Welsh Government

M4 Corridor around Newport

Environmental Statement: Volume 3

Appendix 2.4 Carbon Report

M4CaN-DJV-EGN-ZG_GEN-RP-EN-0031

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Contents

Non-technical Summary

This report provides an assessment of the carbon emissions associated with the M4 Corridor around Newport Project (the Scheme).

The carbon emissions (expressed in tonnes of carbon dioxide equivalent - tCO_2e) associated with the construction operation and maintenance of the Scheme and the user emissions on the wider South Wales network (the tailpipe emissions of all the vehicles using the roads around Newport and Cardiff) with the Scheme in place, would be:

Phase in the life of the Scheme	Carbon emissions
Construction	522,500t CO_2e
Operation and maintenance of the Scheme to 2037	23,800t CO_2e
Total user emissions on the wider South Wales network, including the Scheme to 2037	37,818,200t CO_2e
TOTAL	**38,364,500t CO_2e**

The total user carbon emissions on the South Wales network would reduce (albeit by a negligible amount - less than 1%) with the Scheme, even though the number of vehicle trips would increase. This is due to reduction of the 'stop-start' traffic and smoother, more efficient traffic flow.

The South Wales road network contributes 4.3% of the total carbon emissions in Wales each year. The emissions from the construction of the Scheme ($CapCO_2$), 522,500 $tCO_{2e,}$ are a small fraction (1%) of the total emissions by 2037. The annual emissions on the existing South Wales network would be 2,277,300tCO_{2e} in 2022 and the introduction of the Scheme would reduce them by less than 1% on that year. This means that the total user carbon emissions ($UseCO_2$) on the network from 2022 to 2037 would be 73,000tCO_{2e} less than the predicted future emissions on the existing network.

Whilst the user carbon emissions benefit is negligible (less than 1%), the construction carbon impacts are such that on a whole Scheme assessment basis, carbon neutrality may only be achieved after a longer period time, using current vehicle emissions data. Future user carbon emissions are difficult to project beyond 2037, due to uncertainties in the future technology improvements in the vehicle fleet or the energy generation and fuel mix.

1 Introduction

1.1 General

1.1.1 The purpose of the Carbon Report is to provide an indicative carbon footprint associated with the delivery, annual operations and use of the Scheme.

1.1.2 More specifically, this report aims to:

a) set the background and carbon context against which carbon emissions from the Scheme should be considered;

b) provide transparency on the methodology, input data and boundary conditions used in the assessment; and

c) provide the breakdown of the capital, operational and user carbon of the Scheme.

1.2 Welsh Government Legislation and Policy Context

1.2.1 The Welsh Government has legislation, strategies and policies that support carbon and greenhouse gas emission reduction. These are detailed in Annex A.

1.2.2 Of specific relevance to this report, one of the Transport Planning Objectives (TPO 10) of The Plan (July 2014) is *"Reduced greenhouse gas emissions per vehicle and/or person kilometre".*

1.3 Previous Carbon Appraisal

1.3.1 The Stage 1 and 2 WelTAG Appraisal (Welsh Government, 2014a) published in July 2014, considered the carbon dioxide equivalent (CO_{2e}) emissions resulting from the "use" phase of the Scheme i.e. the CO_{2e} emitted by vehicles using the highway. It did not consider emissions associated with construction, maintenance and operation of the Scheme.

1.3.2 The Stage 1 and Stage 2 WelTAG appraisal calculated carbon emissions for the 'Do Minimum' and 'Do Something' scenarios, to obtain the change in CO_{2e}. The emissions were calculated using the Department for Transport TUBA software.

1.3.3 The assessment indicated that the Scheme would likely result in an increase in carbon emissions over a 60 year appraisal period.

1.3.4 The assessment concluded that carbon emissions were estimated to increase over a 60 year appraisal period by approximately 336,000 tCO_{2e}. However, it identified that the impact of congestion and stop-start conditions along the existing M4 without the Scheme were not fully taken into account and that more detailed simulation of future conditions was necessary to identify additional benefits as a result of the new section of motorway and provide robustness in the predictions.

2 Scope and Method of Carbon Accounting

2.1 General

2.1.1 The approach followed for the carbon accounting process is based on the current best practice principles of carbon assessments of projects. Whilst there is no specific guidance on carbon assessments for highway schemes, the principles set out in "ISO 14064-2:2006 Greenhouse Gases – Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements" (ISO, 2006) and the "Greenhouse Gas Protocol – The GHG Protocol for Project Accounting" (World Business Council for Sustainable Development and World Resources Institute, 2005) have been followed.

2.1.2 Carbon is used throughout this report as shorthand for the carbon dioxide equivalent CO_{2e} of all greenhouse gases.

2.2 Scope

2.2.1 The boundary for the carbon accounting process is defined by considering the life cycle of a highway project, which can be split into phases, as illustrated in **Figure 1.**

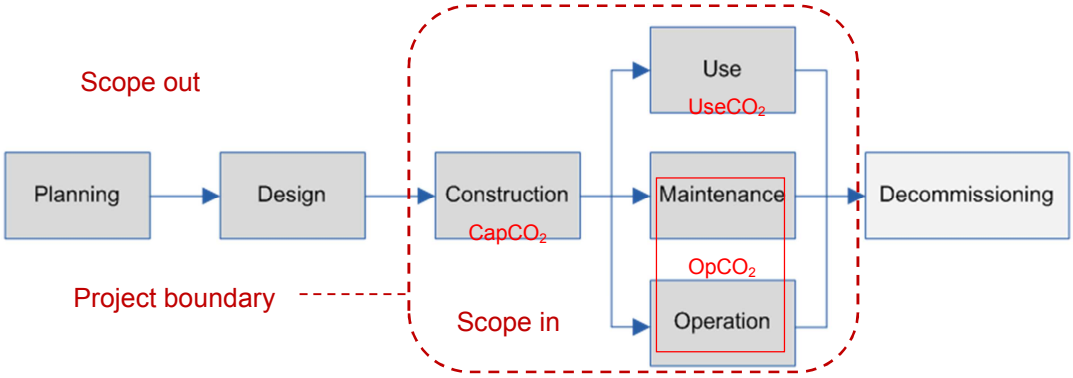

Figure 1: Life cycle of infrastructure projects

2.2.2 The individual phases are detailed below.

- **Planning** – the emissions associated with the planning phase at Key Stages 1 and 2 of highway development are predominantly concerned with paper and office energy consumption as well as emissions produced by staff using vehicles in relation to business (i.e. workers daily commute). It is expected that <1% of total emissions from schemes come from the planning and design stage, and therefore this phase has been scoped out of the assessment.
- **Design** – the emissions associated with the design phase at Key Stage 3 are predominantly concerned with paper and office energy consumption as well as emissions produced by staff using vehicles in relation to business (i.e. workers daily commute). Site surveys and ground investigations are also part of this stage. It is expected that <1% of total emissions from schemes come from the planning and design stage, and therefore this phase has been scoped out of the assessment.

- **Construction** – this is primarily concerned with the emissions of the construction materials used in structures such as bridges, pavements and supporting infrastructure. It also includes the logistical impact of delivering materials to site, the removal of waste, the use of machinery/plant equipment on site and the transportation of labour to site. Using the Infrastructure Carbon Review (HM Treasury, 2013) definitions, this is defined as **Capital carbon**, or '$CapCO_2$'.
- **Use** – the consequential emissions from the functional use i.e. emitted by vehicles using the highway (tailpipe emissions) during its operational life. Using the Infrastructure Carbon Review definitions, this is defined as **User carbon**, or '$UseCO_2$'.
- **Maintenance** – the emissions associated with the periodic maintenance that is required for the highway to be used as intended. For example, the emissions associated with renewal of the wearing course, kerbs and barriers.
- **Operation** – the emissions associated with the day-to-day operation of the trunk road estate. For example, the electricity consumed by lighting, gantries, signals, signs and Intelligent Transport System (ITS). It would also include activities such as gritting. Using the Infrastructure Carbon Review definitions, this, along with emissions associated with maintenance, is defined as **Operational carbon**, or '$OpCO_2$'.
- **Decommissioning** – refers to when infrastructure has reached the end of it serviceable life. If the end-of-life is reached, then the materials can be reused, recycled or disposed of. It is not considered appropriate to include this within the scope of the assessment for this Scheme as it is preferable this phase not be reached with ongoing maintenance keeping it serviceable.

