Revolutionizing Road Infra with Modern Equipment, Technologies, Sustainable Materials and Policy Guidelines

Construma

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Sustainability of Bridges

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International Road Federation India Chapter

INDIA CHAPTER

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*Former Vice President of Intl. Assoc. of Bridge & Struct. Engg, Zurich, (**IABSE**);*

Chair, CEAI – Western India; ExC, IIBE; GC Member, IAStructE

Harshavardhan Subbarao, holds a Ph.D. in Steel Structures from Imperial College, London and M.S. Eng. from Univ. of Michigan. He has been the designer of a number of Landmark award-winning projects such as Signature Cable Stayed Bridge, Delhi; 4.56km Rail-cum-Road Bridge, Patna; Bridge No. 20 on JURL; metros, viaducts, elevated roads, cable stayed, arch and extradosed bridges etc.

He is a former Vice President of IABSE, Zurich and Member of its Technical Committee, Chair of Outstanding Paper Awards Committee and Past-Chair of its Bulletin Edit Board, and serves on several committees of IRC, BIS, IABSE and fib, Highway Research Board of India, and various International and National bodies. He is a member of BIS Apex Committee CED 7 for Steel Structures and Sections, was a committee member of IS:800 Limit State Code and member of IRC Steel and Composite Bridge Committee. He is also actively involved in Sustainability in Bridges & a member of IRC committee on Sustainable Steel. He has over 30 years of experience and serves on various International and National Scientific and Technical Committees, Editorial Boards and has several papers, publications and bridge projects to his credit.

Sustainability Perspective

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Climate Emergency:

- Sustainability, climate change issues and carbon emissions have recently become more prominent both to the public and the engineering profession.
- One of the key issues to limiting climate change is a need to limit our current carbon dioxide emissions.
- Studies shows that bridges and viaducts have a relatively high intensity of carbon compared to the average road or railway per kilometer.

Circular Economy

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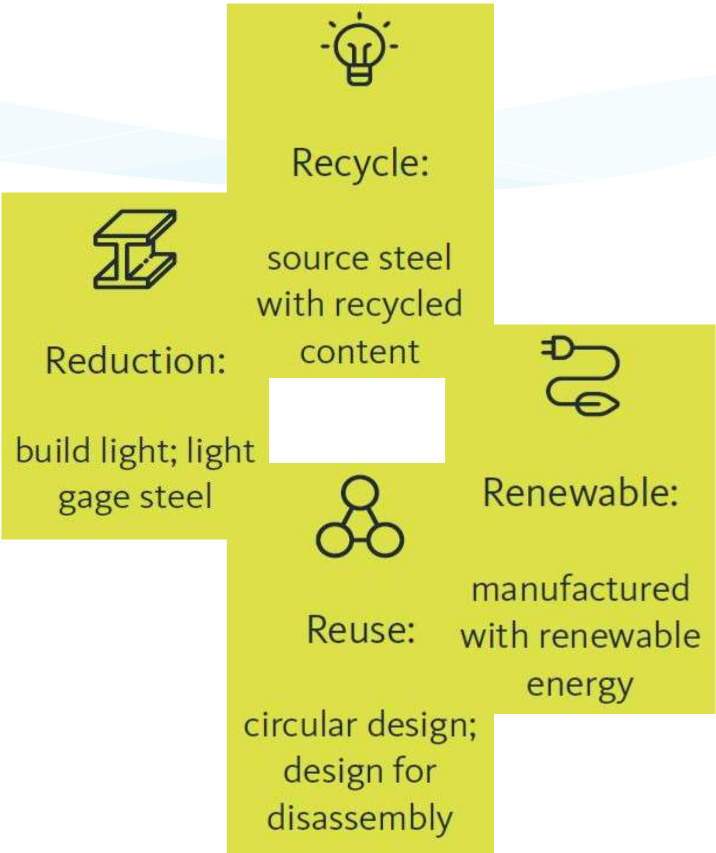
Based on the concept of circular economy CIRCULAR STRUCTURAL DESIGN explores solutions for the future built environment.

This provides a promising concept and is defined by the Ellen MacArthur Foundation as follows:

1) Re-duce: Design out waste and pollution
2) Re-use: Keep products and materials in use
3) Re-new: Regenerate natural systems
4) Re-cycle: For e.g. Steel made from recycled steel

1) and 2) are highly relevant for the steel construction industry in order to decarbonize as soon as possible.



Sustainability Calculator

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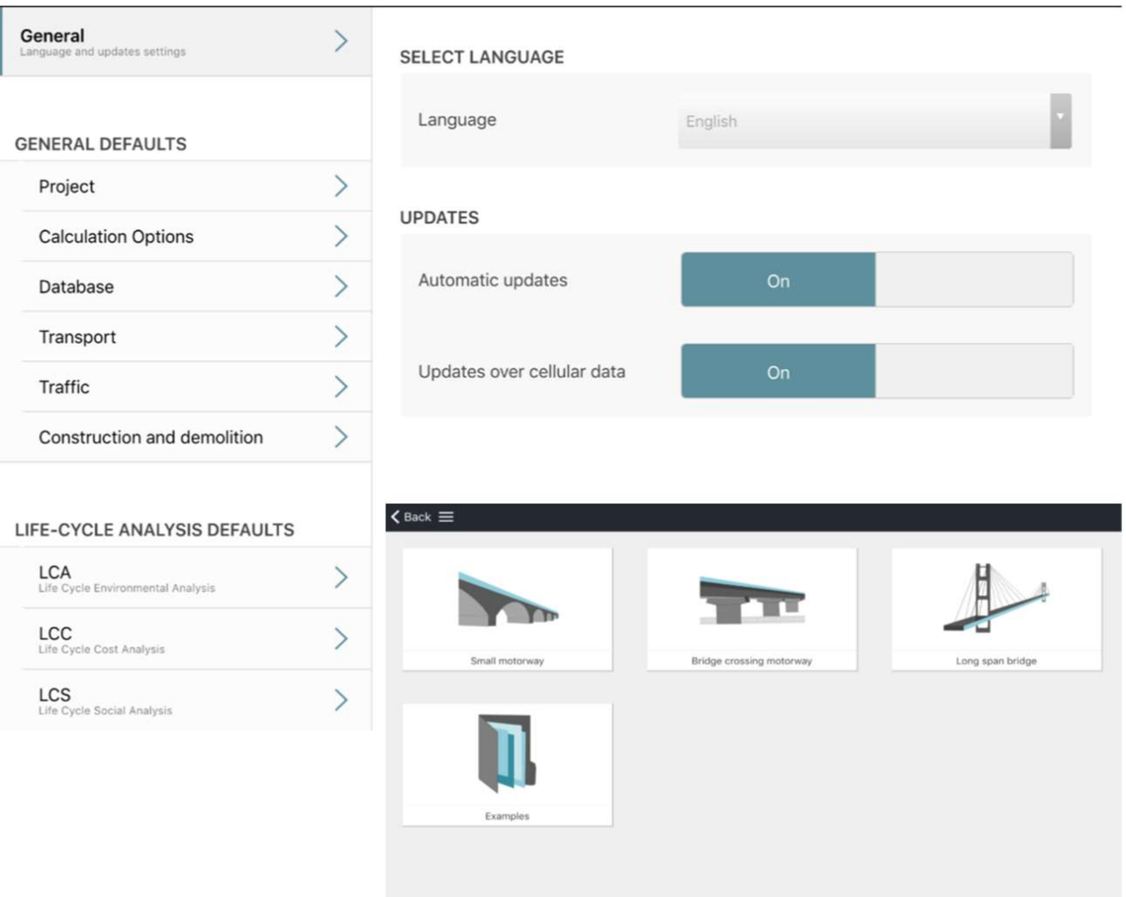

