is committed to identifying hardware which could further reduce energy demands beyond the modelled baseline, but for the reasons outlined above performance and reliability must be the prime considerations.

9.4.5 The baseline energy demand excludes efficiency savings beyond implementing current best design practice; ie. current best design practice is assumed with respect to specifying motors, drives and appliances.

9.4.6 Apart from specifying best available technologies and ensuring that they are operated in an optimum manner as specified, further significant energy efficiency opportunities for the tunnel operation appear limited.

9.5 Grid decarbonisation during operational phase

Analysis

9.5.1 The assumption made for the baseline, as outlined in Section 2 above, is that the UK electricity emission factor will reduce as the grid is decarbonised until the zero carbon target in 2035. This has a dramatic effect on the overall carbon footprint and to avoid any accusation of trying to hide emissions, a second non-decarbonised baseline has been calculated to demonstrate the difference.

9.5.2 This is an ambitious prediction and to illustrate the impact that grid decarbonisation has on the operational phase, a worst case scenario carbon footprint was also calculated assuming 120 years of operation using the UK electricity emission factor for 2012. This results in a significant difference for two reasons, firstly the decarbonisation assumption assumes a zero carbon grid from 2035 onwards which essentially means 105 years (87.5%) of the project's operational phase results in zero carbon impact and secondly the emission factor decreases year on year leading up to 2035 resulting on a year on year reduction. To demonstrate how significant this change is and why it is important not to ignore the operational phase of the project, the decarbonised baseline (All Road) scenario has been directly compared in Table 9.5.1 to its non-decarbonised equivalent. Applying decarbonisation, as per the assumptions in the CCC report and the AEA forecast for DECC, results in a 38% overall reduction in the footprint; this is due to the operational phase seeing a ~96% reduction in CO_2e emissions.

Table 9.5.1 – Projected Annual Energy Demand for the Thames Tideway Tunnel

	Total Footprint (kgCO2e)	Operational Phase (kgCO2e)
Baseline (All Road) Non Decarbonised Scenario	1,358,852,307	532,970,603
Baseline (All Road) Decarbonised Scenario	845,014,772	19,133,068

Conclusion

9.5.3 It can be seen that whilst the decarbonised projection is based on ambitious grid changes and may not be achieved, the non-decarbonised scenario is significantly less likely, given the DECC and CCC projections, EU regulation and global climate change agreements. It is therefore considered that the operational emissions presented are more likely to be at the lower, decarbonised, end of the range than at the high end.

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10 Measures to reduce GHG emissions

10.1 Overview

10.1.1 This section sets out the measures, identified as part of the analysis and review of the Energy and Carbon Model, which have been incorporated in the project and those opportunities which will be taken forward for further consideration at the detailed design stage.

10.2 Incorporated measures

10.2.1 Measures to reduce GHG emissions which are incorporated as part of the project include:

a. **Tunnel length minimised** chosen alignment for project minimises the length of tunnel (this will mitigate embodied carbon by reducing the quantity of construction materials, reducing the amount of transport of construction/excavated materials and reducing the energy consumed due to TBM and other plant activity).

b. **Tunnel gradient** is such that it is self-cleaning, reducing the need for purging and allowing the combined sewage to flow west to east under gravity.

c. **Air management strategy** designed to limit fans in operation. Three new active ventilation sites would be required for the Thames Tideway Tunnel, the remainder of the tunnel would be ventilated by a passive design.

d. **Minimise quantity of construction materials** through design improvements e.g. minimising area of foreshore structures, where not required (this will mitigate embodied carbon by reducing the quantity of construction materials).

e. **Selection of low-carbon materials** - assumed specification of concrete with 25% PFA content (this will mitigate embodied carbon by reducing the quantity of construction materials).

f. **Selection of low-carbon transport modes** - commitment to transport a minimum of 53% of excavated materials and construction materials by river. CoCP measure to low carbon fuel for HGV transport (this will reduce the amount of carbon by reducing the amount of fossil fuel consumed during the logistics stage of the project).

g. **Measures included in the Code of Construction Practice** - the following measures, which seek to reduce GHG emissions, are included in the CoCP:

   i Energy Management Plan: the contractor will produce an energy management plan, containing measures to limit energy consumption and carbon emissions during construction. The energy management plan will also include ways to: measure and reduce energy usage; and monitor, report and set targets for CO_2

arising from site activities and from transportation to and from the site. The procurement, maintenance and use of construction plant will be shown to have considered energy efficiency. There will be consideration and assessment of energy from renewable and/or low emission sources that has been used during construction.

ii Materials Management Plan: the contractor will produce a materials management plan, which will include measures to manage material usage during construction. The material management plan will include ways to: use sustainably sourced materials (eg FSC or PFEC certified timber); use recycled or secondary materials; minimise use of unhealthy materials, which have the potential to harm human health or the natural environment.