2.2.3 **Figure 2** shows how the Capital, Operational and User carbon form the whole life carbon for the Scheme.

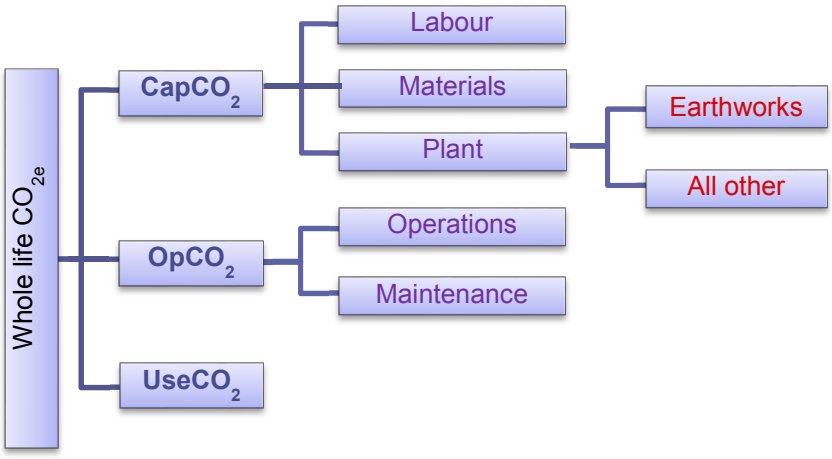

Figure 2: Whole Life Carbon

2.3 Capital Carbon ($CapCO_2$) – Construction Emissions

2.3.1 The scope of the capital carbon assessment covers the following:

- Embodied carbon in materials -The total amount of carbon produced during resource extraction, transportation, manufacturing and fabrication, to bring a product to its existing state.
- Carbon from the machinery used on site - The carbon produced from the combustion of fuel or consumption of energy by machinery and plant used to install a component.
- Carbon from transportation of materials, plant and people to and from site - The carbon produced from the combustion of fuel or consumption of energy by the transportation used to deliver materials to site.

2.3.2 Due to the nature of the Bill of Quantities and how information is collated and presented in terms of spend, carbon elements such as transport for example is accounted for across various elements of construction i.e. transport is included within materials, plant and earthworks. Below is a breakdown of the capital carbon scope:

- **Labour** – includes the travel of construction workers to and from site;
- **Plant** – includes the energy use by machinery on-site during construction as well as any associated transport such as the delivery of plant equipment to site;
- **Earthworks** – includes machinery used for excavation, importing fill and re-soiling. This is essentially plant related emissions presented separately;
- **Material** – includes all construction materials as well as aggregates, the removal of waste, fuel and water use, and transport emissions associated with these material.

2.3.3 The method applied uses the tendered design[1] Bill of Quantities to convert 'activity data' into CO_2e through the application of emission conversion factors from publically available information, listed In Annex C.

2.3.4 Furthermore, the potential for disturbance of peat along the Scheme and its impact on the carbon emissions is reviewed.

2.4 Operational Carbon ($OpCO_2$)

2.4.1 Operation carbon ($OpCO_2$) covers all energy consuming network assets, including all items such as street lights, lit signs, electronic signing, Intelligent Transport Systems (ITS), traffic lights, illuminated bollards and generators. A detailed schedule of power supplies by asset was used to estimate carbon emissions based on a set of assumptions (Annex C).

2.4.2 The second element of operational carbon is the maintenance of the road which includes activities such as the wearing course, road markings, railings and fences, grass cutting or gritting for example. No specific information was available on the maintenance of the existing M4. Based on previous experience, it was assumed that maintenance carbon emissions are in the regions of 4-times smaller than operational emissions.

[1] The Scheme has evolved through the Key Stage 3 design. Some of the frozen design quantities changed at the end of Key Stage 3, but this is not reflected in the carbon calculations. The changes are expected to be small.

2.5 User Carbon (UseCO_2)

2.5.1 The latest Design Manual for Roads and Bridges (DMRB, HA 207/07 Annex E) highlights the importance of considering variations in driving patterns, relating emissions to the vehicle speed-time profile. The SATURN highway assignment component of the M4CaN transport model was used in the assessment of the user emissions of the Scheme. The analysis incorporates these latest DMRB requirements in conjunction with applying emission rates for carbon provided in Interim Advice Note 185/15 (Highways Agency, 2015) to the outputs from the SATURN highway assignment component. By taking the average speed on a link by link basis along the route, the method makes allowance for the increase in emissions from acceleration / deceleration of vehicles due to congestion.

2.5.2 The assessment of user emissions has been undertaken for the entire SATURN model network; this study area (both simulation and buffer network) is shown in **Figure 3.**

Figure 3: The simulation and buffer network study area

2.5.3 Details of the Scheme traffic forecasts are provided in the Traffic Forecasting Report. The assessment of user carbon follows the principles of the regional assessment of pollutants outlined in DMRB HA207/07; it includes all road links of the SATURN model network without any screening of the carbon emissions. This is different to the scope of carbon emissions as part of the Air Quality in Chapter 7 of the Environmental Statement, where only the routes that have the largest effect on carbon are screened.

2.5.4 The scenarios and assessment years are defined in **Table 1**. The baseline for the user emissions is the existing condition at the year 2014. The two options considered in comparison with the user baseline are the following:

- **'Do-Minimum'** i.e. the future year scenario in which committed transport improvement schemes have been added to the base year network;
- **Do-Something**, i.e. as the Do Minimum network but with the Scheme in place, assuming the Opening Year in 2022.

2.5.5 Forecasts for each user scenario are assessed at two key dates, the Opening Year 2022 and the Reference Year 2037 (also referred to as Design Year).

2.5.6 Further information about the 2014 base year traffic model is provided in the Local Model Validation Report (Arup, 2015). This is referred to as Baseline Year 2014.

Table 1: Scenarios and Assessment years

Year	Scenario	Reason for Selection
2014	Baseline	Provides a suitable baseline for the Scheme assessment.
2022	Do-minimum	This scenario allows for an assessment of what changes in atmospheric emissions are expected between the baseline (2014) and opening year (2022) without the Scheme
2022	Do-something	This scenario allows for a comparison with the do-minimum scenario for the same year to determine the

Year	Scenario	Reason for Selection
		effect of the Scheme in terms of atmospheric emissions.
2037	Do-minimum	This scenario allows for an assessment of what changes in atmospheric emissions are expected for a future year (2037) without the Scheme.
2037	Do-something	This scenario allows for a comparison with the do-minimum scenario for the same future year (2037) to determine the effect of the Scheme in terms of atmospheric emissions.

2.5.7 User carbon emissions have been calculated for each of the road links included in the SATURN traffic model using pollutant emission rates provided in the IAN 185/15 (Highways Agency, 2015). This IAN was developed to more accurately assess the effect of congested conditions on emissions and pollutant concentrations. Carbon emission rates for each road link are calculated based on road classification (either motorway, urban or rural), average speed and subsequent speed band (which is defined based on the level of congestion) and the number of Light Duty Vehicles (LDV) and Heavy Duty Vehicles (HDV). Pollutant emission rates provided in IAN185/15 are predicted for future years up to 2030. Therefore, 2022 emission rates have been applied to the opening year assessment and emission rates for the future year (2037) have been held constant at 2030 rates.

2.5.8 The assessment is split down to Light Goods Vehicles (LGV: Cars and LGVs – to which the LDV emission rate has been applied), Heavy Goods Vehicles (HGV: Articulated HGV and Rigid HGV – to which the HDV emission rate has been applied) and buses/coaches (to which the HDV emission rate has been applied), as well as the total of all vehicles.

2.5.9 The effect of the Scheme on user carbon emissions has been determined by comparing the mass carbon emissions in the Do-something scenario with those in the Do-minimum scenario for the same year.

3 Assessment Results

3.1 Summary

3.1.1 The carbon assessment results are summarised in **Table 2** and **Figure 4**. They show that capital and operational carbon are 1% of the whole carbon associated with the Scheme to Year 2037.

