FACTSHEET

Understanding the Carbon Footprint of Box Culverts.

1. Synopsis

This factsheet offers an estimate of the cradle-to-factory gate Greenhouse Gas (GHG) emissions associated with the production of concrete box culverts (also known as carbon footprint). Data from members of the Drainage Association, collected as part of the British Precast annual sustainability Charter, and from the upstream of the supply chain was used to calculate a carbon footprint which accounts for all the emission "hot spots" of the manufacturing box culverts as described at the figure below. Although a few measures of ISO 14040/44 (such as completeness analysis testing) were not employed, the methodology used was broadly based on the provisions of PAS 2050: 2011.

The carbon footprint of 1 tonne of plain concrete used in the production of box culverts was found to be **101.95 kg CO_2e/t**. Four common reinforced box culvert sizes (1300 x 800 x 2000mm, 1500 x 1500 x 2000mm, 2900 x 1950 x 1500mm, 3600 x 2700 x 2000mm) were considered. The carbon footprint of the four sizes were 346 kg CO_2e, 687 kg CO_2e, 920 kg CO_2e and 1,903 kg CO_2e respectively.

2. Introduction

This factsheet offers a basic estimate of the **cradle-to-factory gate** Greenhouse Gas (GHG) emissions associated with the production of concrete box culverts (also known as carbon footprint). Generic data from members of British Precast, and some members of the Drainage Association, was used in order to estimate embodied carbon impacts associated with the supply of raw materials (cement, aggregates, reinforcement steel, and admixtures) and the manufacture (casting, curing ,waste management, etc) of box culverts. Some information on factory **gate-to-site** is added to help members understand how they generally compare to competitors.

It should be noted that the methodology used does not fully comply with all the methodological rules and requirements of ISO 14040/44, PAS 2050, or EN 15804. However most of the calculations and assumptions used should generally comply with the principles of Life Cycle Assessment (LCA).

The functional unit used for GHG emissions reporting will be in **1 tonne of plain concrete** used in manufacturing box culverts. This first-stage functional unit is then used to calculate the cradle-to-gate carbon footprint of the following products:

- 1.30 x 0.80 x 2.00 metres of reinforced concrete box culvert (at the factory gate)
- 1.50 x 1.50 x 2.00 metres of reinforced concrete box culvert (at the factory gate)
- 2.90 x 1.95 x 1.50 metres of reinforced concrete box culvert (at the factory gate)
- 3.60 x 2.70 x 2.00 metres of reinforced concrete box culvert (at the factory gate)

3. The carbon footprint of box culverts: Identifying the 'hotspots'

GHG emissions associated with precast concrete products have been explored and calculated in a number of studies in Europe and North America. In most cases Portland cement production is the main source of carbon dioxide emissions for a concrete product, making around 75% to 85% of the total carbon footprint of a concrete product. This is despite the fact that cement makes no more than 8 to 16% of a concrete product mix. In most cases reinforcement steel comes in second place – the contribution of steel can be between 10 to 25% (based on the source and origin of that steel). Other processes contributing to the carbon footprint include precast factory impacts (due to energy consumption) and sourcing of raw materials. The carbon footprint of concrete can change over time. Concrete is one of the very few products that can have a decreasing carbon footprint during its use due to carbonation.

The following diagram shows the main "unit processes" usually considered to assemble a credible carbon footprint for a box culvert. According to the "Cut-Off" rules of ISO 14044, and Clause 3.33 of PAS 2050, some of the "unit processes" that contribute no more than 1% to the inputs can be eliminated and ignored.