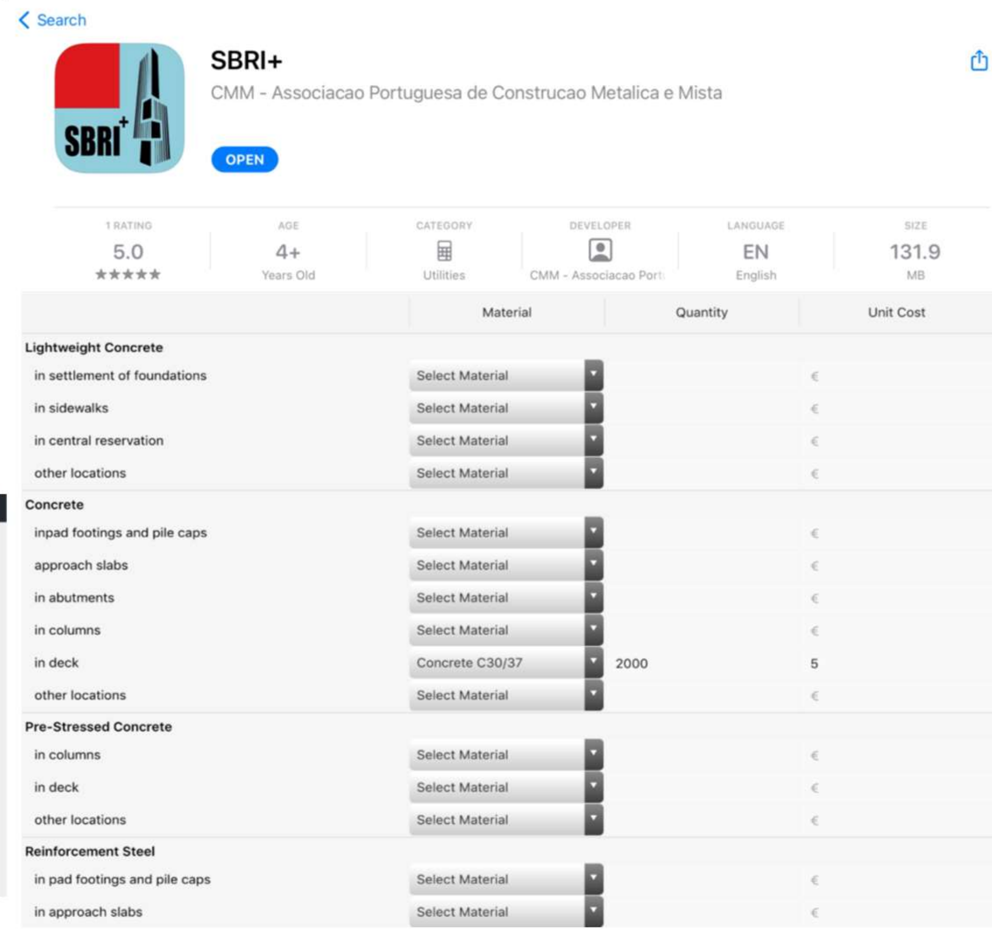

Sustainability Calculator

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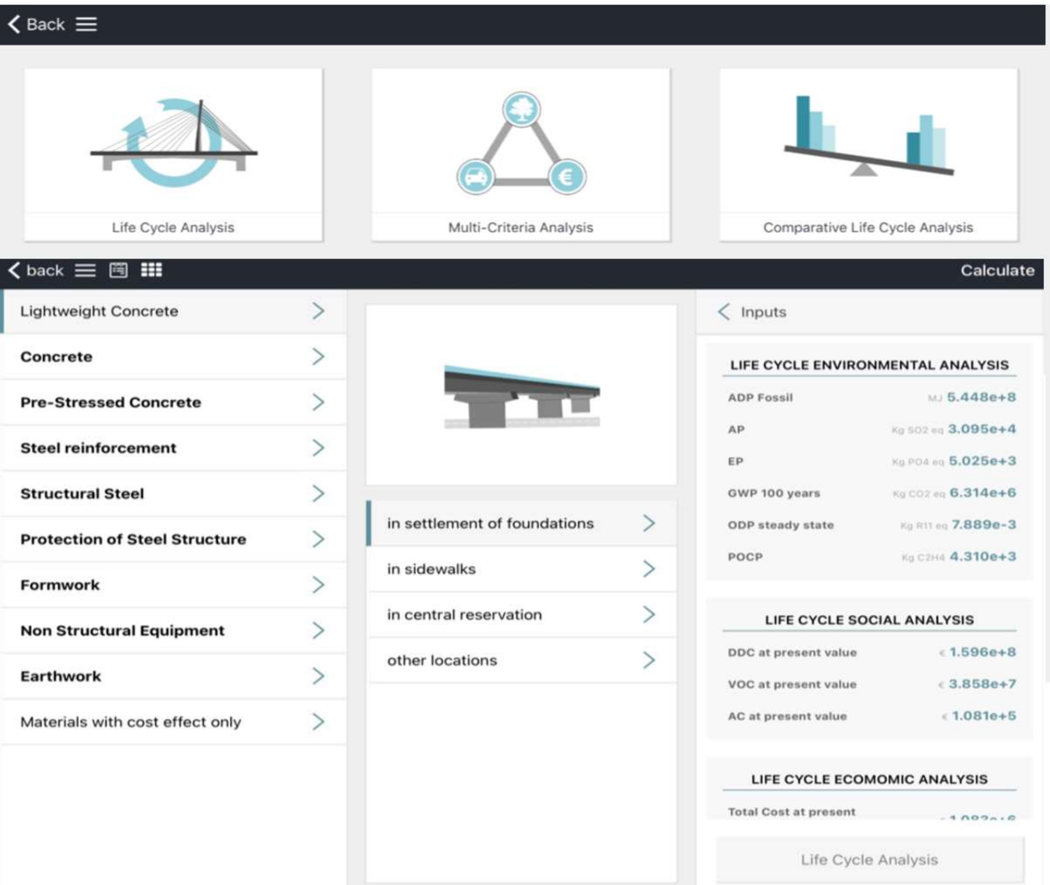

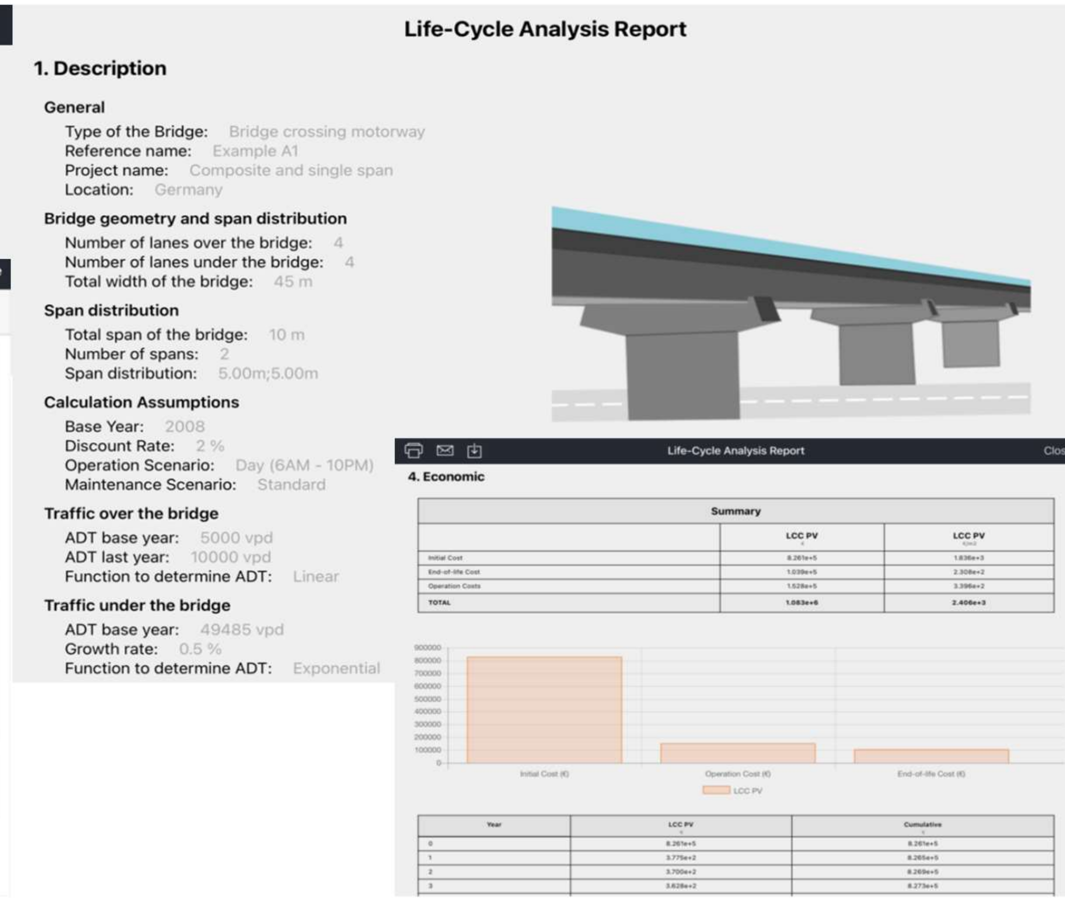

Sustainability Calculator

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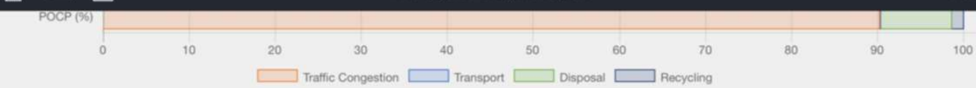
Life-Cycle Analysis Report   Close



3.5 Aggregate Results

Aggregate						
Material	**ADP fossil** MJ	**AP** Kg SO_2 eq	**EP** Kg PO_4 eq	**GWP** Kg CO_2 eq	**ODP** Kg R_{11} eq	**POCP** Kg C_2H_4
Production	5.222e+6	1.545e+3	1.579e+2	7.043e+5	5.983e-3	1.922e+2
Construction	2.686e+7	1.414e+3	2.335e+2	2.723e+5	2.507e-4	2.011e+2
Operation	2.751e+8	1.430e+4	2.382e+3	2.773e+6	9.501e-6	2.053e+3
End-of-life	2.377e+8	1.369e+4	2.252e+3	2.564e+6	1.646e-3	1.864e+3
TOTAL	**5.448e+8**	**3.095e+4**	**5.025e+3**	**6.314e+6**	**7.889e-3**	**4.310e+3**

Life-Cycle Analysis Report   Close

80	8.649e+2	1.277e+3	9.119e+0
85	0	0	0
90	1.397e+2	2.062e+2	1.469e+0
95	1.631e+6	3.866e+5	1.037e+3
100	0	0	0
TOTAL	**1.596e+8**	**3.858e+7**	**1.081e+5**

SBRI+ - Sustainable Bridges Calculator

Version 1.0.0 - 15 Jun 2018

This software enables the user to perform a Life Cycle Analysis of Steel-Composite road bridges. For that it calculates the different impacts associated with the construction, operation and end of life of the bridges. No warranty is given to the user of the software. The user agrees to indemnify and hold harmless from any claim and any direct and/or indirect loss or damage, including but not limited to those resulting from an incorrect use and/or a use made for an inadequate or inappropriate purpose.

Life Cycle Stages & Modules BS EN 15978 & PAS 2080

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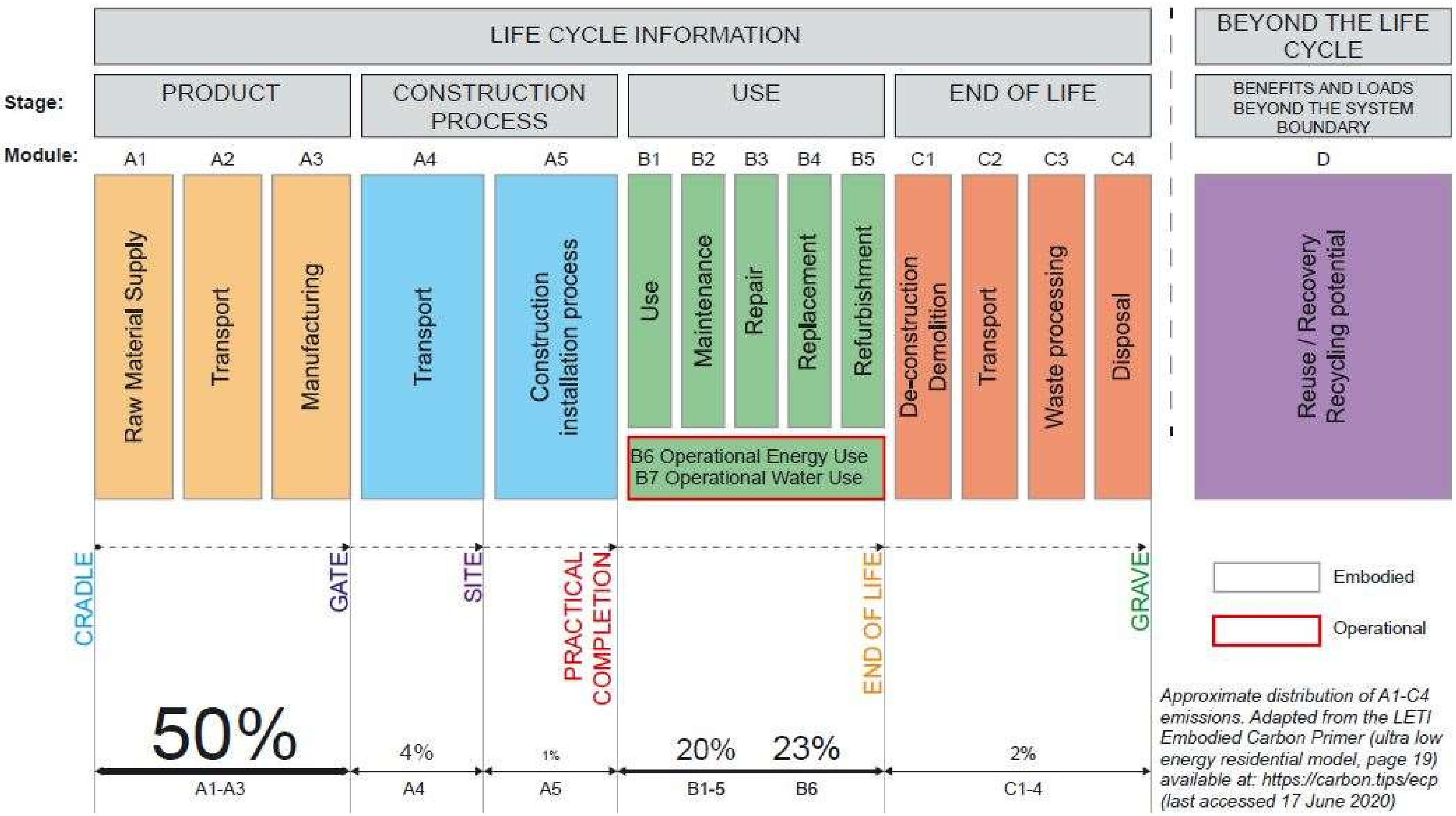