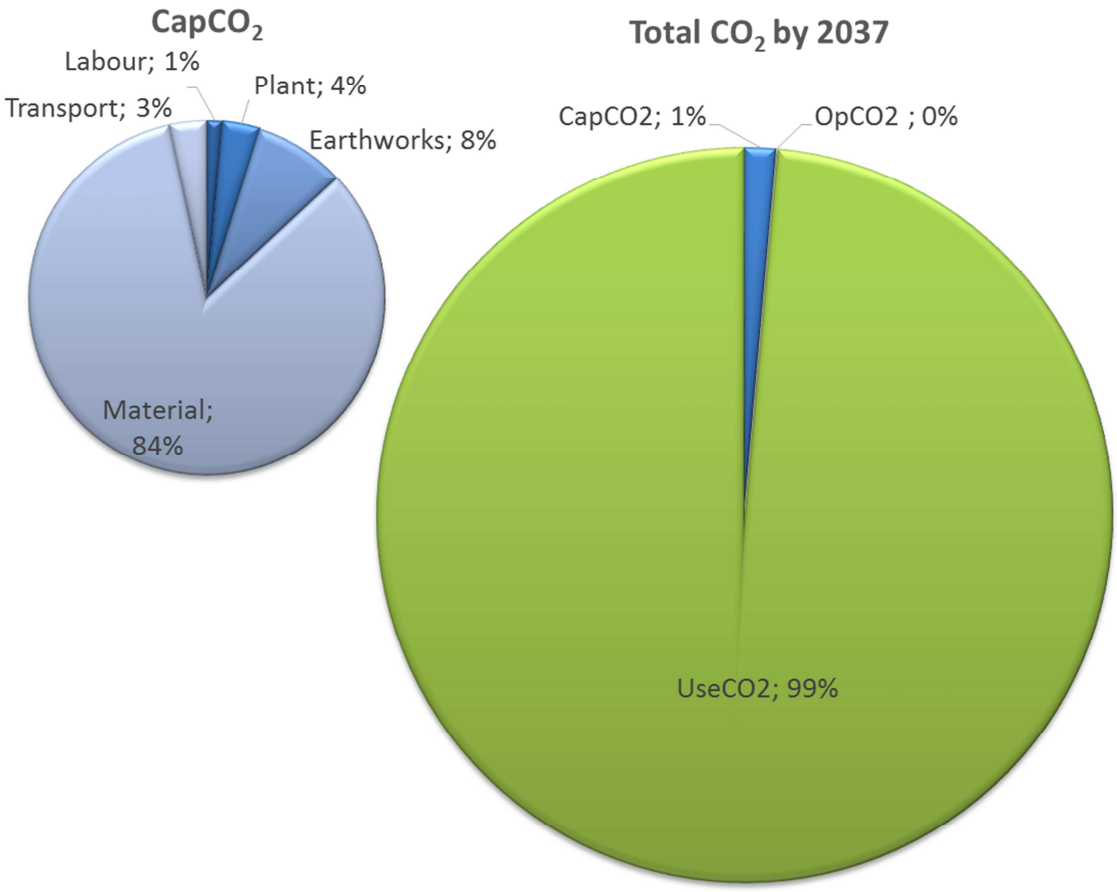

Figure 4: Cumulative carbon emissions for the Scheme by Year 2037

Table 2: Summary of carbon assessment; units expressed in tCO_{2e}

Carbon component		*KS3 Estimated carbon (tCO_{2e})*
$CapCO_2$	**Total**	**522,500**
	Material	436,600
	Labour	7,300
	Plant – earthworks only	43,200
	Plant – all other	17,900
	Material transport	17,600
$OpCO_2$	Operation	To Year 2037: **19,400**
	Maintenance	To Year 2037: **4,400**
$UseCO_2$	Use [2]	2,268,700 / annum in 2022, increasing to 2,458,600/ annum by 2037; remaining constant after that.
		Use total to Year 2037: **37,818,100**

3.2 $CapCO_2$

3.2.1 The carbon emissions resulting from the construction of the Scheme are estimated to be 522,500tCO_{2e}. The majority (84%) of these capital emissions would be in the construction materials and the remaining 16% comes from the labour, plant and construction transport during the works.

3.2.2 Opportunities for capital carbon reduction were considered where possible, in parallel with the Key Stage 3 design development. The final quantities of capital carbon may change in the future as the design of the Scheme is progressed, subject to the Welsh Government deciding to make the Orders. Final capital carbon emissions are anticipated to be similar to the above.

3.2.3 Potential Carbon Emissions from Peat Disturbance

3.2.4 The geomorphological and geotechnical review for the Scheme suggests that the Gwent Levels have a pronounced field pattern, extending almost across their entirety. Where peat is present at surface, it is quite damaged as an active peat system and hence it currently does not perform as a carbon sequestrator (Lindsey, 2010).

3.2.5 The Agricultural Land Classification soil survey work carried out has identified only a limited area where the route of the proposed new section of motorway crosses peat deposits located at or near the surface of the soil profile in the vicinity of Llandevenny and Barecroft Common, corresponding to the Midelney Series of soils identified on the published soils information available for the area. The soils would be left *in situ* as far as possible along the proposed alignment, with only a limited amount of surface disturbance occurring over a 200 – 300 metre area on the lower lying land immediately to the north of Barecroft Common. These works would be likely to generate a mixture of predominantly

[2] The User emissions of the frozen design. It is for the wider South region – not just the M4 corridor – see Section 2.5

clays with peaty horizons, which would be temporarily stockpiled in defined areas prior to being restored within excavations elsewhere along the construction. This mixed material is unlikely to be subjected to significant drying, bearing in mind its likely natural moisture content, the climatic conditions that prevail in the vicinity and the limited period of storage prior to final placement in excavated areas.

3.2.6 Elsewhere, a band of peat up to around 1.5m thick may be present at mid-depth of the soft alluvial deposits of up to 10m thickness. Design proposals for deeper elements, such as soil drainage and piling would penetrate up to 15m into the ground, without causing drying out of the peat and hence no associated release of carbon.

3.3 OpCO_2

3.3.1 The maintenance and operation emissions would be a much smaller component of the whole life carbon of the Scheme, amounting to an annual 1,600tCO_{2e}.

3.4 UseCO_2

3.4.1 The emissions for the user carbon are shown in **Table 3**. A comparison between the total carbon in the Do-something and Do-minimum scenarios shows a marginal change of user carbon emissions as a result of the Scheme (8,549tO_{2e}). The estimated 0.4% change is within the margin of calculation accuracy. The emission rates used to determine the total emissions account for increase in vehicle emissions due to congestion.

3.4.2 There would be an increase in annual carbon between 2022 and 2037, which is largely due to an increase in traffic inflow due to the provision of increased capacity. The model does not allow for the impact of any legislative and policy changes that will aim to provide modal shift and up take of cleaner vehicle technologies such as hybrids or electric vehicles.

Table 3 Annual user carbon predicted– expressed in tCO_{2e}/ year

Year	Do Minimum				Do Something			
	Bus + Coach	Car + LGV	HGV	Total	Bus + Coach	Car + LGV	HGV	Total
Baseline 2014	7,100	1,565,900	663,100	2,236,000	-			
Opening 2022	7,100	1,532,100	738,200	2,277,300	7,000	1,527,900	733,800	2,269,000
Reference 2037	7,100	1,684,600	767,400	2,459,100	7,100	1,688,300	763,200	2,458,600

3.4.3 The average occupancy rates for buses and coaches have been taken from the Department for Transport (DfT) statistics for local buses by metropolitan area (Department for Transport, 2015). The average occupancy rates for cars and LGVs have been calculated from roadside interviews undertaken in 2014 as part of the generation of the traffic model for the Scheme. Changes in occupancy rates in the future year are based on latest WebTAG guidance published by DfT.

3.4.4 Based on the average occupancies shown in **Table 4**, the user emission results are normalised per passenger km in **Table 5** (for passenger vehicles only).