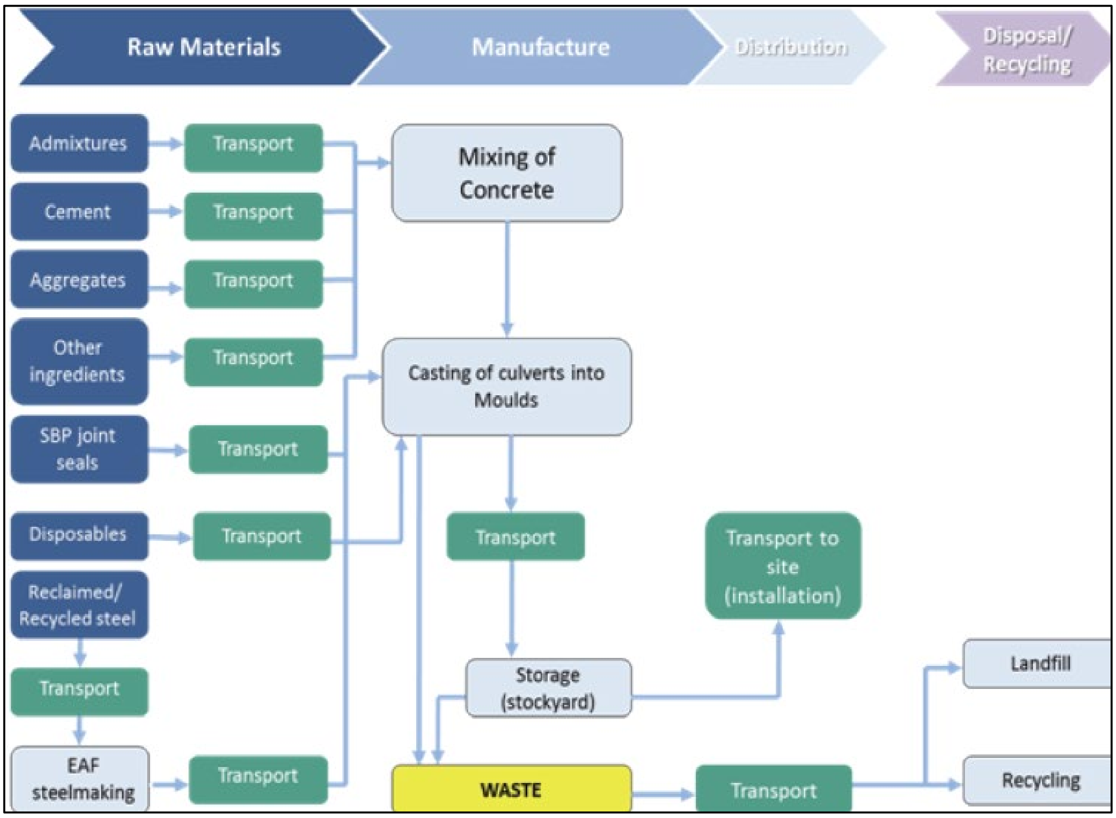

Figure 1. ***Different "unit processes" associated with the cradle-to-site service life of a box culvert***

4. Calculation of Carbon Emissions

The following mix was assumed for box culverts: Coarse Aggregates: 43%, Fine Aggregates: 34%, Cementituous Materials: 16%, Water (including moisture content in aggregates): 8%.

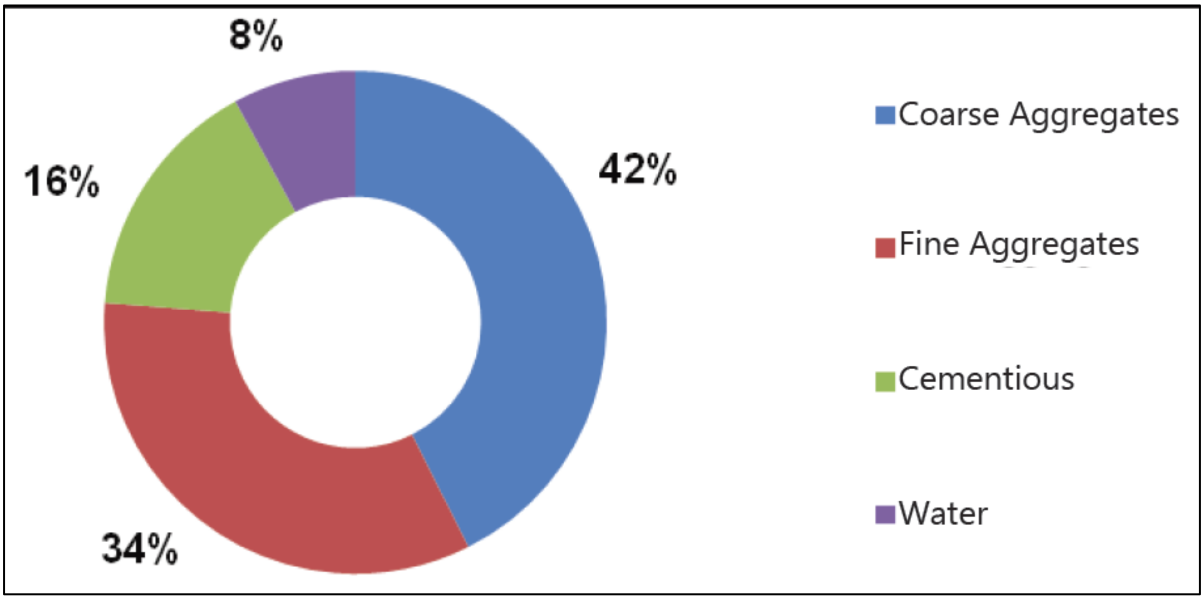

Figure 2. ***Box culvert concrete mix proportions suggested***

4.1 Production of Aggregates

Aggregates have one of the lightest carbon footprints in the construction industry. The impacts are mainly associated with the basic extraction and processing (operations):

- The BRE Environmental Profile reports (considered to be the most accurate in the industry) put the impacts between 6 to 8 kg of CO_2e per tonne. These values are cradle to gate
- The Bath University“Carbon Footprint Database”offers an average of 5 kg of CO_2e per tonne. It should be noted that the exact boundary conditions were not identified

In order to produce an accurate carbon footprint it was decided to go for the potentially more comprehensive value of **8 kg CO_2e/t**. The use of this figure should comply with ISO 14044 requirements for data quality and use of secondary data from reliable and quality sources.