Embodied carbon = quantity × carbon factor

For transport infrastructure PAS 2080 adds:

- Module AO – Pre-construction stage- primarily office-based emissions associated with design, studies, consultations etc.
- Module B8 – Other operational processes
- Module B9 – Users' ultilisation of infrastructure

Appendix C: Supplementary information for bridges in *How to Calculate embodied carbon*, IStructE, UK

John Orr & et. al., (2020) - the structural engineer.org

Production Stage Carbon Factors

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Material	Type	Specification/details	A1–A3 ECF ($kgCO_2e/kg$)	Data source
Concrete	*In situ*: piling, substructure, superstructure	Unreinforced, C30/37, UK average ready-mixed concrete EPD[1] (35% cement replacement)	0.103	MPA, 2018[2]
		Unreinforced, C32/40, 25% GGBS cement replacement[3]	0.120	ICE V3[4]
		Unreinforced, C32/40, 50% GGBS cement replacement	0.089	ICE V3
		Unreinforced, C32/40, 75% GGBS cement replacement	0.063	ICE V3
		Unreinforced, C40/50, 25% GGBS cement replacement	0.138	ICE V3
		Unreinforced, C40/50, 50% GGBS cement replacement	0.102	ICE V3
		Unreinforced, C40/50, 75% GGBS cement replacement	0.072	ICE V3
	Precast	Unreinforced, C40/50 with average UK cement mix	0.178	ICE V3
		Reinforced, 150mm prestressed hollow core slab: British Precast Concrete Federation average EPD	$50.2kgCO_2e/m^2$	BPCF, 2017[5]
Steel	Reinforcement bars	UK: BRC EPD	0.684	BRC, 2019[6]
		Worldwide: Worldsteel LCI study data, 2018, world average	1.99	ICE V3
	PT strands	Assume the same as reinforcement bars		
	Structural sections	UK open sections: British Steel EPD	2.45	BS, 2020[7]
		Europe (excl. UK): Bauforumstahl[8] average EPD	1.13	Bauforumstahl, 2018
		Worldwide: Worldsteel LCI study data, 2018, world average	1.55	ICE V3
	Galvanised profiled sheet (for decking)	UK: TATA Comflor EPD	2.74	TATA, 2018
Blockwork	Precast concrete blocks	Lightweight blocks	0.28	ICE V3
Brick	Single engineering clay brick	Generic, UK	0.213	ICE V3
Timber, excl. carbon sequestration[9], [10]	Manufactured structural timber	CLT, 100% FSC/PEFC	0.437	ICE V3
		Glulam, 100% FSC/PEFC	0.512	ICE V3
	Studwork/framing/flooring	Softwood, 100% FSC/PEFC	0.263	ICE V3
	Formwork	Plywood, 100% FSC/PEFC	0.681	ICE V3
Plasterboard	Partitioning/ceilings	Minimum 60% recycled content	0.39	ICE V3
Intumescent paint	For steelwork	Specific EPD: Amotherm steel WB, Amonn	2.31	AMONN, 2019[11]

Data taken from *CEC* Table 2, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation.

John Orr & et. al., (2020) - the structural engineer.org

Transport Carbon Factors

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Transport Emissions Factors for Different Modes of Transport

Mode	TEF_{mode} ($gCO_2e/kg/km$)	Source
Road transport emissions	0.10650	(BEIS, 2020)[1]
Sea transport emissions	0.01614	(BEIS, 2020)[2]
Freight flight emissions	0.59943	(BEIS, 2020)[3]
Rail transport emissions	0.02556	(BEIS, 2020)[4]

Data taken from *CEC* Table 4, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation.

[1] For HGV (all diesel), all HGVs, average laden.
[2] For cargo ship, container ship, average.
[3] International, to/from non-UK, without RF.
[4] Freight train.
BEIS, 2020. *Greenhouse gas reporting: conversion factors 2020.* London, BEIS. Available online at https://carbon.tips/cf2020 (last accessed 23/02/20)

John Orr & et. al., (2020) - the structural engineer.org

Material Wastage

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Waste Factors for typical Structural Elements

Material/product	Waste rate (WR)	Waste factor (WF)[1]	WRAP Net Waste Tool reference
Concrete *in situ*	5%	0.053	Table 2, concrete *in situ*
Concrete precast (beams and frames)	1%	0.010	Table 2, concrete precast (large precast elements)
Steel reinforcement	5%	0.053	Appendix 1, frame: *in situ* concrete frame generic; Table 2, ferrous metals
Steel frame	1%	0.010	Appendix 1, frame: steel frame generic
Blockwork	20%	0.250	Table 2, bricks & blocks
Brick	20%	0.250	Table 2, bricks & blocks
Timber frames (beams, columns, braces)	1%	0.010	Appendix 1, frame: timber frame
Timber floors (joists, boards)	10%	0.111	Appendix 1, floor: wooden floor
Plasterboard	22.5%	0.290	Table 2, plasterboard; Table 3: boarding
Sprayed cementitious fire protection	10%	0.111	Table 3: cementitious sprays

Data calculated using data from *CEC* Table 5, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation.

[1] WF = (1 / (1 – WR)) – 1
where WR is the % waste rate shown in *CEC* Table 6.

John Orr & et. al., (2020) - the structural engineer.org

- *An Update on Carbon Footprint of Bridges*

Dr. David Collings, et all
Technical Director, ARCADIS, Guildford, Surrey, UK

- Transport Infrastructure accounts for a significant proportion of worlds carbon dioxide emissions.
- Bridges & viaducts use a significant amount of steel & cement, these two industries alone amount to about 16% of total worlds carbon emissions.
- Dr. David Collings used a data base of 200 bridges to estimate the capital carbon.
- Study trends and relationships in plots of carbon with crossing length & bridge area, with span, carbon in substructure & carbon with time are introduced to note progress towards NET ZERO.
- Concludes on 4 key recommendations towards NET ZERO along with key performance indicators of good bridge designs considering carbon footprints.

Trends in the Carbon Footprint of Bridges, Structural Engineering International : SEI : May, 2021

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- Sustainability, Climate Change Issues & reducing carbon emissions have seized the world at large.
- To Limit & Reduce the carbon emission we should understand where and how much we use.
- Bridges and viaducts on major highway projects have a relatively high intensity of carbon compared to the average road or railway track per km
- The carbon content of a bridge can be calculated based on the primary material quantities & construction methods.
- The trend in carbon footprint for different bridge traffic types, materials, spans, lengths, areas, and costs is picked up to give a benchmark for future reductions in the carbon footprint and outline those areas where improvement is possible.
- This data can be used to assist in the reduction of carbon in bridges by benchmarking current carbon footprints.

Carbon Footprint Estimates

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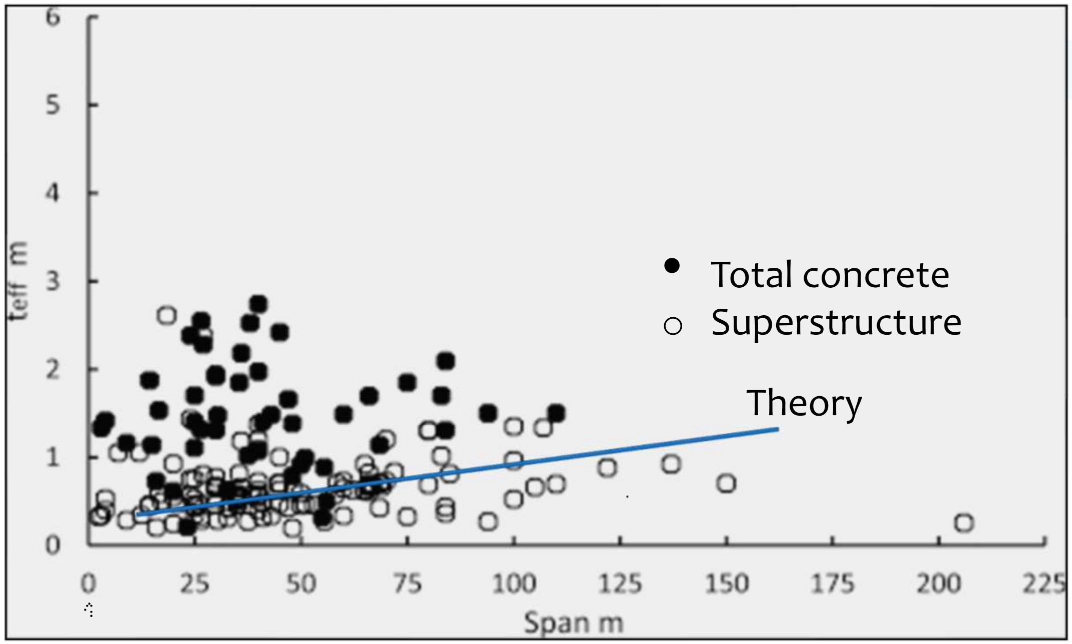
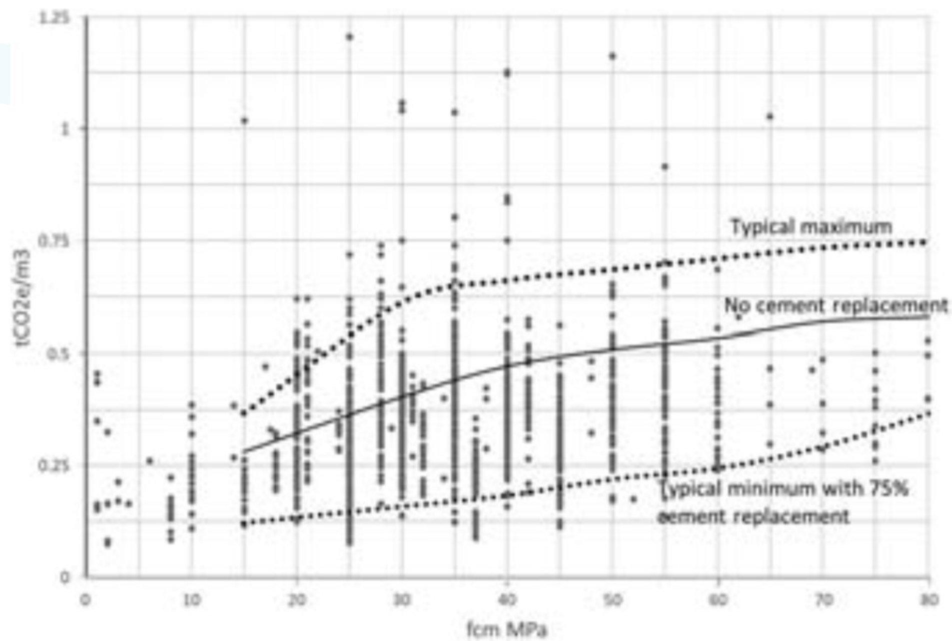