Table 4: Weighted average occupancies (passengers/ vehicle) used in the calculations

	Baseline Year 2014	Opening Year 2022		Reference Year 2037	
		Do Minimum	Do Something	Do Minimum	Do Something
Bus + Coach	8.4	8.4	8.4	8.4	8.4
Car + LGV	1.4	1.4	1.4	1.3	1.3

Table 5: Annual user emissions normalised – expressed in grCO_{2e} / passenger km (HGVs not included) [3]

Year	Do Minimum			Do Something		
	Bus + Coach	Car + LGV	Average	Bus + Coach	Car + LGV	Average
Baseline 2014	84	114	99	-		
Opening 2022	84	97	91	84	97	91
Reference 2037	86	91	89	85	91	88

[3] Numbers are rounded to the nearest integer

4 Benchmarking

4.1.1 Benchmarking of the Scheme against other transport infrastructure projects is shown in **Table 6**. It compares the Scheme carbon with other road projects, which all vary in length and scope in terms of the work undertaken, and the HS2 high speed rail project. Whilst comparing construction emissions (tCO_2/km) it is important to keep in mind that M4CaN is the only project where a completely new road is being constructed. All the other comparison projects are improvements or upgrades to existing roads, which explains the lower emissions per kilometre.

Table 6: Comparison of the M4CaN carbon with other road infrastructure projects and HS2 – expressed in tCO_{2e}

Component \ Length & width		M4CaN	A14 [4]	A465	HA project A [5]	HA project B	HA project C	HA project D	HA Project E	HS2 Phase 1
		23km New relief road	37km improvement scheme	7.8km embankment section	26.6km widening of A road	6.5km single to 2 lane dual carriageway	4km upgrade of existing junction	0.7km Refurbished existing viaduct	22.1km Upgrade from dual to 3 lanes	192km New high speed rail
$CapCO_2$	Material	436,600	740,100	44,300	74,500	77,300	36,100	5,800	213,700	3,691,400
	Labour + Plant	42,800	243,800	5,800	38,500	27,500	8,200	4,000	20,900	1,079,500
	Earthworks	43,200		2,500						587,700
	Construction tCO_2/km	21,800	26,600	6,700	4,300	16,100	11,100	13,900	10,600	27,900
$OpCO_2$	Operation + Maintenance/ annum	1,600	2,400	2,600	n/a	n/a	n/a	n/a	n/a	2,800,000
$UseCO_2$	Use / annum	2,268,700	4,386,400	882,000	n/a	n/a	n/a	n/a	n/a	

[4] Highways Agency (2014)
[5] Personal communication with Highways England; not yet publically available.

5 Discussion

5.1 CapCO$_2$

5.1.1 The results of the carbon assessment confirm the generic whole life carbon split: the capital and operational emissions are a small component of the whole life carbon of the Scheme, compared with the dominant user carbon.

5.1.2 In the next stages of design, there may be an opportunity to further reduce capital carbon through a systematic material specification requiring reduced capital and operational carbon. A "Carbon Accounting Briefing Note" has been drafted that provides to the project team guidance on carbon accounting and reduction (see Annex B) so that the consideration of carbon continues throughout design development work. It provides examples of how material and transport choices can impact upon the Scheme's carbon footprint.

5.2 UseCO$_2$

5.2.1 The latest Greenhouse Gas Inventory suggests the transport sector in Wales contributed 5.7Mt CO_2e, around 11% of total Welsh emissions in 2013 (National Atmospheric Emissions Inventory, 2015) - **Figure 5.**

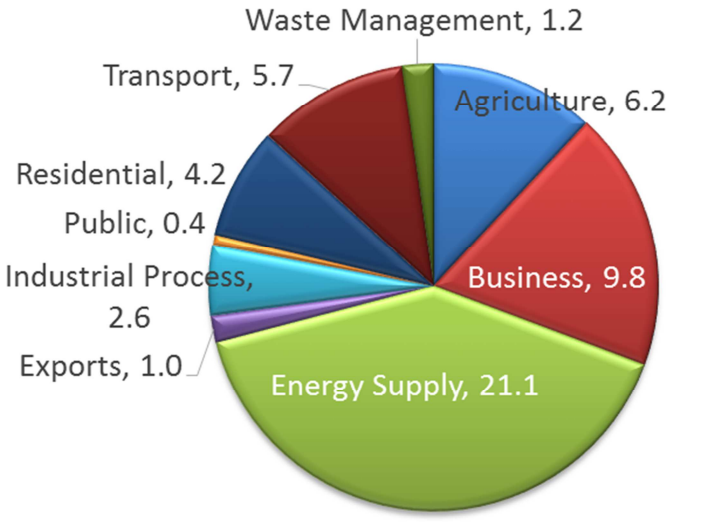

Figure 5: 2013 Welsh GHG emissions in MtCO$_{2e}$

5.2.2 According to the SATURN traffic model used in this study, the wider South Wales region around Newport and Cardiff currently generates 2.2Mt CO_2e (Baseline Year 2014), which is 4.3% of the total annual Welsh emissions. The Scheme would keep the annual transport emissions in the area unchanged from the estimated future emissions on the network, even though the vehicle trips would increase due to the provision of increased capacity.

5.2.3 The user emissions calculations at Key Stage 2 were carried out using the TUBA model and were based on average speeds and average flows. These indicated that the induced additional traffic and increased speeds inherent with building additional highway infrastructure would lead to an overall increase in carbon

emissions. The latest Key Stage 3 assessment takes into account the predicted reduced levels of acceleration and deceleration present in heavily congested traffic conditions. The benefits of free flowing traffic result in benefits in terms of emissions. Further reductions may come by targeting the user carbon through a variety of hard and soft measures, interlinked with the wider transport strategy of the Welsh Government. The existing user models are conservative as they do not include such carbon reductions.

5.2.4 Furthermore, technological changes, as well as decarbonisation of the national energy generation, will be a catalyst for user carbon reduction. These are also not currently included in the models. This assessment assumes a gradual improvement of vehicle emissions over time, in accordance with DMRB guidelines, with limited uptake of vehicle electrification and persistent use of internal combustion engines in the future.

5.2.5 However, the Department of Energy and Climate Change (DECC) has set a trajectory which assumes gross decarbonisation of the grid coupled with electrification of most vehicle types. The ICR Technical Report (Green Construction Board, 2013) indicates that by 2050 car emissions due to these changes could fall by 90% and road freight (HGVs) by 68%.

5.2.6 The Climate Change Act 2008 is concerned with establishing a trajectory for overall emissions reduction, without regulating emissions from specific projects or sectors. The advice of the statutory Committee on Climate Change enables emissions reduction to occur in the most cost effective place. Wales currently has no statutory responsibilities under the Climate Change Act 2008. However, the Environment (Wales) Bill contains proposals for Wales to have similar responsibilities to those of the UK. Furthermore, the Well Being of Future Generations Act 2015 sets out broader sustainable development duties for the WG.

5.2.7 Within the legislative and policy framework, there is flexibility for different sectors to make different levels of contribution to emissions reduction. The assessments that have been carried out to inform the Plan for the Corridor around Newport clearly demonstrate that it is not possible to meet the demand for travel – and that includes freight as well as cars – through other means alone.

5.2.8 The Scheme has been developed within this overall legislative and policy framework, and carbon emissions have been explicitly addressed in this report. The construction carbon impacts are such that on a whole Scheme assessment basis, carbon neutrality may only be achieved after a longer period time, using current vehicle emissions data. Future user carbon projections beyond 2037 are difficult due to uncertainties in the future technology improvements in the vehicle fleet or the energy generation and fuel mix.

6 Conclusions

6.1.1 The report assessed the carbon emissions associated with the whole life of the Scheme at a level of detail appropriate to current stage of design.

6.1.2 The split between the three carbon emissions components is as follows:

Phase in the life of the Scheme	Carbon emissions (% of total)
Construction - CapCO_2	522,500tCO_{2e} (1.4%)
Operation and maintenance - OpCO_2	23,800tCO_{2e} (0.1%) by Year 2037
Use in the wider south region - UseCO_2	37,818,000tCO_{2e} (98.5%) by Year 2037
TOTAL	38,364,500tCO_{2e} by Year 2037

6.1.3 Benchmarking of the carbon emission results with other major transport projects shows a higher capital carbon per km compared other highway improvement projects, although similar to HS2 (new high speed rail project). The annual operation and maintenance is comparable to other known highway projects. The user carbon is also comparable with other highway projects.

6.1.4 The capital carbon of the Scheme is equivalent to approximately 0.3% of the total annual Welsh carbon emissions for four years of construction; the estimated annual operation and user carbon of the Scheme is approximately 4.4% of the total annual Welsh carbon emissions.