The GHG footprint contribution from aggregates per one tonne of generic box culvert = 6.08 kg of CO_2 eq.

4.2 Transport of Aggregates

The Defra standardised average emission conversion factor for >33 artic lorries (published in 2013) is used. For an ongoing trip, a lorry would be fully laden with 23.7 tonnes of load of aggregates (Source: DETR Transport Statistics 1996). However the lorry will be empty for the return trip. DEFRA's greenhouse gas estimations for a 100% laden +33 tonne articulated lorry would be around 1.1724 kg CO_2 per kilometre. DEFRA's estimate for a 0% laden return trip is 0.7078 kg CO_2/km.

It is assumed that the distance from the quarries is around 30 kilometres. This simply means that the contribution to the final drainage concrete product GHG footprint may not exceed **1.81 kg of CO_2 eq**. per 1 tonne of generic box culvert product.

4.3 Production of cement

All members of the Drainage Association use a combination of cements in their mix: This combination contains differing levels of cement (including CEM I, CEM II/A-V, CEM II/B-V, etc.) along with fly ash added at the factory stage. Data from members reveal that fly ash total content could easily reach 30-35%. The calculations will be based on a simplified mix which includes a **67.5% Portland cement (CEM I)** along with a **32.5% fly ash content replacement.**

Portland cement (CEM I) greenhouse gas emission secondary upstream information will be taken from MPA Cement's latest embodied carbon publication: Factsheet 18. The carbon footprint reported at that publication was around **913 kg CO_2eq/ tonne of CEM I.**

Secondary upstream information for Fly ash GHG differ from one source to another (4 to 8 kg CO_2/t) due to different allocation requirements associated with electricity production and the fact that fly ash is a coal-fired stations' by-product. The figure used for this factsheet was sourced directly from the latest MPA factsheet publication on the carbon impacts of cement (Factsheet 18) – Global Warming potential at that profile was **4 kg of CO_2eq/t of fly ash.**

The upstream greenhouse gas footprint for cementituous content will therefore be between **617.6 kg CO_2 eq./tonne** of cementituous.

Accordingly, GHG footprint contribution from cement will be around 98.8 kg of CO_2 eq. per tonne of box culvert concrete.

4.4 Transport of Cement to Factory

The calculation of GHG emissions from transporting cement was based on the same assumptions made above. The amount transported by lorry will be assumed to be 23.6 tonnes of cement (DETR, 1996):

The distance suggested will be 100 kilometres.

This means that the contribution to the manufactured box culvert product's GHG footprint would be around 1.275 kg of CO_2 eq. per 1 tonne of product.

4.5 Production and Use of Reinforcement Steel

It is understood that all members have local suppliers – as known most UK produced steel used for reinforcement is of recycled origins. A carbon footprint of recycled reinforcement steel will therefore be used. This is understood to be around 427 kg CO_2e per tonne. The GHG emissions of the reinforcement content for each of the box culvert sizes considered is added at the table below:

The same transport assumptions will be made for steel, with the amount delivered per journey reaching around 19 tonnes (Source: DETR) and the distance from the supplier around 50 km.

	1.30 x 0.80 x 2.00 m	1.50 x 1.50 x 2.00 m	2.90 x 1.95 x 1.50 m	3.60 x 2.70 x 2.00 m
Steel content (kg)	179	270	478	890
Upstream GHG per box culvert unit (kg CO_2e)	76.31	115.29	204.18	380.03
Transport GHG per box culvert unit (kg CO_2e)	0.89	1.36	2.365	4.4

Table 1. *Estimating GHG emissions associated with the use and sourcing of reinforcement steel*

4.6 Box Culverts Factory Emissions

British Precast possess generic precast factory energy consumption information submitted by a number of member companies as part of their KPI process. Data for pipeline and box culverts manufacturers from 2011 was used to calculate an average GHG emission value for precast factory activities:

For the purposes of this paper the average for pipes and box culvert manufacturers will be used – this is around 13.58 kg of CO_2eq per tonne of box culvert.

