CIDB MALAYSIA

EMBODIED CARBON INVENTORY DATA FOR CONSTRUCTION MATERIALS

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All enquiries regarding this book should be forwarded to:

Construction Industry Development Board Malaysia (CIDB)
10th Floor, Menara Dato' Onn,
World Trade Centre,
No.45, Jalan Tun Ismail,
50480 Kuala Lumpur,
Malaysia

Tel: 603 4047 7000
Fax: 603 4047 7070
Email: standard@cidb.gov.my
Website: www.cidb.gov.my

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EXECUTIVE SUMMARY

Reducing embodied carbon in buildings is critical to achieving low carbon construction targets. Yet, the awareness and knowledge towards embodied carbon and information on how to reduce embodied carbon is still an infant in the Malaysia construction sector. Therefore, the Construction Industry Development Board (CIDB) Malaysia takes the responsibility to support the government to fulfil the need of construction sector in Malaysia. CIDB takes a step ahead to conduct the research on construction embodied emissions, with its research arm, the Construction Research Institute of Malaysia (CREAM) to develop the construction embodied emissions inventory data. This inventory data will assist the government and also construction stakeholders to achieve national and global goals in putting the action towards mitigating emissions and consequently combating climate change.

This report provides information on 500 embodied carbon data for various construction materials and building elements. The information on material cost has also been included to enable the construction stakeholders such as designers, architects, and contractors to compare the environment and cost solution.

This report also intends to show how the embodied carbon of the construction materials can be accounted for and included in an assessment by providing the assessment of embodied carbon. This report intends to elevate consciousness of the climate and biodiversity crises, and the pressing need for the construction sector to act immediately and shift to low-carbon construction.

Embodied Carbon Assessment

Introduction

This report is developed in line with embodied carbon inventory data. This inventory contains a summary of approximately 500 records of embodied carbon for construction materials and building elements. The compilation of the embodied carbon data has been done by providing various alternatives for each type of construction material and building element.

The inventory data consists of relevant information as mentioned below:

i. Classification	The inventory data are divided into two (2) classification: construction materials and building elements. Construction and building materials including raw materials that have been used in constructions, while building elements involve the main components of building structures.
ii. Types	Various types of construction materials and building elements have been categorised according to the same category. This will provide alternatives to stakeholders to compare and select the data values based on the impact on the environment and cost.
iii. Market Price	The current market price for each construction material (Data is current at time of publication)
iv. Embodied Carbon Indicator	The inventory data consists of indicators towards the scales of embodied carbon values. The range of embodied carbon in the scale is referred from the UK- Inventory of Carbon & Energy ICE database. The Inventory of Carbon & Energy (ICE) has developed a database of the embodied carbon of building materials per kilogram, which can be used to see the relative emissions associated with materials compared to one another.

v. Embodied Carbon Factor	Embodied carbon factor is usually expressed in kilograms of CO_2e per kilogram of product or material. The embodied carbon factor also known as embodied carbon coefficient. The embodied carbon factor (kg of CO_2e per kg) is calculated by multiplying the quantity of each material (kg).
vi. Unit	The functional unit for embodied carbon factor is kg of CO_2e per kg.
vii. Boundary:	The embodied carbon factor published here is based on the cradle-to-gate. The cradle to the gate will include the extraction and production of materials and production.
viii. Source of Embodied Carbon	The embodied carbon factors data are collated based on combination of local and international sources, including MyLCID SIRIM, environmental product declaration (EPD), Inventory of Carbon and Energy (ICE v3.0), Integrated Carbon Metrics Embodied Carbon Life Cycle Inventory Database (ICM), Building for Environmental and Cost Sustainability (BEES), Building Research Establishment (BRE) and other published resources.
ix. Description:	Detailed information on the application, properties and performance of construction materials and building elements.

Table 1.1: Range of embodied carbon indicator for construction materials.