6.1.5 The calculations indicate that the annual user carbon emissions would remain largely unchanged in the wider South Wales region around Newport and Cardiff, even though the vehicle numbers would increase as a result of the Scheme. The analysis estimates a negligible reduction (less than 1%) in the user carbon emissions (UseCO_2) on the network, which are approximated as 2,270,000tCO_{2e} / annum in the Opening Year 2022. The total user carbon emissions resulting from the Scheme from 2022 to 2037 would be 37,818,200tCO_{2e}, which is 73,000tCO_{2e} less than the predicted future emissions on the existing network.

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Annex A

Welsh Carbon Policy Context

	Legislation, Policy or Strategy Document	Carbon-related policy aspirations
A.1	One Wales: Connecting the Nation – The Wales Transport Strategy[6] Environmental Outcome (WTSEO) 2008	Environmental Outcome 12: Greenhouse gas emissions - Reduce the impact of transport on greenhouse gas emissions
A.2	Carbon Reduction Commitment Energy Efficiency Scheme[7] 2008	The Welsh Government is seeking to reduce emissions accountable under the Carbon Reduction Commitment Energy Efficiency Scheme. This is a UK-wide mandatory scheme to improve energy efficiency and cut carbon dioxide emissions in large organisations.
A.3	National Transport Plan SEA Objective[8] 2009	Reduce transport related greenhouse gas emissions
A.4	National Transport Plan (NTP)[9] Strategic Priority March 2010	Reducing greenhouse gas emissions and other environmental impacts
A.5	Climate Change Strategy for Wales[10] October 2010	Reduce greenhouse gas emissions by 3% per year from 2011 in areas of devolved competence, against a baseline of average emissions between 2006 and 2010. The transport sector is responsible for approximately a fifth of the emissions covered by the 3% target.
A.6	Welsh Governments Programme for Government[11]Commitment, 2011	Chapter 11 Environment And Sustainability - Living within environmental limits and acting on climate change.
A.7	M4 Corridor around Newport Strategic Environmental Assessment (SEA) Environmental Report[12] Environmental objective (EO) 2013	Environmental Objective 2a (EO2a) - Reduce greenhouse gas emissions per vehicle and/or person kilometre
A.8	M4 Corridor around Newport, July 2014[13]	Welsh Government Aim c) To produce positive effects overall on people and the environment, making a positive contribution to the over-arching Welsh Government goals to reduce greenhouse gas emissions and to making Wales more resilient to the effects of climate change.
A.9	M4 Corridor around Newport - Motorway to the South of Newport: WelTAG Transport Planning Objectives (TPOs)[14] July 2014	TPO 10: Reduced greenhouse gas emissions per vehicle and/or person kilometre.
A.10	Draft National Transport Plan 2015[15]	Key Priorities(December 2014) Sustainable travel and safety: Encourage safer, healthier and

[6] http://www1.bridgend.gov.uk/media/145322/WD76.pdf
[7] http://gov.wales/topics/environmentcountryside/climatechange/emissions/regulations/crc/?lang=en
[8] National Transport Plan Strategic Environmental Assessment Scoping Report, February 2009
[9] http://gov.wales/docs/det/publications/100329ntpen.pdf
[10] http://gov.wales/docs/desh/publications/101006ccstratfinalen.pdf
[11] http://gov.wales/docs/strategies/110929fullen.pdf
[12] M4 Corridor around Newport Strategic Environmental Assessment (SEA) Environmental Report (http://www.m4newport.com/assets/issue-m4-sea-environment-report---publication---c2.pdf)
[13] http://www.m4newport.com/assets/the-plan---english.pdf
[14] http://www.m4newport.com/assets/weltag-s1-2-report.pdf
[15] http://gov.wales/docs/det/consultation/150216consultationdraften.pdf

	Legislation, Policy or Strategy Document	Carbon-related policy aspirations
		sustainable travel.
A.11	The Well-being of Future Generations (Wales) Act 2015[16]	The act became law in Wales on 29 April 2015. The act strengthens existing governance arrangements for improving the well-being of Wales to ensure that present needs are met without compromising the ability of future generations to meet their own needs. The act requires all public bodies to embed climate change into their decision-making.
A.12	Environment (Wales) Bill[17]– Part 2 Climate Change[18] May 2015	Provides the Welsh Ministers with powers to put in place statutory greenhouse gas emission reduction targets and carbon budgeting to support their delivery. 2050 Greenhouse Gas Emissions Target - To ensure Wales is contributing to the reduction of greenhouse gas emission, the Bill places a duty on Welsh Ministers to ensure that in 2050 they are at least 80% lower than the baselines for each greenhouse gas. Interim emission targets - These will be introduced, which must be consistent with the 2050 target. These targets can be set anytime between 2016 and 2050. They will guide the setting of carbon budgets in the medium term and assist in evaluating the progress made towards meeting the long-term 2050 target.
A.13	Active Travel (Wales) Act 2013	As part of its 'Rationale for Government Intervention' (see Active Travel (Wales) Bill Explanatory Memorandum), its sets out at (41) that "Encouraging more people to walk or cycle rather than travel by car is also expected to deliver wider benefits through lower greenhouse gas emissions and reduced congestion."
A.14	Planning (Wales) Act 2015	As part its Explanatory Memorandum, its sets out at (7.300) that "delays in development caused by slow decision-making undermine Ministerial aims of encouraging economic recovery and building a sustainable and low-carbon economy."
A.15	Climate Change Act 2008	The Act imposes a duty on the Secretary of State to reduce UK wide greenhouse gas emissions in 2050 to a level which is at least 80% below the level of emissions in 1990. It also obliges the Secretary of State to set carbon budgets for successive five year period and to prepare proposals and policies for meeting those carbon budgets. Part 2 of the Act establishes the Committee on Climate Change. Parts 4 and 5 of the Act impose limited duties and confer limited powers on Welsh Ministers in terms of contributing towards meeting the UK wide carbon targets. The Environment Bill (Wales) 2015 will, when enacted, impose specific carbon budgeting duties on Welsh Ministers similar to those to which the Secretary of State is subject.
A.16	The Wales Spatial Plan (Update 2008)	It is a principle of the Wales Spatial Plan that development should be sustainable. An indicator used to monitor the significant environmental effects and major uncertain effects predicted to result from implementation of the Wales Spatial

[16] http://www.legislation.gov.uk/anaw/2015/2/pdfs/anaw_20150002_en.pdf
[17] http://gov.wales/topics/environmentcountryside/consmanagement/natural-resources-management/environment-bill/?lang=en
[18] http://gov.wales/docs/desh/publications/150512-climate-change-en.pdf

	Legislation, Policy or Strategy Document	Carbon-related policy aspirations
		Plan, is 'Estimated emissions of greenhouse gases in Wales and the UK, million tonnes of carbon dioxide equivalent'.
A.17	Planning Policy Wales (Edition 8, January 2016)	Section 8 of PPW8 refers to the Welsh government's aims to extend choice in transport and secure accessibility in a way which supports sustainable development and helps to tackle the causes of climate change by encouraging a more effective and efficient transport system, with greater use of the more sustainable and healthy forms of travel and minimising the need to travel.
A.18	One Wales: One Planet. (May 2009)	One Wales: One Planet also sets out sustainable development as a core principle of the Welsh Government's founding statute. The Welsh Government has a statutory duty to set out how it proposes to promote sustainable development. Its Scheme for Sustainable Development includes an overarching principle shared with the UK framework, to achieve a sustainable economy: by setting out how we want to transform our economy so that it is low carbon, low waste. In addition, a Main Outcome of its aspiration for sustainable resource use includes that "We have a low carbon transport network which promotes access rather than mobility, so that we can enjoy facilities with much less need for single occupancy car travel."
A.19	Environment Strategy for Wales (2006)	The Environment Strategy for Wales (2006) is the Welsh Government's long-term strategy for the environment of Wales, setting the strategic direction for the next 20 years. The vision is to see the distinctive Welsh environment thriving and contributing to the economic and social wellbeing and health of the people in Wales. To achieve this, the Strategy states that the pressures we place on our environment need to be managed more effectively and to address challenges like climate change and sustainable resource use.
A.20	The UK Low Carbon Transition Plan (July 2009)	Within the Low Carbon Plan, a section is dedicated to transport. It highlights that domestic transport in the UK contributes to approximately a fifth of the UK's greenhouse gas emissions. In an effort to combat the increasing emissions the plan states it will: • continue to improve fuel efficiency of new conventional vehicles; • support the low carbon vehicles and fuels of the future; • encourage people to make low carbon travel decisions; • require international aviation and shipping to reduce emissions; and secure oil supplies to the UK by sustaining investment in the North Sea and work to improve the functioning of international oil markets and working with the downstream oil industry to address the issues that sector face.
A.21	Newport Local Development Plan 2011-2026	General Development Principle 1 – Climate Change, sets out that development proposals should: ii) be designed to minimise energy requirements and incorporate appropriate renewable, low or zero carbon energy sources, including onsite energy provision where practicable; and