10.3 Opportunities at detailed design stage

10.3.1 There are opportunities, at the detailed design stage, where further measures to reduce GHG emissions could be considered for incorporation in the project design, including:

a. **Minimise further, the quantity of construction materials** through specification at detailed design stage e.g. using innovative tunnel segment design requiring less concrete (this will mitigate embodied carbon by reducing the quantity of construction materials).

b. **Contractor detailed enactment scenarios** – reducing emissions in the supply chain by encouraging contractors, through contract incentives, to be carbon conscious. Machinery (or fuel types, eg biofuels) may be specified in contract documentation or site environmental management plans. Specific measures may include keeping detailed records of fuel consumption and enforcing minimal idling of equipment.

c. **Introduce renewable technology** to offset the fossil fuel based energy consumed by the project.

d. **Utilise the captured combined sewage** for example, for energy from waste or take advantage of the kinetic energy for micro hydro.

10.3.2 The following paragraphs consider items b - d above.

Detailed design and working with contractors

10.3.3 The Thames Tideway Tunnel project would be a design and build project, meaning that future contractors would undertake the detailed design. It would therefore be at a later stage when decisions are made around resource use, particularly the detailed specification of materials required. Performance specifications are being developed which guide the future contractors, however ultimately the final materials selected for construction would be developed by the contractors.

10.3.4 A primary performance requirement is the need to construct a durable tunnel, able to tolerate some considerable pressures, both from external ground conditions, but also internally, from the combined sewage itself.

10.3.5 Efforts will be made to evaluate the specification of materials with a view to improve the sustainability and carbon footprint of these materials where practical. The tender process will require contractors to demonstrate how sustainability could be promoted in further design and specification of materials used. Sustainability would be one of a number of considerations that influence the awarding of contracts to the principal contractors. Thames Water is developing ways in which contractors will be encouraged to innovate, for example in the procurement process, requiring contractors to hold a materials policy and demonstrate a proven track record of how resource efficiency can be promoted, in accordance with Thames Water's climate change policy and procurement policy. Further information on promoting the use of sustainable resources is given in Section 6 of the *Sustainability Statement*.

Incorporating renewable energy

Overview

10.3.6 The operational phase of the Thames Tideway Tunnel represents the most realistic opportunity to introduce locally generated renewable energy. Interventions into materials production, gird electricity generation and plant / vehicle fuels are not realistic at a project level and rely on macroeconomic and national policy drivers. However, as the future owners of certain material assets and land parcels, there are opportunities for Thames Water to explore renewable energy generation.

10.3.7 There is not presently a commitment to provide renewable energy though the project is keen to explore viable options. The London Plan and Thames Water Utilities' voluntary target suggest that 20% of the operation energy be offset; it must be stated that, particularly in the London Plan, these targets were not drawn up with tunnels in mind and are more aligned to traditional built assets of a commercial and residential nature

Potential renewable energy options

10.3.8 The operational tunnel and its associated constructs, has no material need of heating or cooling. It requires electrical energy only to operate the plant and machinery hence there is no saving to be gained, within the project boundary, from renewably-generated heating or cooling. The selection of the most suitable renewable options will be guided by this maxim.

Screening

10.3.9 According to the UK Renewable Energy Roadmap (DECC, July 2011)[12], the eight technologies with the greatest potential to ensure the UK meets the 2023 target in a cost-effective and sustainable way are:

a. onshore wind;

b. offshore wind;

c. marine energy;

d. biomass electricity;

e. biomass heat;

f. ground source heat pumps;

g. air source heat pumps; and

h. renewable transport.

10.3.10 This report also states that wind, biomass and heat pumps are the leading renewables contributors, including offshore wind - where the UK has abundant natural resource and is already the world's largest market.

Anaerobic digestion

10.3.11 There may be potential to utilise biogas produced via Anaerobic Digestion to generate renewable electricity that would help deliver the requirement for 1.7 GWh per year of renewable electricity.

Low head hydro

10.3.12 This technology does not feature on the DECC shortlist as it will have limited application; however the water and wastewater industries are perhaps best placed to realise its potential. Thames Water has undertaken a preliminary feasibility study and cost benefit analysis of a low-head mini-hydroelectricity plant which would recover energy from the Beckton sewage treatment works main outfall effluent as it drops through several metres to enter the River Thames. Discussions continue on more detailed feasibility and future ownership issues. Preliminary investigations suggest that such a mini-hydro plant could generate around 20% of the Thames Tideway Tunnel's operational energy.

Ground source heat pumps

10.3.13 The majority of construction sites are in densely populated urban parts of London and many are in the vicinity of the sites of future residential and commercial development. It has been suggested that the sinking of CSO shafts represents an opportunity to install heat exchange pipework for ground source heat pumps installed at future developments whilst the ground is being worked.

10.3.14 Discussions on the feasibility of this option are ongoing.

Delivering renewable energy

10.3.15 The incorporation of renewable energy technologies into the project requires further analysis and viability testing. It is envisaged that such work will be carried out in tandem with the detailed design and procurement processes and will be taken forward, with progress monitored, as part of the project's sustainability strategy and Integrated Management System. The strategy includes climate change mitigation: maximising energy efficiency and minimising the carbon footprint of the project as one of the key objectives.