Bridge effective thickness
(concrete volume/bridge deck area)



Variation in embodied capital carbon of concrete with strength (fcm) and amount of cement replacement

Embodied Carbon Factor for Steel tCO2e/t

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Steel Section		Material A1–A3	Fabrication	Total A1–A5
Reinforcement Bars	World Average	1.99	0.01	0.83-2.1
	UK	0.76		
Cables and Strand		2.0	0.05	2.20
Rolled sections	World Average	1.55	0.26	1.44-2.90
	Europe	2.50		
	UK	1.13		
Plate	World Average	2.46	0.30	1.58-3.05
	Europe	1.13		
	UK	2.70		

Carbon Database Trends

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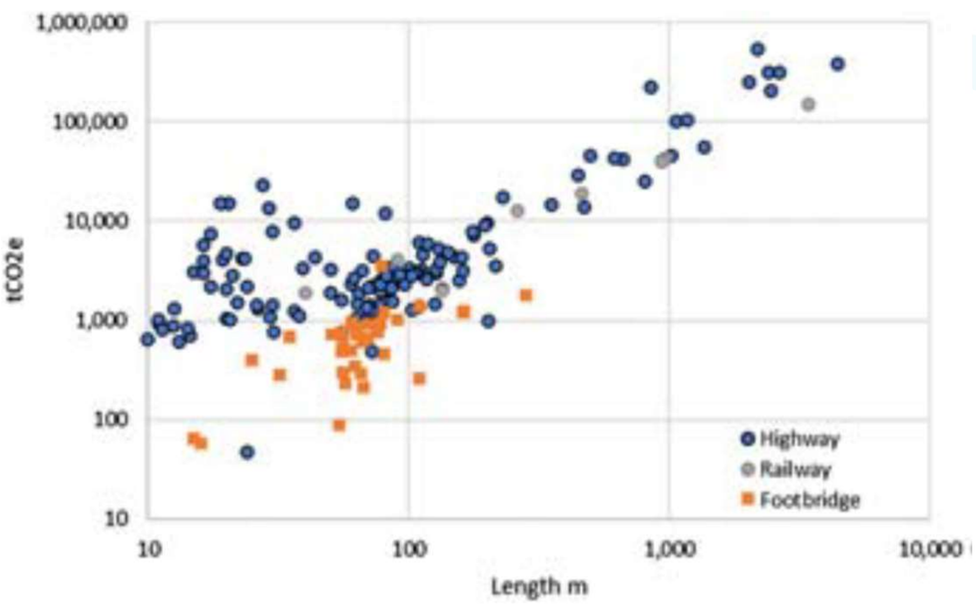
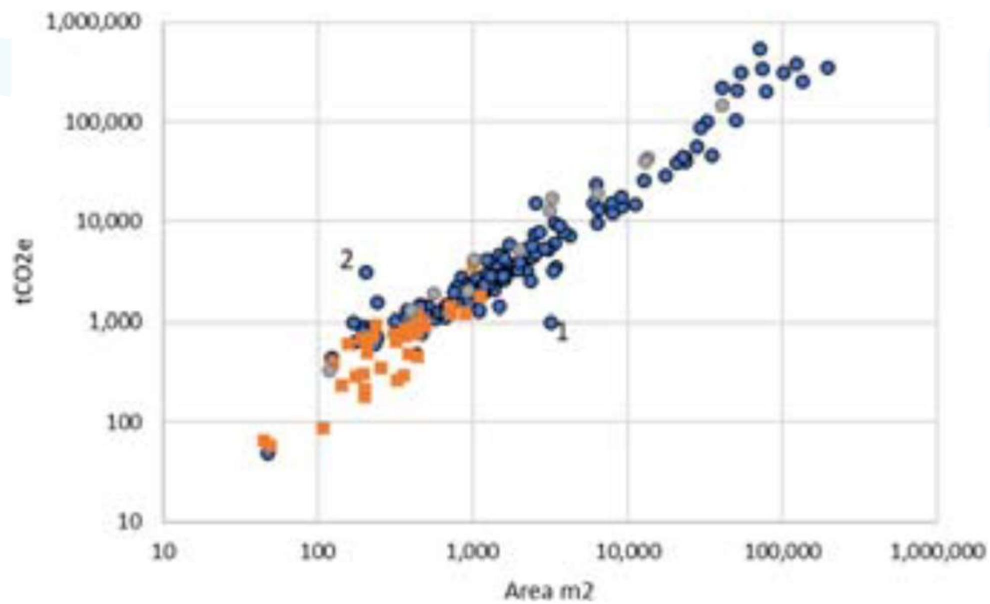
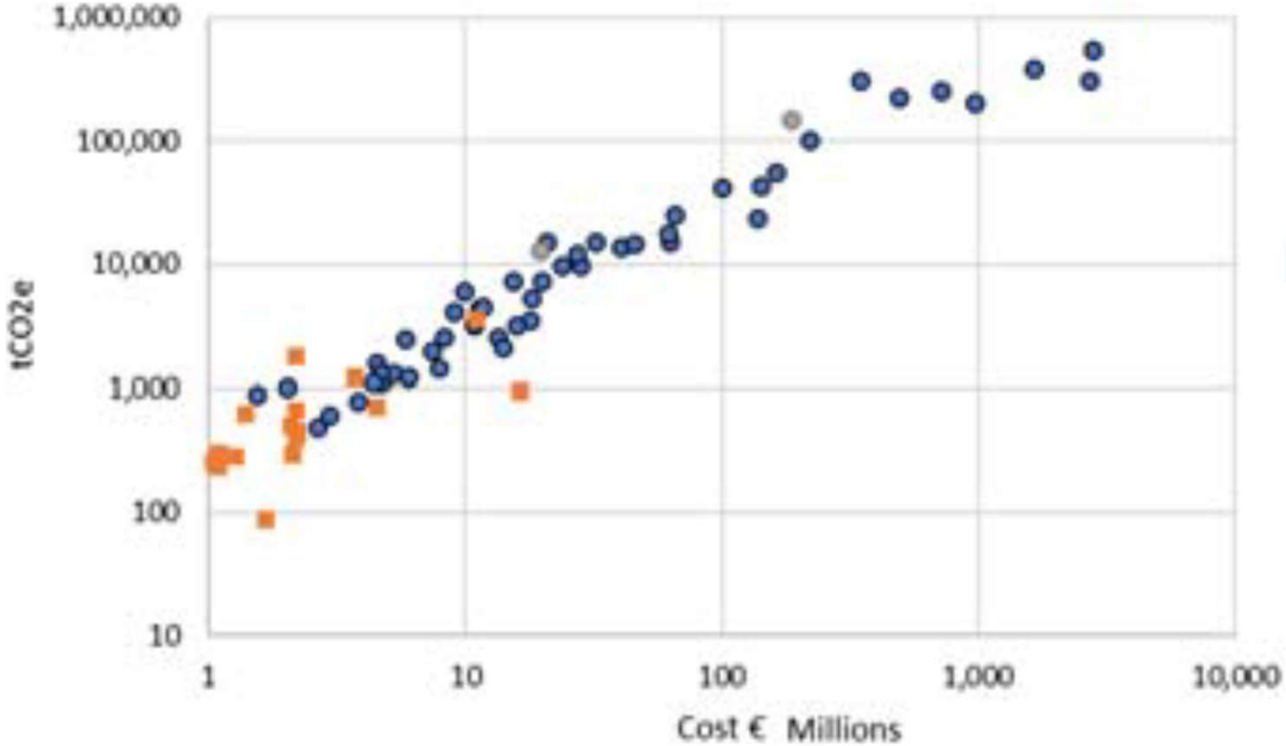


Capital carbon content (t CO2e) of project with length (m), and with loading type



Capital carbon content, (t CO2e) of bridge with area (sq. m.), and with loading type

Carbon Database Results



Capital carbon content, (t CO2e) of bridge with cost (€ million), and with loading type