Fuels delivery, factory consumables, and other impacts
These impacts will likely not exceed 1% of the final footprint and can therefore be accounted for by scaling the final footprint value up by 101%.

Note: Extra proof is needed if such assumption is used in a PAS2050 certified study.

Production waste from factory
A 2% concrete waste ratio will be assumed. The carbon footprint of all input materials (except reinforcement steel) will be assumed to be 2% higher per 1 tonne of net production.

Note: This is purely hypothetical and will need sufficient proof and primary data to meet the requirements of PAS2050.

4.7 Calculating a Carbon Footprint for Box Culverts

Based on all these assumptions, the carbon footprint of the concrete used within box culverts would be around **125 kg of CO_2e** per tonne of product. The table below adds this value (multiplied by box unit weight) up to other GHG emission impacts from use of steel reinforcement, fuels and factory consumables use and generation of waste.

	1.30 x 0.80 x 2.00m	1.50 x 1.50 x 2.00m	2.90 x 1.95 x 1.50m	3.60 x 2.70 x 2.00m
Plain Concrete Weight (t)	2.601	5.53	6.912	14.71
GHG footprint for plain concrete (kg CO_2e)	*2.601 x 125* 325.13	*5.53 x 125* 691.25	*6.912 x 125* 864	*14.71 x 125* 1,762.5
GHG footprint for reinforced box culverts (kg CO_2e)	*76.31+0.86+325.13* 402.3	*115.29+1.29 +691.25* 807.83	*204.18+2.29 +864* 1,070.47	*380.03+4.26+ 1,762.5* 2,146.79
Adjustment to account for additional impact (additional waste, consumables, fuel delivery, etc.)	*1.01 x 402.3* **406.3** kg CO_2e	*1.01 x 807.83* **815.9** kg CO_2e	*1.01 x 1,070.47* **1,081.2** kg CO_2e	*1.01 x 2,146.79* **2,168.3** kg CO_2e

Table 2. ***Calculating the overall cradle-to-gate carbon footprint of box culverts per unit***

1The precast box culvert industry average may be identical

APPENDIX

Removing temporary CO_2 emissions

The new version of PAS 2050 (2011) accounts for a fixed 100 years assessment period after the formation of the product. Any emissions or removals (not lasting for over 100 years after the formation of the product) should be removed. This newly introduced rule can have a significant impact on concrete products as any emissions absorbed through the **carbonation of concrete** during the first 100 years after manufacture will to be excluded from calculation: A longer time period may be considered if significant removals/ emissions may occur afterwards: e.g. at the end-of-life and exhumation, crushing of the box culverts.

Absorption of CO_2 at the end-of-life (and 100 years beyond) is estimated below based on a BRE publication. That publication calculates CO_2 absorptions by precast concrete: reaching **3.28 kg CO_2/m^3** during service life, **15.3 kg CO_2/m^3** at end-of-life if the crushed precast waste is landfilled, and **55.6 kg CO_2/m^3** at end-of-life if the crushed precast waste is reused as graded aggregates. It is assumed that 90% of the crushed box culverts at end of life will be recycled into graded aggregates and 10% will go to landfill:

Total CO_2 absorbed due to carbonation = 3.28 + (0.9 x 55.6) + (0.1 x 15.3) = **54.85 kg CO_2/m^3**
= **23.05 kg CO_2/tonne**

That absorbed CO_2 is then removed from the Cradle-to-Gate Carbon Footprint of box culverts to produce a Footprint more in line with the new PAS 2050 requirements. The cradle-to-gate carbon footprint will therefore be adjusted to **101.95 kg CO_2/t**.

	1.30 x 0.80 x 2.00 m	1.50 x 1.50 x 2.00 m	2.90 x 1.95 x 1.50 m	3.60 x 2.70 x 2.00 m
Plain Concrete Weight (t)	2.601	5.53	6.912	14.71
GHG footprint for plain concrete (kg CO_2e)	*2.601 x 102* 265.3	*5.53 x 102* 564	*6.912 x 102* 704.7	*14.71 x 102* 1,499.7
GHG footprint for reinforced box culverts (kg CO_2e)	*76.31+0.86+265.3* 342.5	*115.29+1.29 +564* 680.6	*204.18+2.29 +704.7* 911.17	*380.03+4.26+ 1,499.7* 1,884
Adjustment to account for additional impact (additional waste, consumables, fuel delivery, etc.)	*1.01 x 342.5* **345.9** kg CO_2e	*1.01 x 680.6* **687.4** kg CO_2e	*1.01 x 911.17* **920.3** kg CO_2e	*1.01x 1,884* **1,902.8** kg CO_2e

Table 3. *Calculating the overall cradle-to-gate carbon footprint of box culverts per unit (with temporary emissions removed)*

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