10.3.16 As the project moves into the next phases of development, the objectives set out in the *Sustainability Strategy* will be further developed and will guide Thames Water's approach. For further details, refer to the implementation section of the strategy.

11 Conclusions

Modelling energy and GHG emissions

11.1.1 In order to evaluate the sustainability of the project the overall energy demands and Greenhouse Gas emissions have been modelled and evaluated, using two linked models. One model deals with electrical and diesel energy demands from the construction and operational phases of the project; this is referred to as the Energy Model. The other is more detailed and synthesises the outputs of the Energy Model and other significant project activities into Greenhouse Gas emissions. This is known as the Carbon Model.

11.1.2 The different aspects of the project modelled and evaluated in this report were; the route, materials, logistics, construction and the operational phase.

11.1.3 The carbon footprint of the Thames Tideway Tunnel project has been calculated based on the product of the following data with publicly-available and well validated carbon emission factors:

a. Embodied carbon of bulk materials

b. GHG emissions produced directly from vehicles delivering materials and removing waste material (i.e. excavated/demolition material) during the construction phase

c. GHG emissions produced directly from plant and machinery and indirectly from electrical energy required by construction plant at each worksite during the construction phase

d. GHG emissions produced indirectly from UK grid electricity suppliers to meet the operational energy demands of the Tunnel over its 120 year design life.

Findings

11.1.4 Overall GHG emissions due to the construction of the Thames Tideway Tunnel project have been significantly reduced following the adoption of the Abbey Mills Route in place of earlier, longer alignments. In addition, measures incorporated in the design, for example use of lower carbon materials and transport modes and passive design features, have sought to minimise the overall carbon footprint of the project.

11.1.5 Further investigations into lower carbon materials in the ultimate supply chain may offer additional opportunities to reduce the overall project carbon footprint, but the engineering requirements of the project must not be compromised in the pursuit of avoiding GHG emissions, particularly since a tunnel which requires little maintenance or partial replacement represents optimal GHG performance by design

11.1.6 There are opportunities for smaller GHG savings through modal shift to barge where practicable, and from the installation of renewable energy sources

11.1.7 Of the renewable energy sources investigated, the low-head hydroelectricity project at the Beckton Sewage Treatment Works main outfall appears the most promising.

Delivery

11.1.8 This Energy and Carbon Footprint Report summarises the findings of the energy and carbon footprinting assessments undertaken for the project. From the outset, the design of the project has been developed with regard to seeking to maximise energy efficiency and minimise GHG emissions. This has been expressed through design development, whereby a shorter tunnel solution has been adopted, reducing materials use and seeking low carbon alternatives, incorporating river transport for transporting construction materials.

11.1.9 Through the assessment process, the measures to reduce GHG emissions identified for the project in this report can be separated into two broad categories:

a. those incorporated in the project design and where their achievement is inherent in the scheme proposals, and will be secured through the successful delivery of the project; and

b. those that can be worked towards through activities taken in further design, procurement and in construction.

11.1.10 Thames Water is in the process of developing an Integrated Management System. The system will provide a key way in which the objectives of seeking to maximise energy efficiency and minimise GHG emissions, will be planned and further developed with contractors.

11.1.11 As the project moves into the next phases, the objectives set out in the *Sustainability Strategy* will be further developed and will guide Thames Water's approach, with regard to seeking to reduce GHG emissions, in the detailed design, procurement and construction phases.

Appendix A: UK decarbonisation projections

A.1 Greenhouse Gas Emissions

A.1.1 The nature of the UK grid electrical supply is such that currently, the majority of electricity generation is via the combustion of fossil fuels and consequently, the consumption of electrical energy results in the emission of greenhouse gases, principally carbon dioxide from the combustion process.

A.1.2 The Climate Change Act sets out a number of seriously challenging targets for the decarbonisation of the United Kingdom such that by 2050, total annual emissions of carbon dioxide will be reduced to 80% of the mass emitted in 1990.

A.1.3 The emission factor published by Defra as part of the DUKES dataset for UK electricity generation in 1990 was 858 grams of carbon dioxide equivalent per kilowatt hour generated (858 g CO2e / kWh). This factor had reduced to 594 by 2009. The majority of this reduction can be explained by the “dash for gas” which emits less CO2 per kWh generated than the coal it partially replaced.

A.1.4 In estimating CO2e emissions from the operational Thames Tideway Tunnel, two works have been consulted; The first report of the Committee on Climate Change (2008 – Chapter 5) which includes a trajectory for the decarbonisation of the UK economy (hereafter referred to as the CCC Report), and AEA’s Pathways to 2050 report for DECC (2011), hereafter referred to as the DECC Report

A.1.5 Both reports assume a degree of decarbonisation of supply in the years to 2020, at a rate of around 25g CO2e/kWh per year. 2020 is the expected opening year of the Thames Tideway Tunnel.