Trends in Normalized Carbon Data

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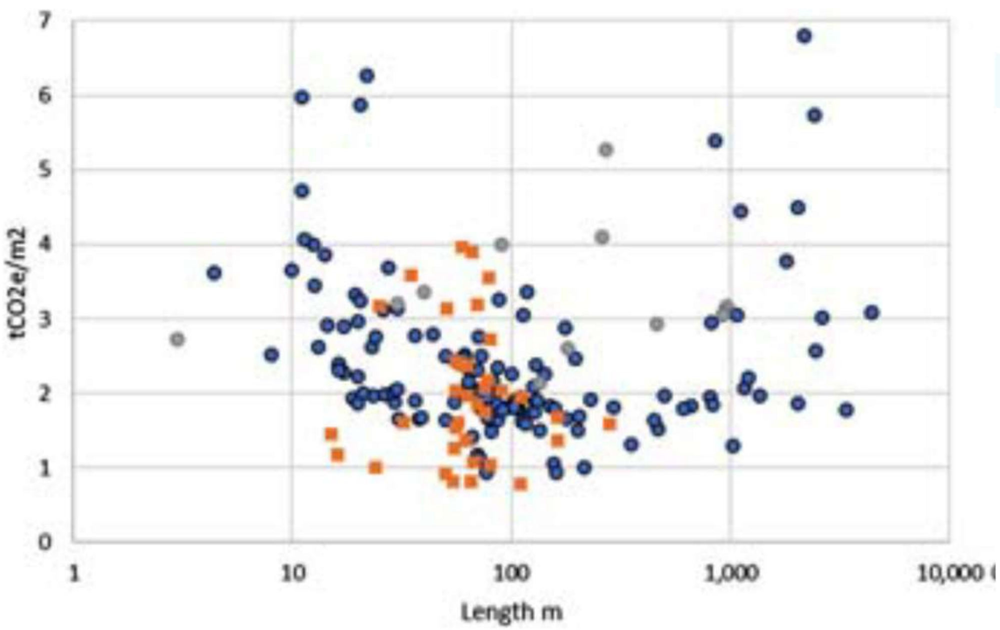
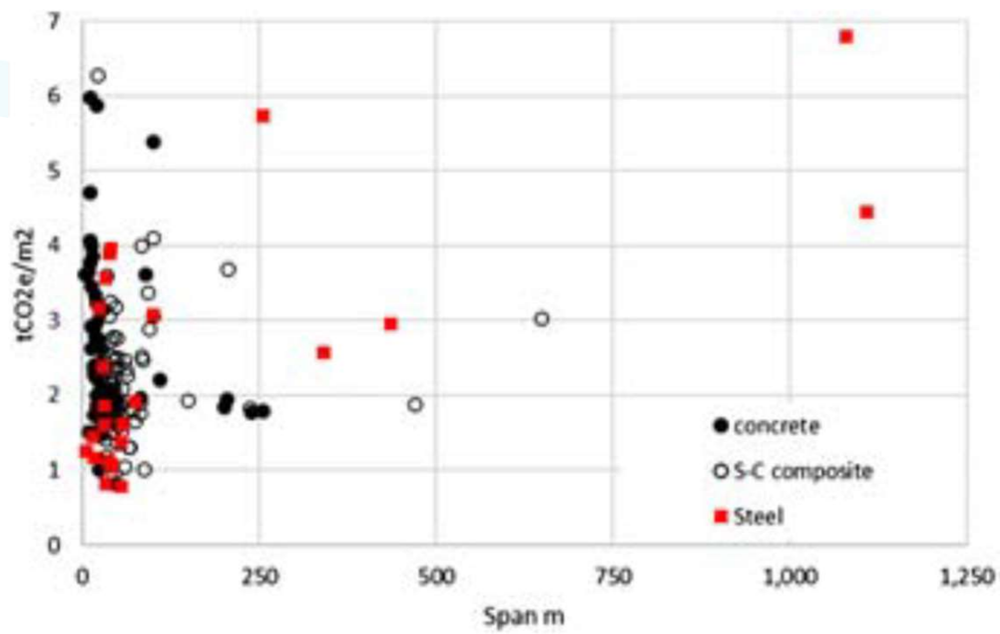
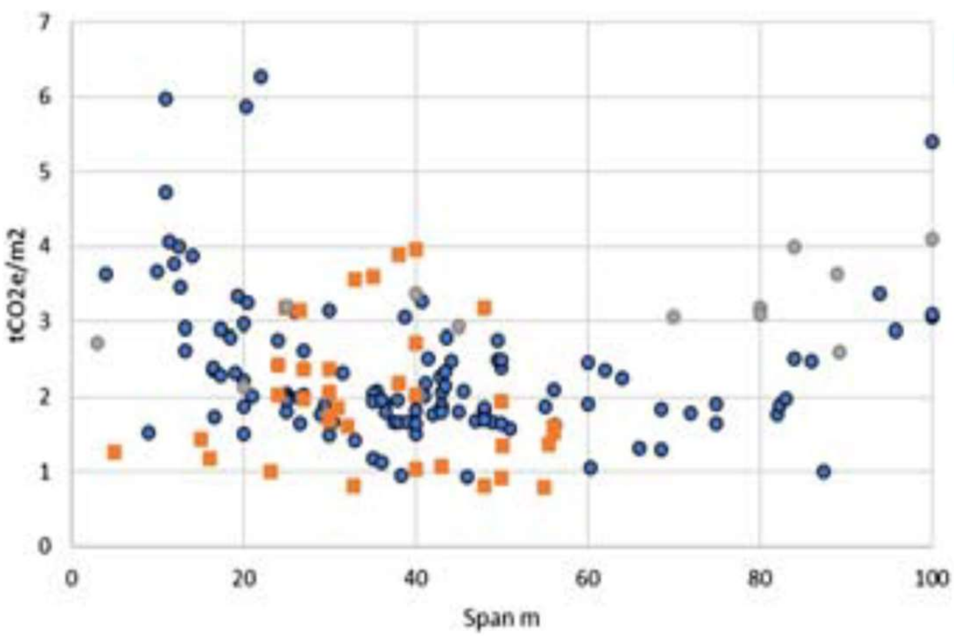


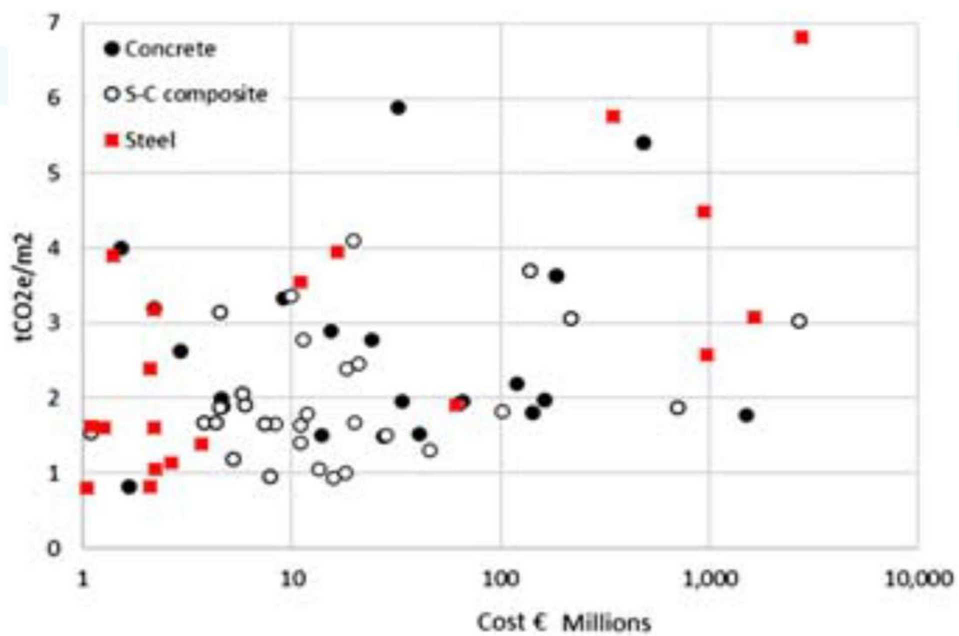
capital carbon (t-CO2e/m2) with crossing length (m), and with loading type.



capital carbon (t-CO2e/m2) with bridge span (m), and with material type

Normalized Carbon Data





Capital Carbon (t CO2e/m2) with bridge span (m), for spans less than 100 m and with loading type

Capital Carbon (t CO2e/m2) with bridge cost (million €), and with material type. Cost data plotted on a Log scale to show the full range of data

Update on Carbon Footprint of Bridges

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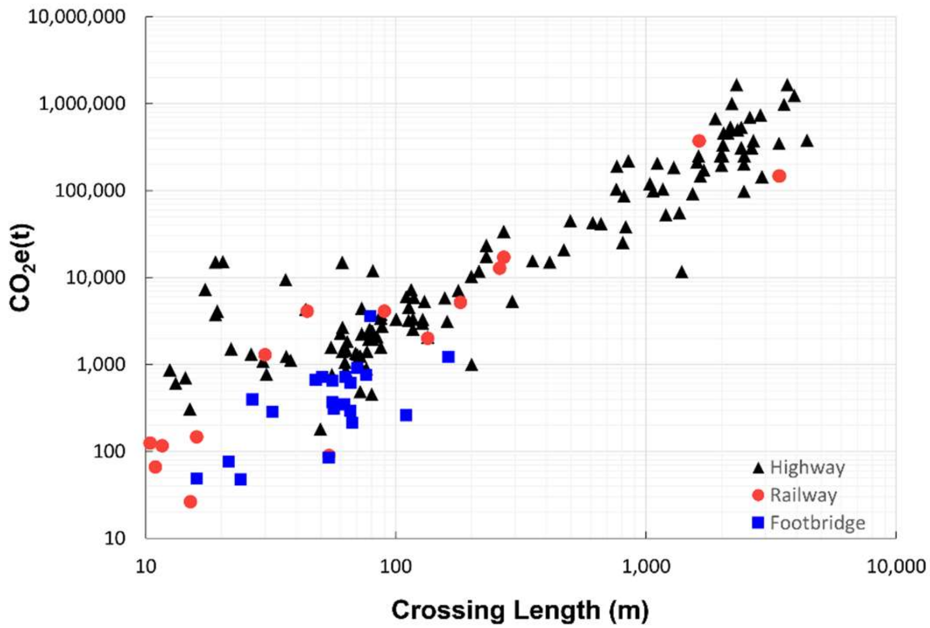
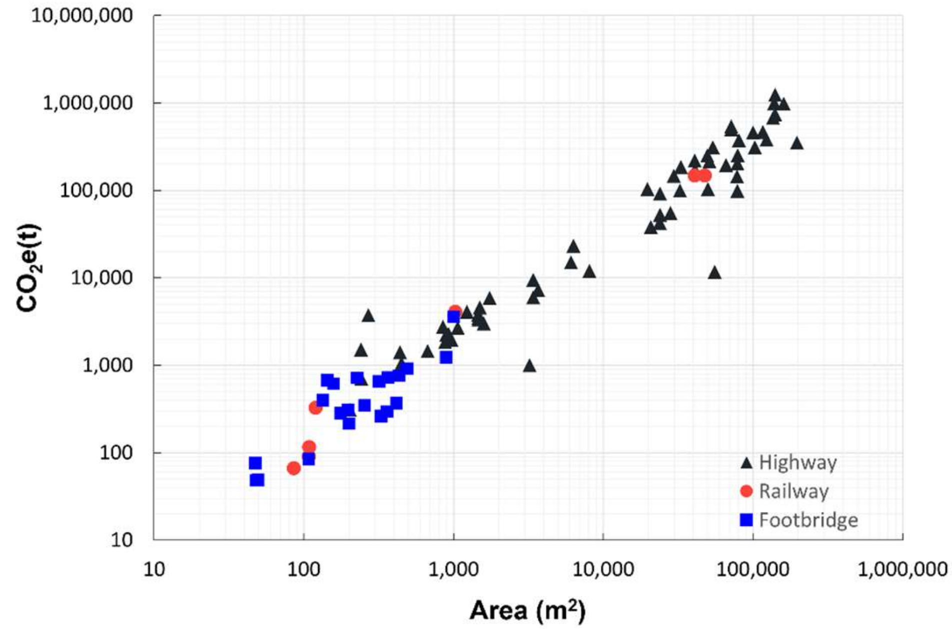
Capital Carbon Content (t CO_2e) of project with length (m), deck area (m2) and with loading type