	Legislation, Policy or Strategy Document	Carbon-related policy aspirations
		iii) be designed to reuse or recycle existing construction materials present on the site. It sets out as part of Strategic Policy 1 – Sustainability, that: "Transport is a key producer of CO2 emissions, so providing forms of development that reduce the need to travel or which are accessible by sustainable modes of transport, such as walking and cycling, are favoured."
A.22	Monmouthshire Local Development Plan 2011-2021	As part of its Key Environmental Characteristics at (3.20) it states that "Monmouthshire's greenhouse gas emissions are predominantly due to road transport (39%), followed by industrial /commercial end users (31%) and domestic sources (27%)3. In 2010, the County recorded 2.7 domestic tonnes per capita of carbon dioxide, broadly in line with the Welsh average of 2.5." Objective 11 of the LDP is: To ensure that new development can adapt to the impacts of a changing climate and to also promote opportunities for carbon reduction in order to reduce the contribution made by residents, businesses and industry in Monmouthshire to climate change.
A.23	Cardiff Local Development Plan (2006-2026)	An Objective identified with the LDP is for 'People in Cardiff have a clean, attractive and sustainable environment', with a Key Priority to 'Establish Cardiff as a sustainable 'Carbon Lite' city. Key Policy 15: Climate Change, is: To mitigate against the effects of climate change and adapt to its impacts, development proposals should take into account the following factors: i. Reducing carbon emissions; ii. Protecting and increasing carbon sinks; iii. Adapting to the implications of climate change at both a strategic and detailed design level; iv. Promoting energy efficiency and increasing the supply of renewable energy; and v. Avoiding unnecessary flood risk by assessing the implications of development proposals within areas susceptible to flooding and preventing development that unacceptably increases risk.

Annex B

Carbon Briefing Note

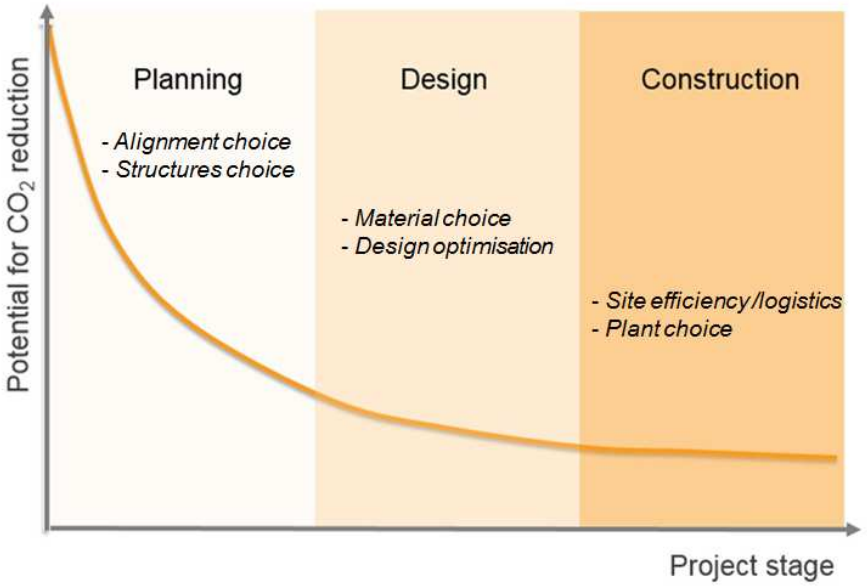
1. Introduction to Carbon Accounting - Terminology

- **Greenhouse gas** (or **GHG** for short) is any gas in the atmosphere which absorbs and re-emits heat, and thereby keeps the planet's atmosphere warmer than it otherwise would be. There are six main greenhouse gases which cause global warming and are limited by the Kyoto protocol. Each gas has a different global warming potential. The six regulated gases are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).
- **Carbon footprint** - The total set of greenhouse gas emissions caused directly and indirectly by an individual, organisation, event or product. Carbon footprints are typically calculated to include all greenhouse gases and are expressed in tonnes of CO_2 equivalent (tCO_2e)
- **Carbon dioxide** (**CO_2**) - the most common GHG emitted by human activities, in terms of the quantity released and the total impact on global warming.
- **Carbon dioxide equivalent** or "**CO_2e**" is a term for describing different greenhouse gases in a common unit. For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2 which would have the equivalent global warming impact.
- **Embodied carbon** – the amount of carbon released from material extraction, transport, manufacturing, and related activities. This may be calculated from cradle to (factory) gate, cradle to (installation) site, or (ideally) from cradle to grave.
- **Carbon Emission Factor** – a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant.

2. Carbon Accounting – What is in the Works Information Contract

- The Contractor shall be responsible for providing an **indicative carbon footprint** of the carbon emissions associated with delivery of the Scheme.
- The Contractor shall **actively manage**, and **reduce**, the carbon footprint, wherever possible.
- The Contractor shall include carbon reduction planning in their **design, assessment and appraisal work** on the Scheme and provide records for carbon accounting as appropriate for Key Stage 3, Key Stage 4 and Key Stage 6.
- Carbon reduction planning covers the proposed changes to the road network, the design and implementation of the Scheme, waste management and the provision of any offsetting measures, which may be off-site or associated with other projects.

3. Carbon Reduction during the Project Life Cycle



Opportunities for greater carbon reduction are present at the early stages of a project. As we are now in the design phase, it is critical the design is optimised to reduce the carbon footprint.

4. Carbon Reduction Plan at Key Stage 3

- The design team must work with the carbon accounting team to identify **the most significant cost-effective opportunities** to reduce the embodied carbon emissions associated with the Scheme.
- The Schedule of Changes from Tender Design will be used to identify carbon reduction opportunities. It is important that **quantitative** changes are detailed to enable a carbon footprint to be calculated.
- Reductions (or increases!) in **plant, materials, labour and transport** resulting from changes to the tender design will be estimated to quantify the carbon savings in terms of CO_2e.
- The carbon accounting team will report actions and outcomes as part of the M4CaN Carbon Accounting Report.

5. Carbon Calculation Approach

- To calculate the carbon footprint, measures of plant, materials, labour and transport are converted into CO_2e by using standard emissions factors.
- For example:

Measure of activity	**X**	**Emission Factor**	**=**	**Tonnes CO_2e**
1000 litres of petrol	X	2.315kg CO_2/litre	=	2.315 Tonnes CO_2e