A.1.6 The CCC Report estimated that the grid electricity emission factor would be 310g CO2e/kWh in 2020 and The AEA Forecast for DECC estimated 340g CO2e/kWh. These are assumed to be “All Scope” emissions in the context of the Greenhouse Gas Protocol, that is to say including indirect emissions. Assuming a linear rate of decrease from 2009 until 2030, when both reports suggest an emission factor of 69g CO2e/kWh, the factor for 2020 would be 319g CO2e/kWh.

A.1.7 Using the factor of 319g CO2e/kWh and an annual energy requirement of 8.5 GWh, the total estimated CO2e emissions from the operational Thames Tideway Tunnel in its opening year of 2023 is around 2,700 tonnes.

A.1.8 This figure falls annually until through a combination of technology switching, capture and offsetting, the UK electricity generating network is effectively supplying zero carbon electricity by 2035.

A.1.9 If these assumptions prove accurate, the operational Thames Tideway Tunnel will only give rise to net greenhouse gas emissions during the first 14 years of operation.

A.1.10 The annual projected emissions from the operational Thames Tideway Tunnel are presented in Table A.1. The figures calculated assume a steady requirement of 8.5 GWh per year over the project's design life (until 2140).

A.1.11 On this basis, the lifetime CO2e emissions of the operational Thames Tideway Tunnel would be in the order of 19.1 kilotonnes.

A.1.12 Any comment on how realistic these projections from the CCC and DECC reports is well beyond the remit of the Energy and Carbon Footprint Report.

Table A.1 – Greenhouse gas emissions 2020 – 2034 (tCO_2e)

Year	Emission factor (gCO_2e / kWh)	Emissions of CO_2e (tonnes per year)
2020	319	2700
2021	294	2488
2022	269	2276
2023	244	2065
2024	219	1854
2025	194	1642
2026	169	1430
2027	144	1219
2028	119	1007
2029	94	796
2030	69	584
2031	54	457
2032	39	330
2033	24	203
2034	9	76
2035 onward	0	0

Appendix B: Carbon footprint assessment (carbon model output)

B.1 Introduction

B.1.1 In order to evaluate the sustainability of the project, the overall energy demands and Greenhouse Gas emissions have been modelled and evaluated, using two linked models. One model deals with electrical and diesel energy demands from the construction and operational phases of the project; this is referred to as the Energy Model. The other is more detailed and synthesises the outputs of the Energy Model and other significant project activities into Greenhouse Gas emissions; this is known as the Carbon Model. This appendix presents the output from the Carbon Model.

B.2 Knowledgebase overview

B.2.1 The Carbon Model has been constructed using Atkins' Carbon Critical Knowledgebase software package. The Carbon Knowledgebase relies on a database of emission factors (carbon factors), which have been used in the Carbon Model. As the quality of these data evolves and understanding of carbon improves, so the variety of elementary carbon data will increase. It is recognised that carbon-related decisions, including the calculation and analysis of carbon, are only as good as the data that underpin them and as such the efficacy, accuracy and quality of these data is fundamental. For this reason the Carbon Knowledgebase was created to store, manage and control fundamental carbon factor information. The Carbon Knowledgebase forms the centralised body of knowledge upon which all carbon calculations and decisions are based.

B.2.2 The overall energy demands and GHG emissions arising from the Thames Tideway Tunnel's construction and operation have been modelled in as much detail as the information emerging from the detailed design of the project allowed. This has not been simply undertaken as an accounting exercise – the real value in undertaking such a detailed modelling exercise is found in the analysis of the model outputs. These outputs have been examined to identify the activities which are the most GHG-intensive, with a view to targeting suitable interventions for mitigation at these areas of potential greatest significance. They have been applied so that the user can be assured of their fitness-for-purpose in terms of source, robustness and crucially, their applicability in any given geographical region. Typical units for carbon factors are $kgCO_2e$ per kg of material, $kgCO_2e$ per item, $kgCO_2e$ emitted directly per hour from plant, machinery or vehicles, or $kgCO_2e$ per unit of electrical energy consumed (GJ, kWh etc), where CO2e is the Carbon Dioxide Equivalent.

B.2.3 The Knowledgebase is a web-based application that allows the team to calculate the carbon footprint of their project, evaluate design options with regards to their comparative carbon footprint and analyse the relative contribution of different carbon sources. It provides facilities to 'mine' a project's design so that the best carbon mitigation strategy can be adopted.

B.2.4 Carbon packages are the fundamental building blocks; they are compiled into design options and quantified so that complex designs can be simply analysed to determine effective carbon mitigation strategies. A further benefit is that simple scenarios can be created quickly using pre-defined high-level packages that represent less granular project components.

B.2.5 As with all carbon accounting methodologies (e.g. GHG Protocol) the calculations per CO_2e Package are generally simple (e.g. mass or activity multiplied by factor), although the tool provides a customisable calculation engine so that users can define more complex calculations. The interface will generate carbon reports and allow the user to identify the most carbon-intensive packages or materials. By modifying these packages, for instance to substitute road transport with a low-carbon alternative, areas for meaningful interventions are identified. These project-specific 'design iterations' can be saved and revisited as the user requires and therefore appropriate security and auditing mechanisms are an integral aspect of tool integrity.