Data plotted on a Log-Log scale



Length plotted on a Log scale

Update on Carbon Footprint of Bridges

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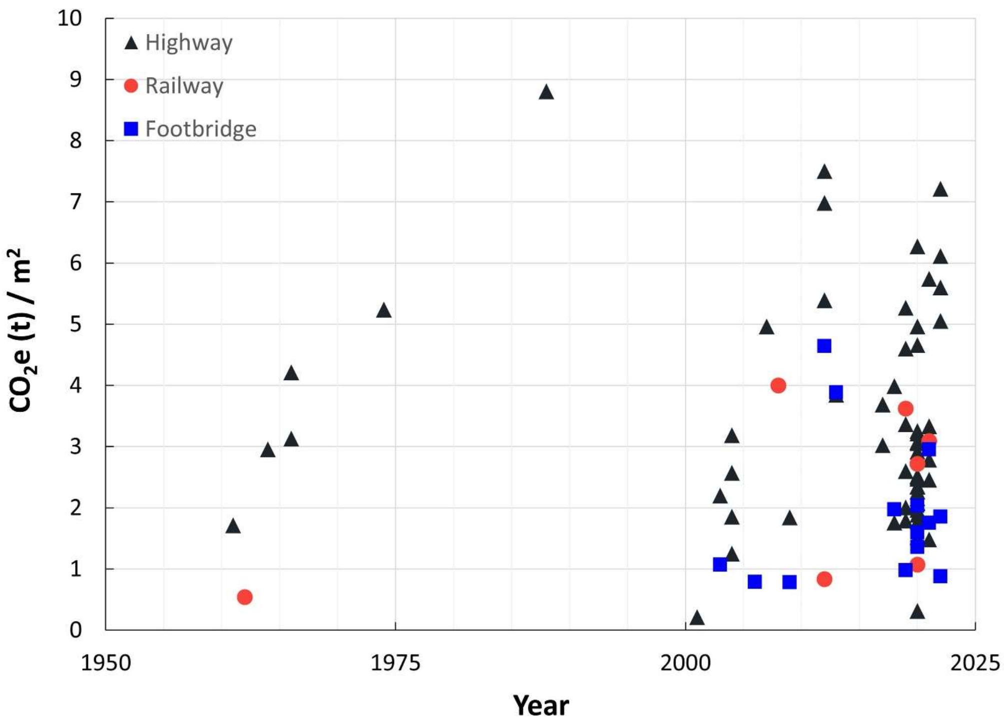
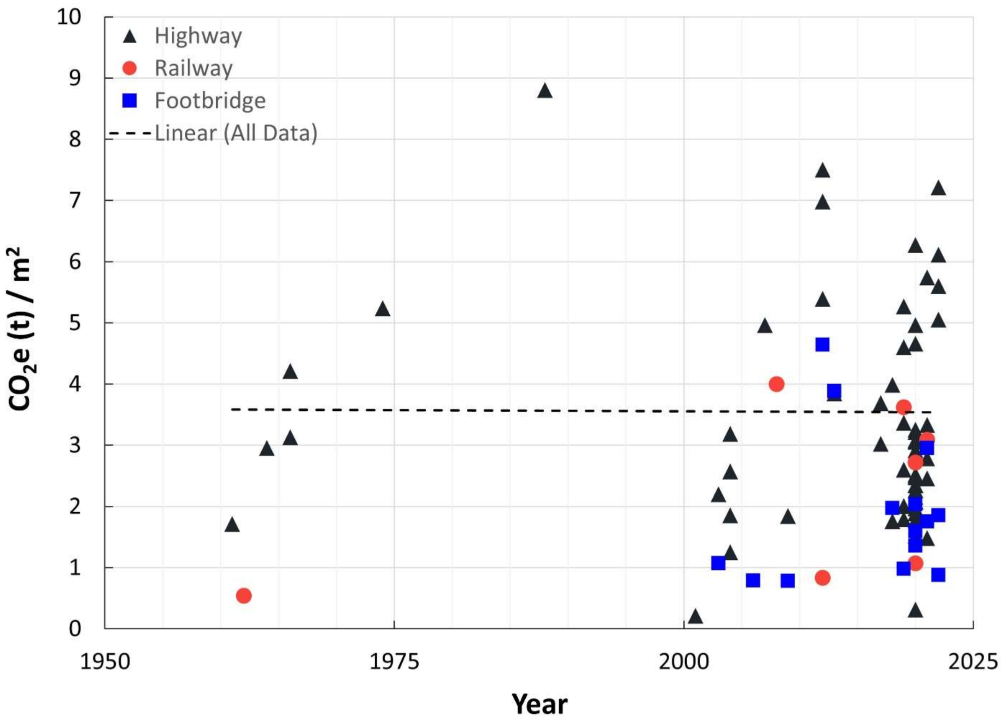
Progress towards Net Zero





Update on Carbon Footprint of Bridges

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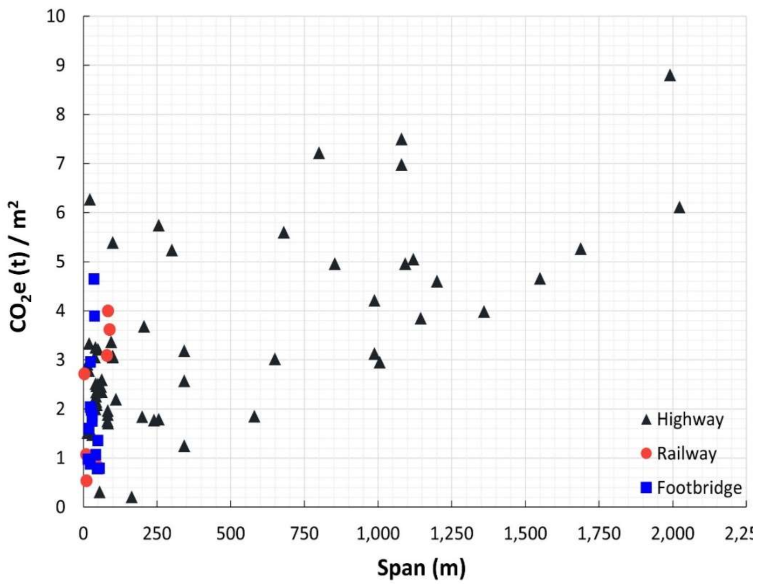
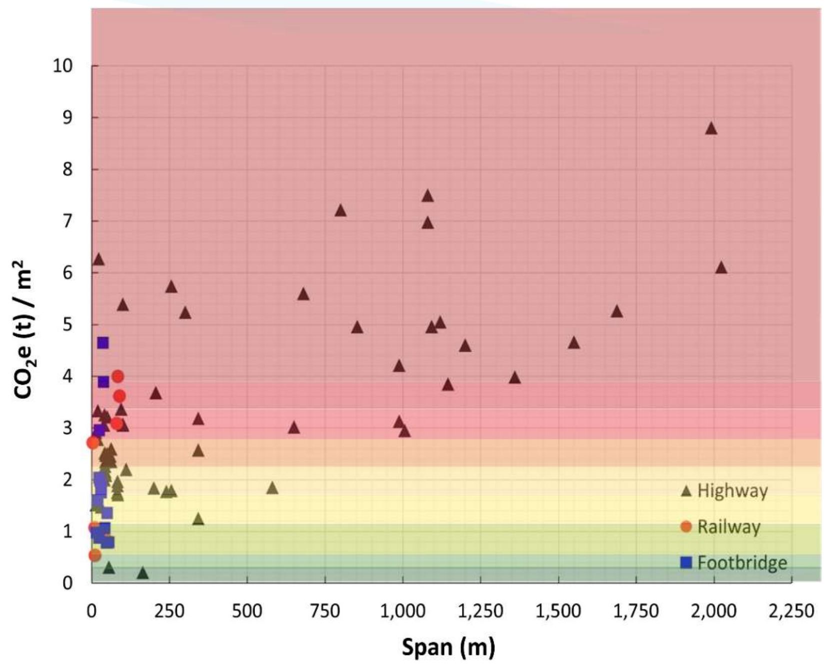
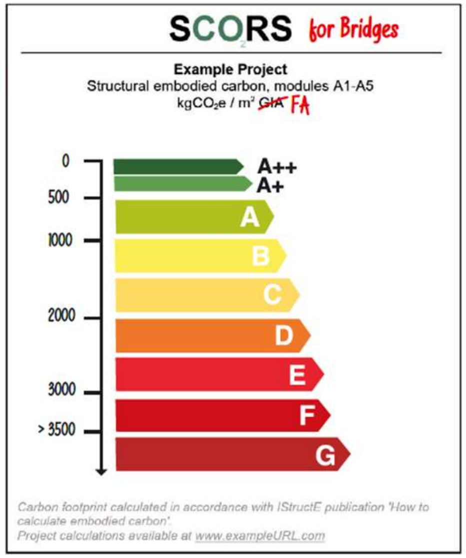
SCORS Rating







Ref: Archer-Jones, C., & Green, D. Carbon targets for bridges

A proposed Estimate of Embodied Carbon

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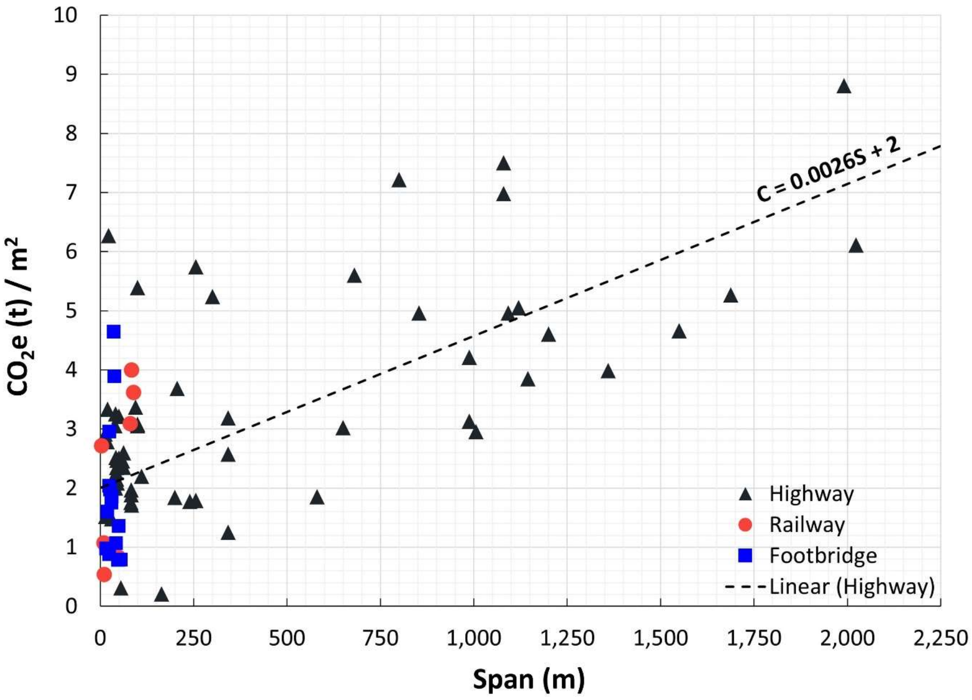
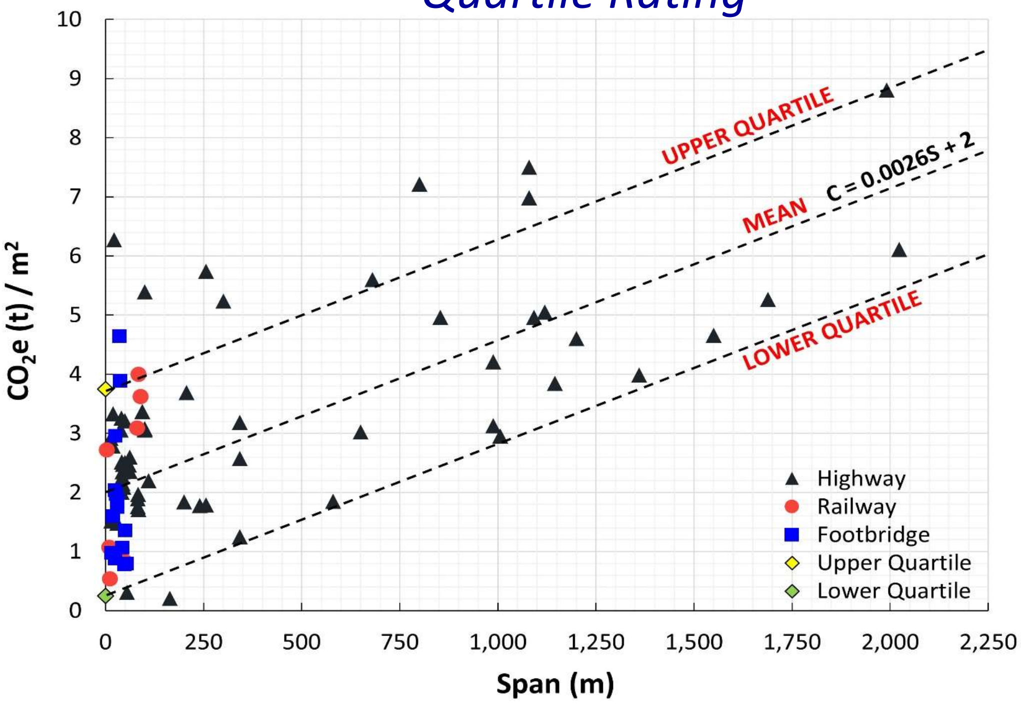
Embodied Carbon = 0.0026Span + 2