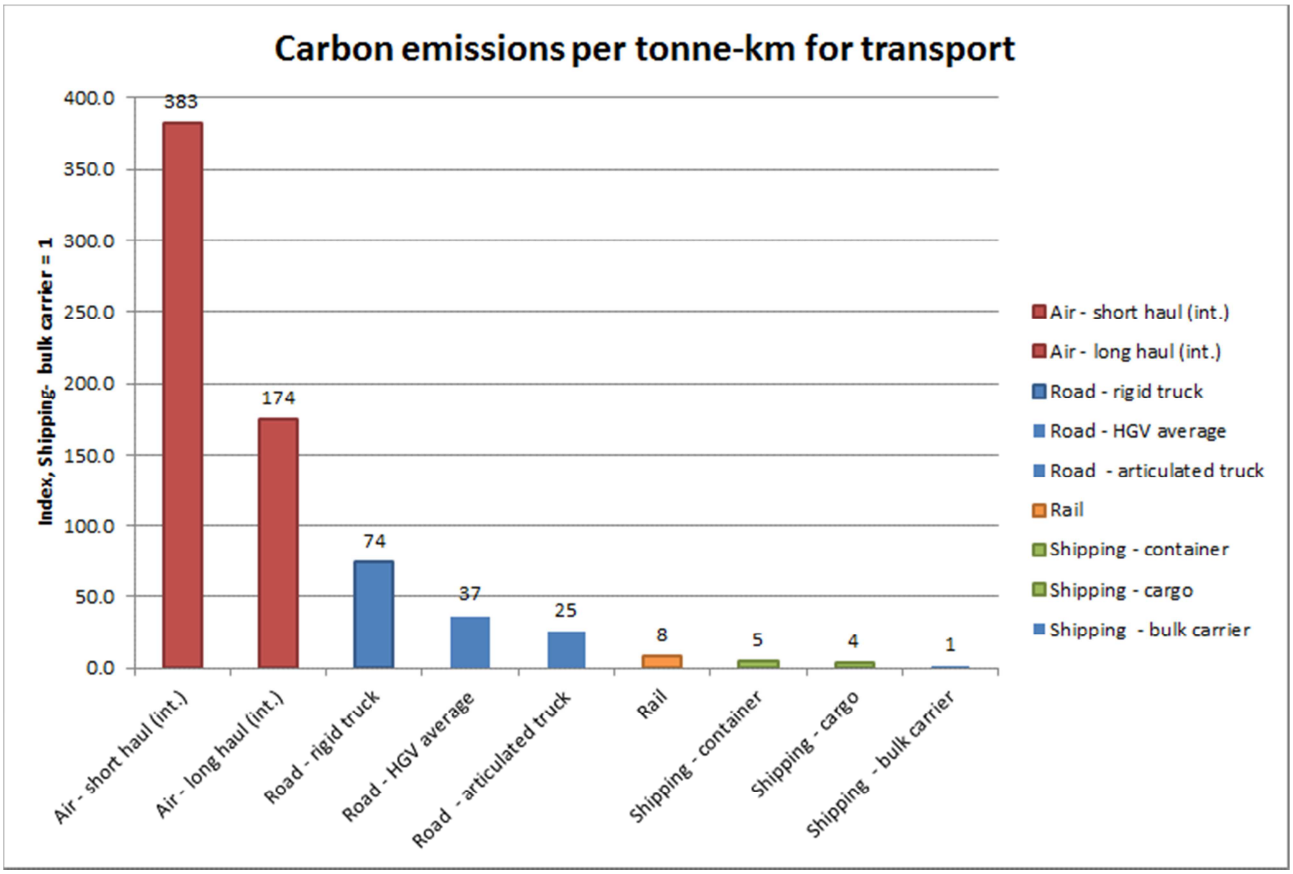
6. Types of action the design team should consider and record

- The table provides examples of carbon saving actions which could be considered for the Scheme.

Carbon saving action	Example
Using less materials	
Efficient design	Make the most of in-situ materials
Change the specification of elements	Reducing the thickness of carbon-intensive asphalt layers by using hydraulically bound mixtures in the bases and sub-bases
Design for less waste on site	Cut wastage rates on the top 10 materials from baseline to good practice
Design for off-site construction to benefit from lower wastage and efficient fabrication	
Using alternative materials	
Select materials with lower carbon intensities	Buy less energy-intensive materials e.g. cold-mix asphalt, cement substitutes or sustainably-sourced materials such as timber
Select reused or higher recycled content products and materials offering lower carbon intensities	e.g. reclaimed bricks, higher recycled content blocks, locally recycled aggregates
Select materials with lower transport-related carbon emissions	Locally-sourced aggregates
Select materials with high levels of durability and low through-life maintenance	
Designing and implementing energy efficient equipment	
Select most energy efficient and economically viable equipment available	e.g. LED lighting

7. Transport Consideration - Comparison of Transport Options based on 1 tonne travelling 1km

- The bar chart shows how the consideration of transport for materials can impact upon the Schemes carbon footprint.
- For example, the carbon footprint of rail transport is 8 times that of shipping by bulk carrier.
- For road transport, an articulated truck is nearly a third that of a rigid truck.



Annex C

Input assumptions and carbon factor references

Input assumptions

Element of the carbon assessment	No.	Assumption
Labour	1	Assumed that the average working day for labourers is 9 hours. Divided total working hours (Usage Rate) by 9 to estimate number of trips made by the labour force and multiplied by 2 to assume a return trip
Labour	2	Assumed that the average single trip is 20 km long (40km return) by the labour force
Labour	3	100% of the labour force travels by car. Assumed there is no public transport access to the site
Plant	4	The average working day is 9 hours - but cannot assume that plant equipment will be in use for 100% of the time. For example, lighting or concrete mixers won't be used every single minute of the 9 hours. I've assumed a 50% usage rate.
Plant	5	Assumed a 50 hour working week (9 hrs Mon-Fri, and 5 hr on Sat)
Plant	6	For lighting assumed a 15 kW generator was needed
Plant	7	Compressed air tools - no data on energy consumption (kWh or ltr of diesel)
Plant	8	Compressors - assumed an average of 15 ltr/hr consumption (range size 20-150kW)
Plant	9	Lighting - assumed a 15kW generated used
Plant	10	Mixers - assumed an average of 3 ltr/hr consumption (range size 5 - 20kW)
Plant	11	Concrete Mixers - assumed around 5 ltr/hr of diesel consumptions, or a power rating of 167kW for a large concrete mixer
Plant	12	Water pump - assumed an average power rating of 15kW (electric water pump)
Plant	13	Steel & poly hoses - no data, what is this used for and does it consume energy or is it a structure / material?
Plant	14	Concrete equipment - no energy use
Plant	15	Concrete pumps - assumed an average power rating of 100kW (vehicle size range24-42 m truck concrete pump)
Plant	16	Cherry pickers - assumed an average fuel use of 8 ltr/hr (size range 40-60ft reach) based on 'access platforms' data
Plant	17	Scaffolding - no fuel consumption, assumed hired material and scoped out of the assessment
Plant	18	Scissor lifts - assumed to be similar to cherry pickers, 8 ltr/hr fuel use, data based on 'access platforms' data
Plant	19	Crawler cranes - assumed fuel use to differ depending on weight and size of the crane, ranging from 20 to 40 ltr/hr (50 to 600 tonne crane)
Plant	20	Mobile cranes - assumed average fuel use of 36 ltr/hr (range of size 100 - 300kW)
Plant	21	JCBs - assumed average fuel use of 11 ltr/hr
Plant	22	Compactors & Rollers - assumed average fuel use of 8.5 ltr/hr (range of size 10 -100kW)
Plant	23	Dumpers - assumed average fuel use of 5 ltr/hr apart for the larger 23t dumper where we assumed 39 ltr/hr. Rest of dumper size ranged 5-9t
Plant	24	Tracked excavators - assumptions on fuel consumption based on size (t): 12t - 13 ltr/hr, 20t - 21 ltr/hr, 32t - 38 ltr/hr
Plant	25	Rubber ducks - fuel consumption assumptions based on size (t): 13t - 31 ltr/hr, 20t - 21 ltr/hr
Plant	26	Manhole boxes - assumed to be hire equipment and re-useable so scoped out of the assessment and is not fuel consuming equipment
Plant	27	Trench boxes - assumed to be hire equipment and re-useable so scoped out of the assessment and is not fuel consuming equipment
Plant	28	Trench sheets - assumed each sheet is 600mm wide and 50kg/m width. Assumed made of steel and not temporary so included in assessment
Plant	29	Piling plant - assumed crawler mounted rig with 150kW size engine
Plant	30	Environmental plant (silt buster, 6yrd skip, TVCB and cash plant) assumed to be re-useable equipment and excluded from the carbon assessment
Materials	31	Bricks - assumed 2.3kg per brick, and ready-mix mortar 1:3 density if 1,900 kg/m3
Materials	32	Concrete - assumed 2,200 kg/m3, ST1 = GEN0, ST2 = GEN1, ST4 = RC 25/30, and that zero recycled content (fly ash or GGBS) is specified