B.2.6 As with any GHG emission calculation, the mathematics are very simple but rely on robust activity and carbon factor data (e.g. mass quantity of material and the factor in kgCO_2e/kg for that material). The quantity of CO_2e is simply the product of these two values. Carbon factors have been taken from the Carbon Critical Knowledgebase, the same software in which the Carbon Model was constructed.

B.2.7 The Knowledgebase draws on published carbon factors from academic and industrial research. Factors for materials have been primarily taken from the Bath University Inventory of Carbon Emissions (ICE) v2.0; whereas factors for electrical energy generation and all modes of transportation have been taken from Defra's annual Greenhouse Gas Factors for Company Reporting (2011 version).

B.2.8 Factors for plant and machinery are largely taken from the EU EMEP database, formerly CORINAIR.

B.2.9 The full model structure is reproduced below (electronic version only) and summarised at the end of this appendix. The CO_2e emissions are grouped according to site type; with a nested breakdown of emissions due to material, transport / logistics, construction and operation at each site.

B.3 Carbon Model – fully expanded outputs

This appendix is only available electronically only due to its length.

Appendix B Full Carbon Model.pdf

B.4 Summary

B.4.1 An aggregated summary of output from the Carbon Model for the preferred scenario (the project, as proposed) is presented in Table B.1 below. This also shows the potential for avoiding GHG emissions due to various design and construction interventions which have been achieved during the planning phase of the project.

B.4.2 The operational GHG emissions are defined assuming decarbonisation. The GHG emissions for non-decarbonised operation (2023-2143) are 532,970 tCO2e.

Table B.1 – Preferred Scenario (Decarbonised, with Barge)

Project phase	**GHG emissions (tCO_2e)**	**Potential carbon avoided (tCO_2e)**
Materials (2016-2023)	702, 882	Up to 199,000 t from decrease in tunnel length
Transport and logistics (2016 – 2023)	28,837	Up to 7,000 t from partial barge transportation
Construction plant and machinery (2016 – 2023)	87,182	Marginal
Operation (2023-2140)	19,133	Up to 3,800 t from renewables if achieved
Total:	**Approx. 838,000**	**Up to 210,000**

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Appendix C: Materials and logistics breakdown

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Appendix D: Construction energy and GHG breakdown

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Construction Model v6 0412.xlsx

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Appendix E: Operational energy model details

E.1 Introduction

E.1.1 The Model is a composite spread sheet including separate tabs for each operational Tunnel site.

E.1.2 The Model systematically presents itemised energy demands identified for the project; a 'bottom-up' strategy. It incorporates the lowest denominator source information available enabling demand to be analysed in detail. An additional allowance is made for small power, being non-itemised loads at active Tunnels sites.

E.1.3 The advantages of this modelling approach are:

- each operational site has a demand profile enabling full transparency and easy data transfer for carbon assessment;
- each operational site demand comprises an itemised and non-itemised energy load schedule; and
- energy demands are easily aggregated on an annual or life cycle basis as required.

E.1.4 Based on the information supplied by Thames Tideway Tunnel and applying our assessment rules presented, the projected energy demand has been modelled on an annual and lifetime basis by aggregating demand data from the lowest practical level.

E.2 Logic

E.2.1 The demand assessment uses a load and activity model listing based on itemised electrical loads.

E.2.2 All listed energy loads are rated in kilowatts (kW) and adjusted by an activity factor, an efficiency factor and a load factor; i.e.

Equation 1: Annual Energy Demand (kWh/year)

$$\frac{\text{Rated output power (kW) x operational hours}}{\text{(load factor\% x efficiency)}}$$

Where

- Rated output power = nameplate motor or load size (kW)
- Load factor = % of full load consumption typical of normal operation
- Efficiency = aggregate performance efficiency including motor & drive losses.
- Operational hours = predicted activity per year.

Equation 2: Lifetime energy demand (kWh)

Annual energy demand x number of active years (2023 to 2143)

Where

- Annual Energy demand (as above).
- Number of years of demand (120)

E.3 Model fields

E.3.1 Table E.1 lists the Demand Model fields together with their rationale.

Table E.1 – Energy model fields

Energy Model Field	Notes
Reference	Unique identifier in model
Load Description	Brief load details
Energy type	Electricity – Low voltage Electricity – High voltage
Plant Rating kW (A)	Load nameplate rating or specification
Loading Factor % (B)	The percentage of full load rating likely under typical operating conditions
Efficiency (C)	Best delivery (shaft) performance
Power factor	Default set to 1.0 (see below)
IEC kW (Instantaneous Energy Consumption)	A / (B x C)
Hours per year (D)	Nominal Hours of operation per year
Annual Energy Consumption kWh (AEC)	= IEC x D
Lifetime Consumption kWh (EClife)	AEC x operational years (120)

E.4 Notes

E.4.1 The Baseline energy demands represent ‘typical’ current design practice.