Quartile Rating



A Proposed Equation for Calculating Embodied Carbon in Bridges

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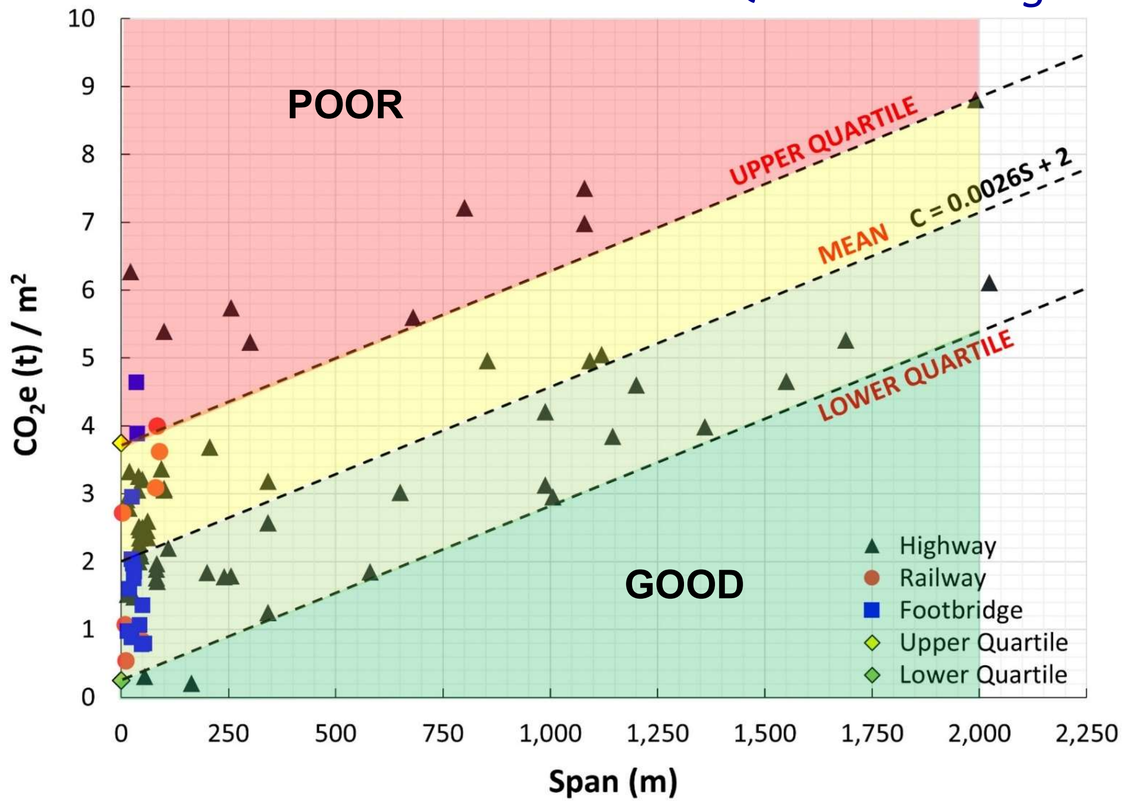
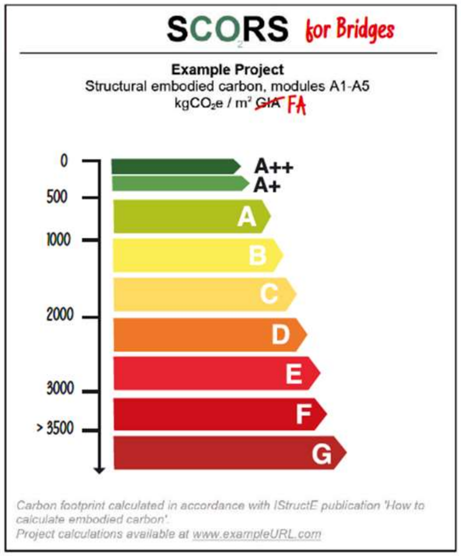
Quartile Rating



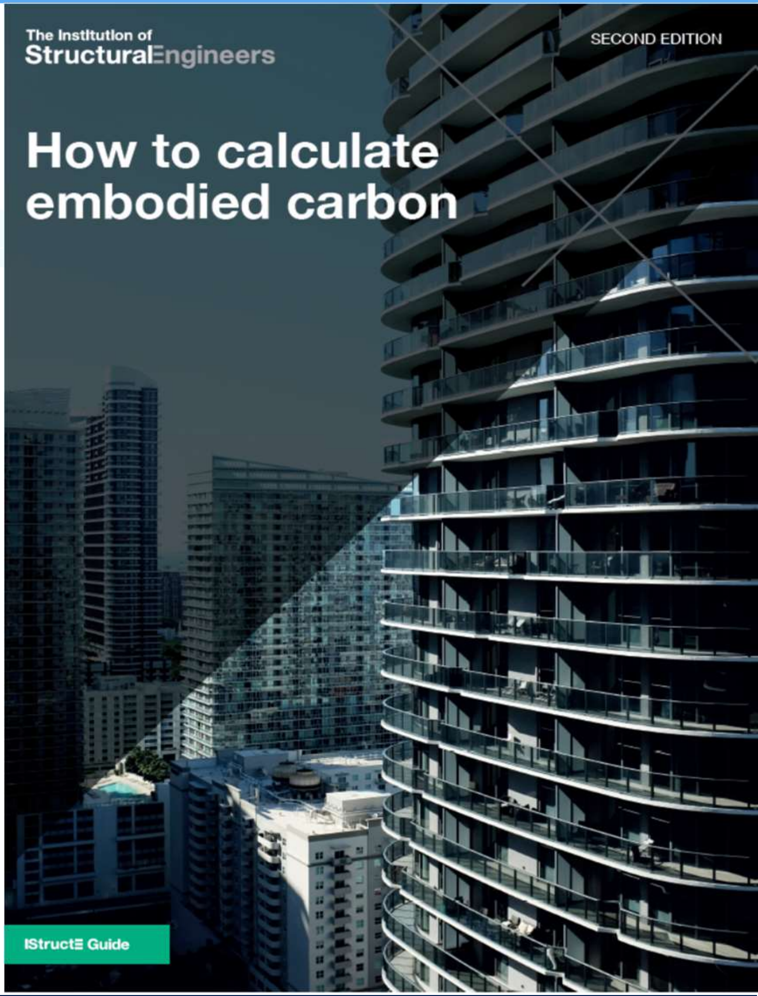
SCORBS Rating



Ref: Archer-Jones, C., & Green, D. Carbon targets for bridges

References

1. Collings D. : An Update on Carbon Footprint of Bridges. IABSE Congress New Delhi, 2023
2. Collings D. : The Carbon Footprint of Bridges. Structural Engineering International. 2021
3. Green Construction Board. PAS 2080, Carbon Management in Infrastructure. British Standard Institution; 2016
4. Archer-Jones, C., Green, D.: Carbon targets for bridges: a proposed SCORBS-style rating scheme. The Structural Engineer.
5. ISO: 5686 - Guidelines for Performing Life Cycle Costing
6. EN 15978 - Sustainability of construction Works, Assessment of environmental performance of buildings, Calculation Method, 2011
7. Arnold W. (2020) : 'The structural engineer's responsibility in this climate emergency', The Structural Engineer, 98 (6), pp. 10–11
8. Royal Institution of Chartered Surveyors (2017) Whole life carbon assessment for the built environment [Online] available at: www.rics.org/ global assets/RICS-website/media/ news/whole-life-carbon-assessment for-the--built-environment -November-2017.pdf



Conclusion from Research on Database

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- This study consist of 200 structures ranging from culverts to suspension bridges.
- The material content of the bridge superstructure and substructure are the significant parts of the carbon footprint for most bridges, so the optimization of materials has a place in reducing the carbon in bridges.
- The optimization of substructures to reduce capital carbon, in particular, is an area that requires further consideration particularly for smaller bridges where the substructure is the largest part.
- Normalised material data can be used as a benchmark to assist with the reduction of material and hence carbon in bridges
- There is a positive co-relation between span and carbon, this is clearer for the longer spans, for bridges in the smaller span range the carbon is also significantly influenced by the substructure.
- The load type has an influence on the carbon content of a bridge, railway bridges tend to have more carbon than highway and footbridges.

Conclusion from Research on Database

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- Steel & Carbon Bridges had similar normalized carbon contents, steel-concrete composite bridges had slightly less carbon.
- World average values for materials is used for early estimates.
- For the detailed design stage, data with local material carbon content, recycling of steel & replacement of concrete is suitable.
- There is a clear correlation between carbon content & bridge lengths.

Based on the data the key areas for improvement are:

- Giving more consideration to minimizing foundations and substructures, as these appear to be a major part of the capital carbon on many bridges.
- Reducing the variation in amounts of material and carbon, aiming for all bridges to be towards the lower end of the range nearer the theoretical carbon contents.

Conclusion from Research on Database

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4 Key Actions are Proposed :

- Reduce and minimise the size (length or area) of all bridges.
- Reduce the bridge span to the minimum.
- Reduce the substructure, and optimise piles caps and piers.
- Benchmark new designs against the data presented, to be in the lower (good) quartile redesign until it is.
- Trend line for the carbon data over time is flat indicating that carbon over the last 60 years has been relatively constant, with no sign of improvement in recent years.

Hence there is an urgent need to improve the design of bridges to consider carbon and aim towards net zero.

Signature Cable Stayed Bridge - Delhi

Inauguration of Laser Show & Fireworks !