Element of the carbon assessment	No.	Assumption
Materials	33	Portland Cement - assumed 2,200 kg/m3, CEM1 Portland Cement
Materials	34	C32/40 pump mix - assume a density of 2,300 kg/m3
Materials	35	Porous no-fines concrete - do not have a carbon factor for this, or know the density (weight) of this construction material - scoped out
Materials	36	Grano - assumed similar to general or typical aggregates
Materials	37	Precast concrete for beams - assumed RC40/50 with steel reinforcement concrete specified w/ zero fly ash or GGBS
Materials	38	DtP granular fill - assumed general aggregates carbon factor
Materials	39	Drainage aggregates - again, assumed the same as general aggregates carbon factor
Materials	40	Pavement aggregates - assumed the same as general aggregates carbon factor
Materials	41	Sand aggregates - assumed to be the same as general or typical sand (applied carbon factor)
Materials	42	Single size aggregates, aggregate & fill sundries and surfacing - assumed density of 2.1t/m3
Materials	43	Teram 3000 aggregate- assumed made of polyethylene / polypropylene
Materials	44	Surfacing - assumed the same as general aggregate density of 2.3 t/m3
Materials	45	Muckaway - assumed this was construction / excavation waste removal using >17t rigid vehicles with 8.5m3 capacity
Materials	46	Muckaway - assumed distance travelled 19.3km Ifton Quarry to East Abutment of the River Usk Crossing
Materials	47	Muckaway - assumed that trip out the vehicle load is full (100%) and return is empty (o%)
Materials	48	Manhole covers - assumed to be made of precast concrete with 1.9t/m3 density
Materials	49	Tokstrip - assumed to be rubber sealant (PVC injection moulding) with density of 1.32 grams/m3
Materials	50	Vitrified clay pipes - assumed to be 1cm thick and clay to have a density of 1.9 t/m3 (same a clay tiles)
Materials	51	Plastic pipes & ducts - assumed to be made of HDPE plastic and typical length of 6m per unit. 150mm = 1.5 kg/m, 225mm = 3.7 kg/m, 300mm = 5.9 kg / m
Materials	52	Weholite pipe - assumed 80 kg/m of pipe made of HDPE plastic, and that each unit of pipe is typically 10m long
Materials	53	UPVC perforated land drain - assumed to be made of HDPE plastic and typical length of 6m per unit. 150mm = 1.5 kg/m, 225mm = 3.7 kg/m, 300mm = 5.9 kg / m
Materials	54	Permeable drainage layer - assume 270 g/m2 of polyethylene / polypropylene
Materials	55	PCC pre-stressed beams - assumed a 225mm beam with 57 kg/m of unit, and each beam being 24.7m long. Assumed precast concrete
Materials	56	PCC culverts - depending on size of culvert had 10t or 18t per culvert with headwalls 450mm thick, and 1.9t/m3 precast concrete density
Materials	57	What is the weight of a PCC Sluice gate? Made of steel?
Materials	58	Bridge bearings - assumed that all bearings weight and average of 23 kg/ unit and made of steel
Materials	59	Waterproofing - assumed that bitumen paint weighed 1kg per litre of paint
Materials	60	EMJ GRP panels - assumed 14.5 kg/m2, made of steel reinforced glass fibre
Materials	61	Rebar - assumed steel with typical UK recycled content
Materials	62	Assumed that all reinforcement mesh and sundries is either engineering steel or steel wire
Materials	63	Drainage equipment (pipes etc.) assumed to be HDPE plastic with varying weights (1.5 to 3.6 kg per meter of pipe)
Materials	64	Pourform is assumed to be plywood formwork with a density of 9.3 kg/m2, along with separate softwood formwork (assumed to be sawn softwood) of 510 kg/m3
Materials	65	Mould oil assumed to be lubricant oil (0.85 kg/ltr)
Materials	66	Tie rods (0.029 kg/m) Waler plate bolt (1.3 - 2.3 kg/unit) and racking prop connectors (0.5 kg/unit) all assumed to be made of engineering steel
Materials	67	Nails, clamps and bolt (0.5 kg/m2) assumed to be all made of engineering steel
Materials	68	TM equipment, cones and signs (0.77 kg/unit) all assumed to be made of

Element of the carbon assessment	No.	Assumption
		engineering steel
Materials	69	Wood (90 kg/m^2) assumed to be general hardwood, and marine plywood (540 kg/m^2) assumed to be typical plywood
Materials	70	Expanded mesh assumed to be made of engineering steels (2.0 kg/m^2)
Transport	71	It was assumed that construction material would be transported to site by road
Transport	72	The vehicle type assumed is a Rigid Lorry (>17 tonnes, 100 % laden i.e. that the lorries are full)
Transport	73	Distances travelled assumed either 50, 100 or 150 km
Transport	74	A return trip was not included as it was assumed that lorries may have had other deliveries as well
Subcontractor and Earthworks	75	It was assumed that engineering steel would be used for the Usk Bridge
Subcontractor and Earthworks	76	Surfacing (material use) - Cement bound granular material and sub base was assumed to be similar to 'general aggregate' with a density of 2,240 kg/m^3
Subcontractor and Earthworks	77	Surfacing (material use) - Dense bitumen macadam (DBM50) was assumed as similar as 'general bitumen', again with a density of 2,240 kg/m^3
Subcontractor and Earthworks	78	Surfacing (material use) - The thin surface course system (35mm thick) as assumed to be asphalt (8% binder) with a density of 2,300 kg/m^3
Subcontractor and Earthworks	79	Surfacing (plant) - 'Plane out 100mm depth' assumed to be the use of a milling machine (550 m^3/hr and 145 ltr/hr)
Subcontractor and Earthworks	80	Surfacing (plant) - 'High friction surfacing' assumed to be the use of a polymeric binder (1.35kg/m^2) and calcinated bauxite (7.5 kg/m^2)
Subcontractor and Earthworks	81	Surfacing (plant) - 'Perforation of redundant pavement' assumed the same energy use of a milling machine (550 m^3/hr and 145 litres/hr)
Subcontractor and Earthworks	82	Earthworks excavation (plant) - assumed a rate of 185 m^3/hr (gang) and 32 ltr/hr (machinery)
Subcontractor and Earthworks	83	Earthworks excavation (plant) - assumed a rate of 185 m^3/hr (gang) and 32 ltr/hr (machinery)
Subcontractor and Earthworks	84	Earthworks imported fill (plant) - 1,460 kg/m^3 (common earth) and 7,862,897 tonne-km
Subcontractor and Earthworks	85	Earthworks (material) - the use of geotextile lining assumed to be HDPE membrane (0.25 - 3.5mm thick with a density of 940 kg/m^3)
Subcontractor and Earthworks	86	Piles (material) - 150 kg/m^3 of steel (rebar)
Subcontractor and Earthworks	87	Piles (material) - assumed GEN1 (8/10 MPa) concrete used at a density of 2,400 kg/m^3
Subcontractor and Earthworks	88	Precast Piles (material) - assumed 900,000 m of pilling in total with pile dimensions of 0.275m × 0.275m
Subcontractor and Earthworks	89	Ground remediation - 2.36 kgCO_2e per m^3 of soil treated (source: Celtic enGlobe)
Subcontractor and Earthworks	90	Communication (material) - duct chambers size (1m×1m with a 10cm thickness), copper cables (0.30 kgCO_2e/m), gantries (6t rebar and 30 m^3 of concrete/unit), CCTV cameras (3 m^3 of concrete/unit, and 0.5t steel/unit), cabinets (1 m^3 of concrete/unit, and 0.15 t of steel/unit), and Cantilever gantries and signs (6 m^3 of concrete/unit, and 1t of steel/unit)
Subcontractor and Earthworks	91	Communication (labour) - assumed 120,000 man-hours, 9hr day, 15km single trip to site
Subcontractor and Earthworks	92	Communication (labour) - 60,000 hrs of van use (1.5ltrs/hr.)
Subcontractor and Earthworks	93	Communication (labour) - JCB or Hiab use (20,000 hrs. at 13 litres/hr. based on a 60kw excavator hydraulic backbone)
Subcontractor and Earthworks	94	Cable stays - assumed to be made of engineering steel
Value engineering	95	2 Castleton Interchange bridges are removed (5 tCO_2 per m^2 of bridge saved on average)
	96	17,000 tCO_2 is saved through more efficient transport of earthworks
Operation and Maintenance	100	Operation - equipment cabinets are assumed to be in operation 24/7
	101	Operation - gantry or cantilever mounted message signs and / or signals are not expected to be in operation 100% of the time, only for travel information, courtesy messages and advisory for incidents, warnings and pictograms. 5 hours/day was assumed
	102	Operation - total energy was calculated at 1,078,000 kWh per year

Element of the carbon assessment	No.	Assumption
Operation and Maintenance	103	Maintenance - energy and carbon emissions were assumed to be 4 times less than those of Operation based on ICE Bath data and existing literature.

References for carbon emission factors

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