E.4.2 The Baseline energy demand excludes efficiency savings beyond implementing current best design practice; i.e. current best design practice is assumed with respect to specifying motors, drives and appliances.

E.4.3 The Baseline energy demand refers to consumptions post site metering, it does not include grid transmission or transformation losses. These are accounted for in carbon dioxide emission factors discussed in Chapter 5.

E.4.4 Power factor for inductive loads significantly affects how much energy is drawn from the grid. The lower the power factor, the more current a load draws for the same duty.

E.4.5 Most of the Tunnel's electrical loads will be inductive and therefore will potentially reduce the uncorrected power factor. The main exception is variable speed drives which have a power factor approaching unity. For most electrical motors a power factor of around 0.8 can be assumed.

E.4.6 At site level power factor fluctuates as inductive loads start and stop. As power supply utilities usually require a minimum power factor of around 0.9 at the site connection, power factor correction technology is installed to ensure site power factor remains between 0.9 and 1.0.

E.4.7 The model therefore assumes a power factor of 1.0 for all inductive loads. This on the basis that:

- if applicable, site power factor correction will be installed to the incoming supply;
- if power factor correction is not applied to small loads (for example, motors less than 10kW), the effect on the overall site power factor is negligible;
- power factor is not linear. The difference in energy drawn from the grid by improving the power factor from 0.8 to 0.9 is significant, but the difference in energy consumed by improving the power factor from 0.9 to 1.0 is marginal; and
- the nameplate rating of most machines in quoted in Watts, which takes account of power factor at rated speed or power output.

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Appendix F: Operational energy model

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Operational Model v7 GmB.xlsx

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Appendix G: Renewables screening

Renewable Option	Typical Power Rating	Estimated Capital Cost per Item	Estimated Electricity Generation/Year	Estimated No. to Achieve 20%	Land Use Estimation to achieve 20%	Pros/Cons
Wind[ii] (Offshore & Onshore)						
Building-Mounted Micro	2.5 kW	£10,000 (1 kW: £2,000)	6,570 kWh	300	Variable depending on wind turbine size, type, spacing and number of turbines required.	One of the most cost-effective renewable energy sources in the UK. The UK is the windiest country in Europe. Communities and local authorities can reap significant financial benefits by installing wind turbines. Wind turbines are available in a range of sizes to suit different locations, onshore or offshore. Pay back periods can be significant. Capital costs can be high, especially with offshore.
Micro	6 kW	£20-£28,000	15,768 kWh	130		
Small	20-50 kW	£50-£125,000	52,560-131,400 kWh	15-40		
Medium	100-850 kW	£250k-£1.8m	0.26-2.24GWh	1-8		
Large	1-2.5 MW	£2m-£3.3m	2.63-6.57 GWh	1		
Photovoltaics[iii]						
Domestic	1-3 kW per 6-27m²	£5,000-£8,000 per kW	This is dependent on the type of PV material selected and the technology type. Can assume on average 850 kWh per kWp.	Based on this data it works out as 0.22kW/panel. Therefore TT would need ~9,000 PV panels.	Based on this data it works out as 1.6m²/panel. Therefore TT would need ~15,000m². In practice this is an underestimate based on the following two case studies: **Tesco:** 75,000m² for 2.7GWh/year **Solyndra:** 34,000m² for 2.4GWh/year	PV is eligible for the feed-in tariffs No noise Space efficient as can be used as an alternative building material or roof mounted. Ground mounted systems can make use of unused space, such as embankments, vacant plots or agricultural land Potentially toxic chemicals are used in the manufacturing process of some modules
Non-Domestic	1 KW per 6-9m²	£10,000-£15,000 per kW				
Solar Farm	5MW per 5-10 hectares	£4.5m per MW				

[ii] *The estimated kWh/year is based on the formula from BWEA;* ***Electricity produced = B x 0.3 x 8760*** *where B = the rated capacity of the wind energy development in kW and constants are 0.3 (capacity factor or efficiency) and 8760 (hrs per year). The sources used were: http://www.idea.gov.uk/idk/core/page.do?pageId=25288347; British Wind Energy Association www.bwea.com, European Wind Energy Association www.ewea.org and US Wind power www.windpower-monthly.com.*

[iii] Dorset County Council Renewable Energy Factsheets, idea.gov.uk and case studies from *http://www.pv-magazine.com/news/details/beitrag/solyndra-completes-3-mw-rooftop-pv-system-in-belgium_100003313/*, *http://www.solar-trade.org.uk/solarHeating/photovoltaics.cfm* & *http://www.uni-solar.com/real-stories-2/tesco-fresh-easy/*

Notes:	*There are many different types of solar power all of which gather the suns energy in slightly different ways and can greatly affect the efficiency; solar tracking, concentrated PV, parabolic, solar towers etc There are also different types of PV material; Monocrystalline are the most expensive but the most efficient (~15%), Polycrystalline are less expensive but also less efficient (~8-12%) and Amorphous (thin, flexible which allows a variety of shapes) are the least efficient (~4-7%). All these changes will effect efficiency and land use – the less efficient, the more PV panels will be required which result in more land use. Tracking PVs will require space between etc*