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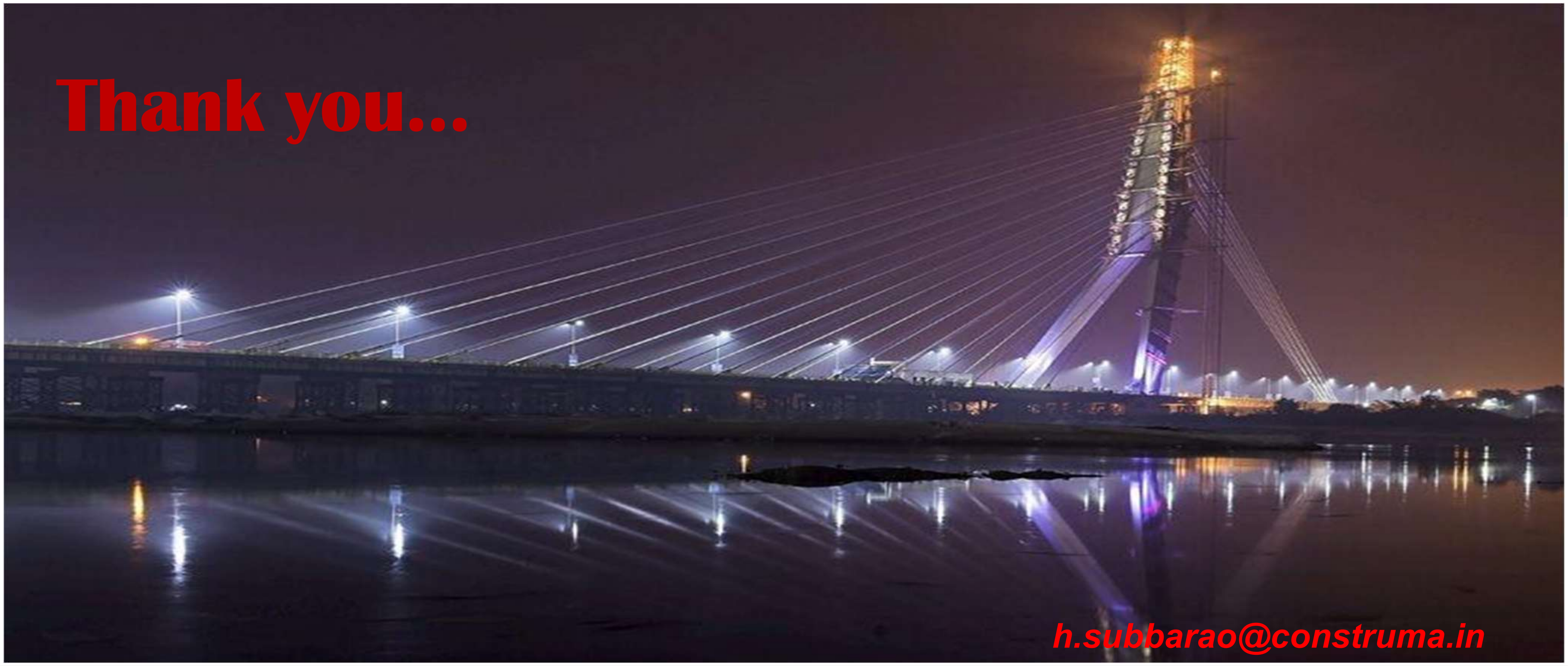

"Intelligently select materials of construction and the method of construction without any prejudice in order to reduce the Carbon Footprint of the structure.
Circularity- Repair, Repurpose, Recycle, Reuse to the maximum extent to reduce GHG effects."

Conclusion from Research on Database

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- Trend line for the carbon data over time is flat indicating that carbon over the last 60 years has been relatively constant, with no sign of improvement in recent years.

Hence there is an urgent need to improve the design of bridges to consider carbon and aim towards net zero.

Broad Conclusions on Sustainability

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In a fast developing country like India there has to be more thrust by the owners through *mandatory contractual provisions on material related issues for sustainable construction* such as:

- Mandatory use of recycled materials from demolishing and construction wastes.
- Mandatory use of manufactured aggregates (including Slag & Ash aggregates) as per IS: 383.
- Mandatory replacement of OPC with mineral admixtures to the maximum extent.
- Encouraging HPC, HSC and High grade steel for enhanced sustainability. Etc.
- Encouraging Self-Compacting Concrete, UHPC along with HTS as a composite structural element with so many of its sustainability characteristics.
- Encouraging "Design-Build Contract type" for project delivery to enable value engineering.
- Specifying the limits for CO_2 emissions and energy consumption in the contract and the stringent penalty clauses for exceeding the same & high rating for less footprint in tender evaluation based on QCBS.

Gaps Identified and Future Prospects

Construma

- As Global Demand for Construction continues to grow, potential for significant growth in emerging markets such as India, China, Vietnam, Australia and Indonesia will increase.
- The world needs to invest 75% more than the current investments in order to support the growth rate.
- Main aim should be sustainable infrastructure and building bridges based on service life considerations taking into account 'whole life carbon'.
- Innovative technology should be used to replace deficient bridges. Technology should be used to provide faster design-time, accelerated construction, and improved monitoring.
- Infrastructure owners need to educate and expertise their workforce through continued education for introduction of new products and technology.

Proposed Solutions - Measure for Reducing Carbon Footprint During Transportation Fabrication & Erection

Construma

1. Use of Renewable Energy: Wind turbines, Biomass, etc.
2. LED lighting, Reduction in compressed air leak & gas
3. systems.
4. Power optimization, use of inverters, new generation weld sets.
5. Hybrid/electric company vehicles, maintenance vans and electric equipment on-site to reduce emissions.
6. Waste minimisation including consumables.
7. Transportation by Sea, Train, etc

Proposed Solutions - Role of Standards & Code Makers in Decarbonization

Construma

1. Review safety factors to make the structures less carbon embodied.
2. Reduce over specifications of designed loads.
3. Specifying span to depth ratios.
4. Allowing Composite piles for pile foundation.
5. Design guidelines:
   Extradosed, Cable stay, Tub girder, Corrugated web bridges, etc.
6. The codes & standards should catch up with emerging new technologies and material science very fast for application.
7. The idiosyncrasy among the standards and code makers that the construction deficiencies have to be factored in "factor of safety" should not have any place in the era of climate action.

STANDARD SPECIFICATIONS
AND
CODE OF PRACTICE FOR ROAD BRIDGES

SECTION V
STEEL ROAD BRIDGES
(LIMIT STATE METHOD)
(Third Revision)

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Proposed Solutions

Construma

1. **Policy makers should be carbon neutrality oriented.**
2. Use of very high strength Steel & Concrete to reduce mass; using of these allows the same structural function to be performed with less material.
3. The optimization of energy intensive substructures in particular is an area that requires further consideration particularly for smaller bridges where the substructure is the largest part.
4. Reducing the variation in amounts of material and carbon, aiming for all bridges to be towards the lower end of the range nearer the theoretical carbon contents.
5. Use of composite steel construction with Ultra High Performance Concrete (CFT and Hybrid Structures).
6. Standardization with prefabrication.
7. Adoption of orthotropic plates for decks & pylon shells.
8. Design for future upgradation, widening & reuse.
9. Optimizing connection designs.
10. Standardisation for waste reduction.
11. Improving education and teaching of Steel Design, fabrication and erection. Capacity building.

Signature Cable Stayed Bridge - Delhi

Inauguration of Laser Show & Fireworks !

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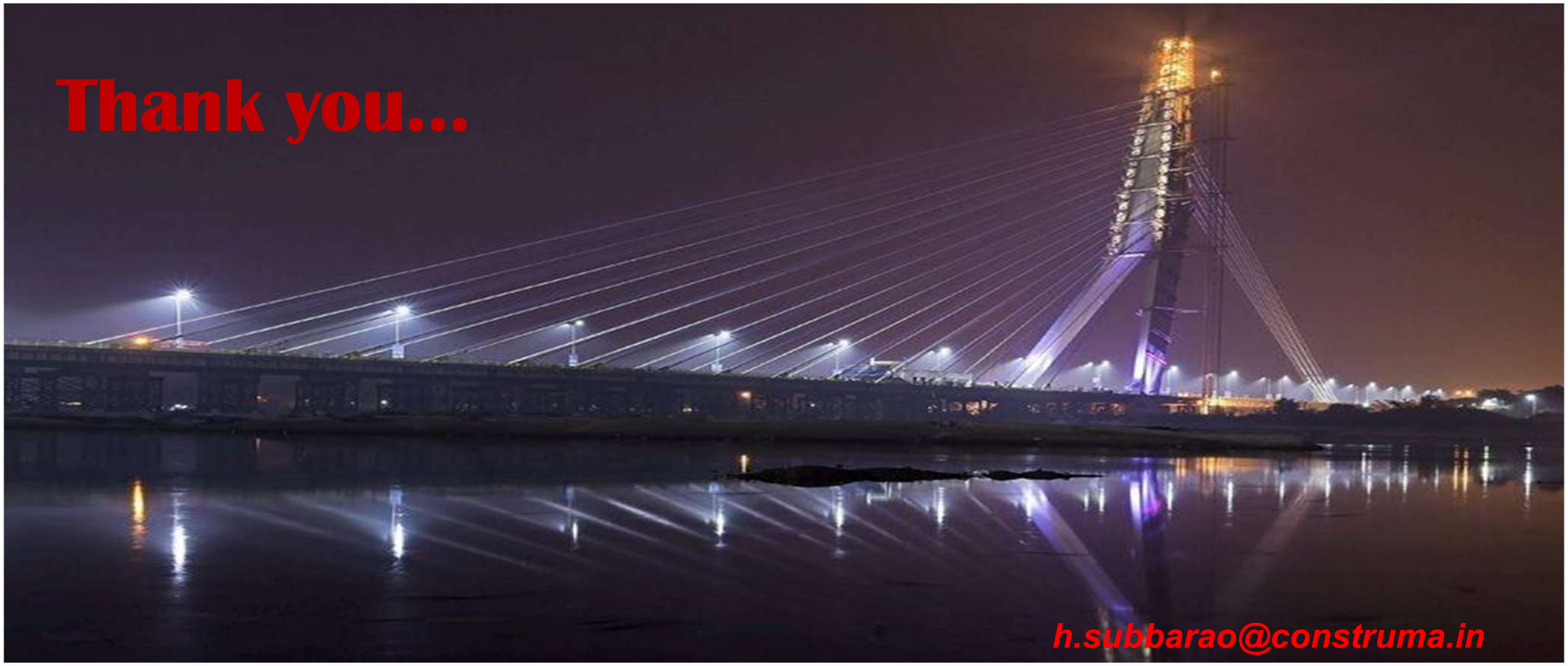

"Intelligently select materials of construction and the method of construction without any prejudice in order to reduce the Carbon Footprint of the structure.
Circularity- Repair, Repurpose, Recycle, Reuse to the maximum extent to reduce GHG effects."

Thank You for Listening and for your invaluable time