Renewable Option	Typical Power Rating	Estimated Capital Cost per Item	Estimated Electricity Generation/Year	Estimated No. to Achieve 20%	Land Use Estimation to achieve 20%	Pros/Cons
Biomass						
Anaerobic digestion (+ Gas Combustion)	Depends on the AD operated by TWUL	Depends on Size of Facility	500 to 900 kWh per dry tonne of municipal wastewater solids (i.e., sewage sludge) digested may be generated.	Around 2-4,000 dry tonnes per year of municipal solid waste required to produce ~2GWh per year.	Depends on the facility.	Already an AD facility at Beckton There will be extra fuel due to solid waste being diverted from the Thames to Beckton Even if this is not enough to meet the 2GWh/year target it could be topped up with PV or Wind energy. Additionality issue
Hydro[iv]						
Micro Hydro	10-100 kW	£4,000-£7,000 per kW	35,000-350,000 kWh	6-60	Variable depending on turbine size, type, spacing and number of turbines required.	Something worth exploring by TT as there is scope to achieve the required 20% just from this technology and they have plenty of flowing water to utilise for hydro energy. May be complex to implement with changes to the current TT design required.
Small Hydro	<10 MW		<35 GWh	1		
Medium Hydro	10-50 MW		35-175 GWh	1		
Large Hydro	>50 MW		>175 GWh	1		
Archimedes screw turbine	63 kW		240,000 kWh	14		

[iv] Source: www.british-hydro.org; Also note two **Case Studies:** Two 5 nozzle Pelton turbines set on the raw wastewaters of Amman City, As Samra plants (Jordan) (ΔZ = 104 m, Qn = 2 x 1.25 m3/s, 2 x 830 kW, 12.5 GWh/year, 2007) & Two Francis turbine set on the treated wastewaters of Amman City, As Samra plants (Jordan) (ΔZ = 42 m, Qn = 2 x 2.3 m3/s, 2 x 807 kW, 8.6 GWh/year, 2007)

Renewable Option	Typical Power Rating	Estimated Capital Cost per Item	Estimated Electricity Generation/Year	Estimated No. to Achieve 20%	Land Use Estimation to achieve 20%	Pros/Cons
Marine Turbines[v]						
Atlantis AS-500 (Example)	1MW @ 2.65m/s of water flow velocity. (Atlantis AR series	£0.9-5m for every megawatt depending on the scale of the project/ (Large plant – e.g. 100MW would be much cheaper than a 1.2MW plant)	3.504GWh per year	1	No land use as under water – roughly 18m diameter. Space required would vary depending of scale required.	According to Atlantis, it is estimated that in the United Kingdom, there is 18TWh/yr of technically extractable tidal current resource. 40% of this technically extractable resource is concentrated in the far north of Scotland (Pentland Firth and Orkney Islands). Water is 832 times denser than air – this means that tidal turbines have a smaller rotor size than an offshore wind turbine of equivalent power rating. (e.g. 18m diameter instead of 120m) This allows tidal farms offshore to have high packing density, thereby reducing infrastructure costs and minimising the amount of seabed required to locate a commercial scale project. Tidal current electricity is clean, renewable, reliable and predictable.
Fuel Cell[vi]						
Phosphoric Acid (PAFC) – distributed generation	50kW-1MW (250kW module typical)	Not clear without more in depth research	0.92GWh/year (assuming 42% efficiency @ 250kW) (80-85% overall with CHP; 36-42% electric)	2-3	Minimal space required.	Clean, efficient technology but quite high risk as it is still not widely established. Any recommendation regarding fuel cells would require significant research before hand to ensure minimal risk in investment.
Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM) – back-up power, portable power, small distribution grid & transportation.	<250kW		1.2GWh/year (assuming 55% efficiency @250kW) (50-60% electric)	2-3		

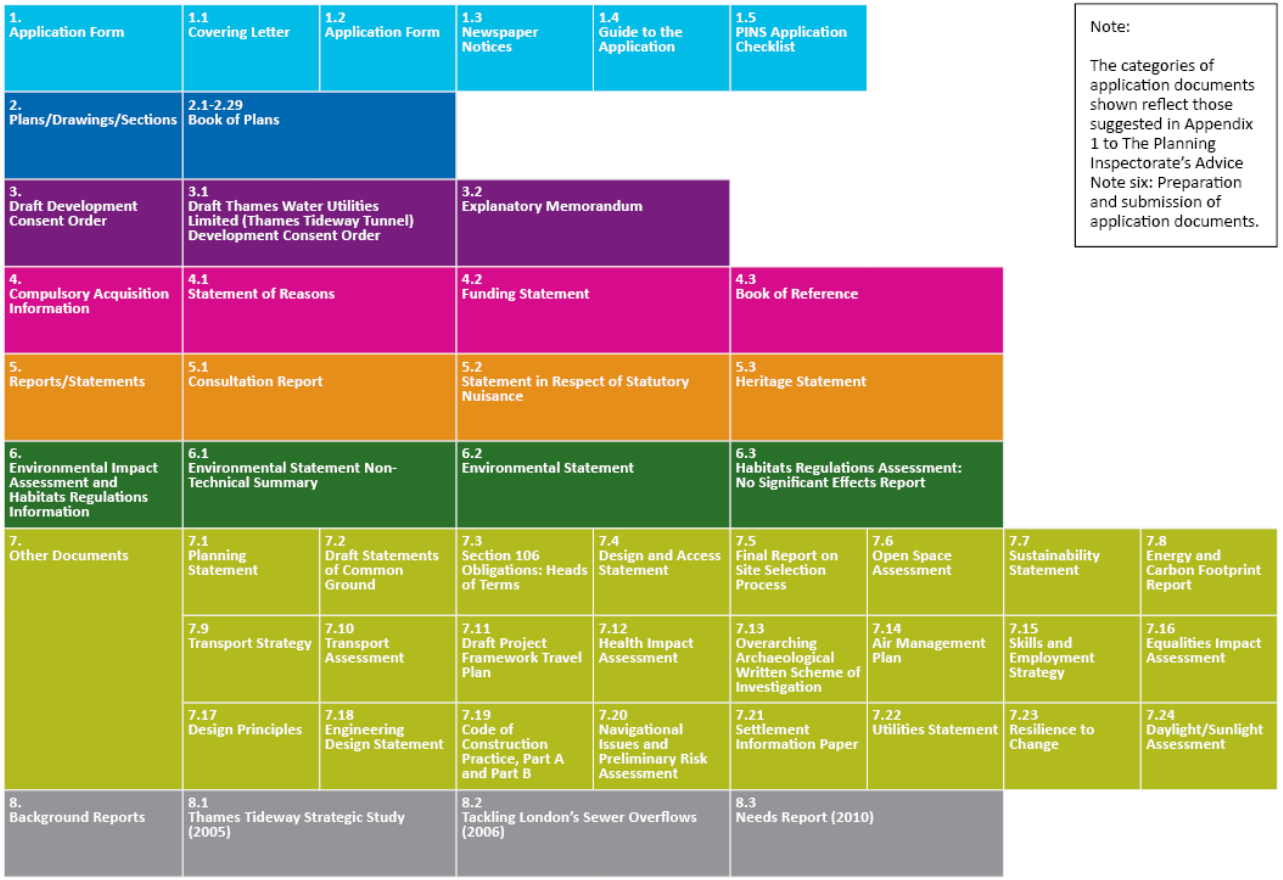
[v] *Atlantis (http://www.atlantisresourcescorporation.com)* - Based on the AS-500 which has an efficiency of 42% - an efficiency of 40% will be assumed for illustrative purposes.

[vi] **Source: DOE Energy Efficiency – Hydrogen Fuel Cells → Central power usually 1-200MW plant or higher.**

Renewable Option	Typical Power Rating	Estimated Capital Cost per Item	Estimated Electricity Generation/Year	Estimated No. to Achieve 20%	Land Use Estimation to achieve 20%	Pros/Cons
Molten Carbonate (MCFC) – electricity utility & large distribution grid	<1MW (250kW module typical)		1.3 GWh/year (assuming 60% efficiency @250kW) (85% overall with CHP; 60% electric)	2-3		
Solid Oxide (SOFC) – auxiliary power, electric utility & large distribution generation.	5kW-3MW		7.8 GWh/year (assuming 60% efficiency @1.5MW) (85% overall with CHP; 60% electric)	<1		

Appendix H: Documents accompanying the application

Plate H.1 Documents accompanying the application for development consent



Note:

The categories of application documents shown reflect those suggested in Appendix 1 to The Planning Inspectorate's Advice Note six: Preparation and submission of application documents.

References

[1] Defra, *National Policy Statement for Waste Water (2012)*

[2] European Union - *Urban Waste Water Treatment Directive (91/271/EEC) (1991)*

[3] GLA – *Energy Planning – GLA Guidance for Preparing Energy Assessments (2011)*

[4] ISO 14044:2006 – *Environmental management – Life cycle assessment – Requirements and guidelines* (2006).

[5] GHG Protocol - *Project Accounting Protocol and Guidelines* (2005)

[6] Committee on Climate Change (CCC) *First Report*; Chapter 5 (2008).

[7] AEA, *Pathways to 2050 report for DECC* (2011).

[8] Thames Water - *Corporate Responsibility and Sustainability Report (*2011/12*).*

[9] GHG Protocol - *Corporate Accounting and Reporting Standards* - *Corporate Standard*, (2004).

[10] Defra, Greenhouse Gas Conversion Factors for Company Reporting (2012).

[11] European Union, *Biofuels Directive (2003/30/EC) (2003).*

[12] DECC, *UK Renewable Energy Roadmap* (2011).

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