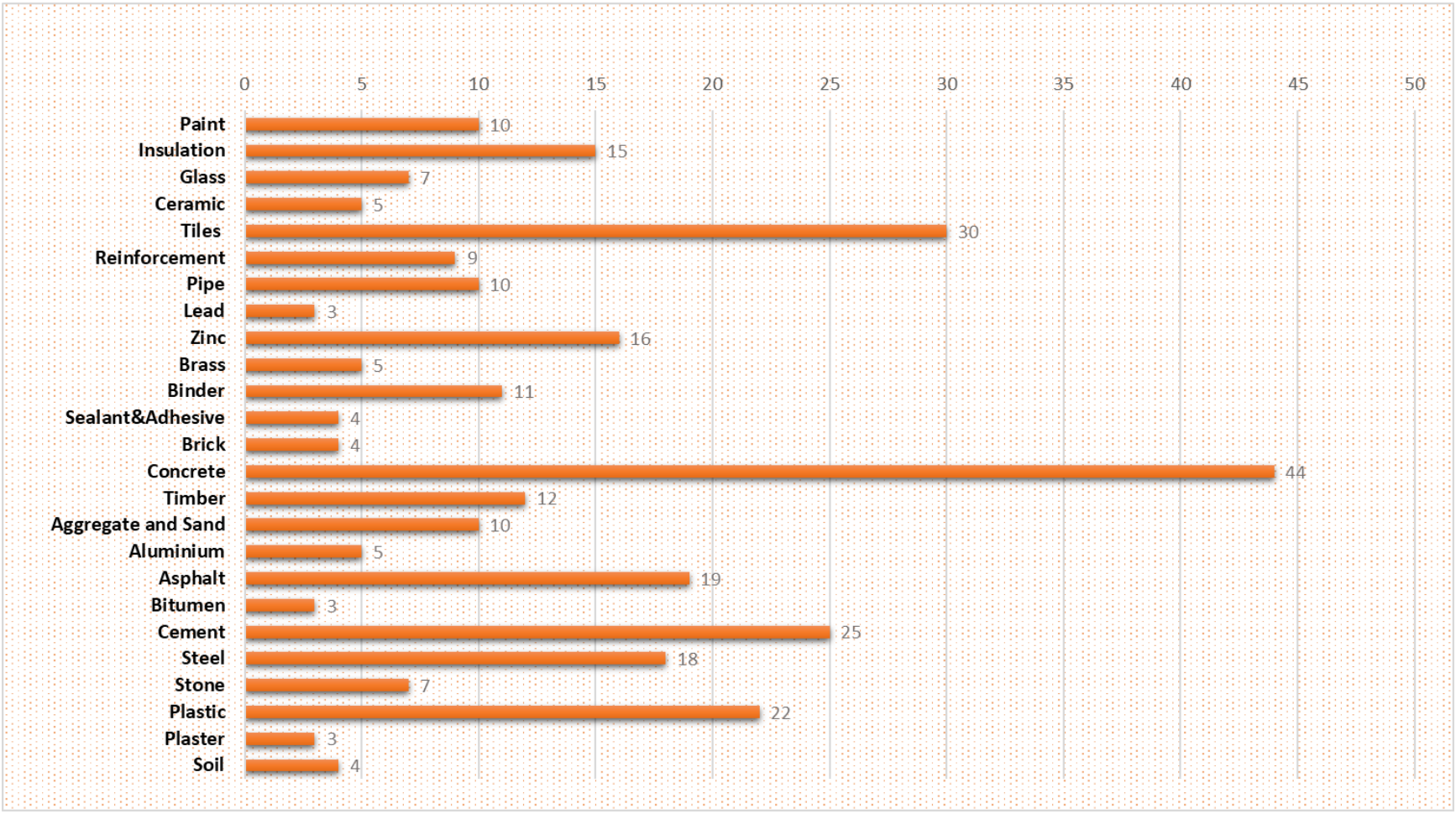
Embodied carbon scales range (kg CO_2e/kg)	Colour	Description	Colour coding
0 – 0.5	Dark green	Very low	
0.5 – 2.0	Light green	Low	
2.0 – 2.8	Yellow	Medium	
2.8 – 5.0	Orange	High	
>5.0	Red	Very high	

Table 1.2: Range of embodied carbon indicator for building elements.

Embodied carbon scales range (kg CO_2e/m^2)	Colour	Description	Colour coding
≤ 10	Dark green	Very low	
11 - 100	Light green	Low	
101- 250	Yellow	Medium	
251-350	Orange	High	
>350	Red	Very high	

CONSTRUCTION MATERIALS

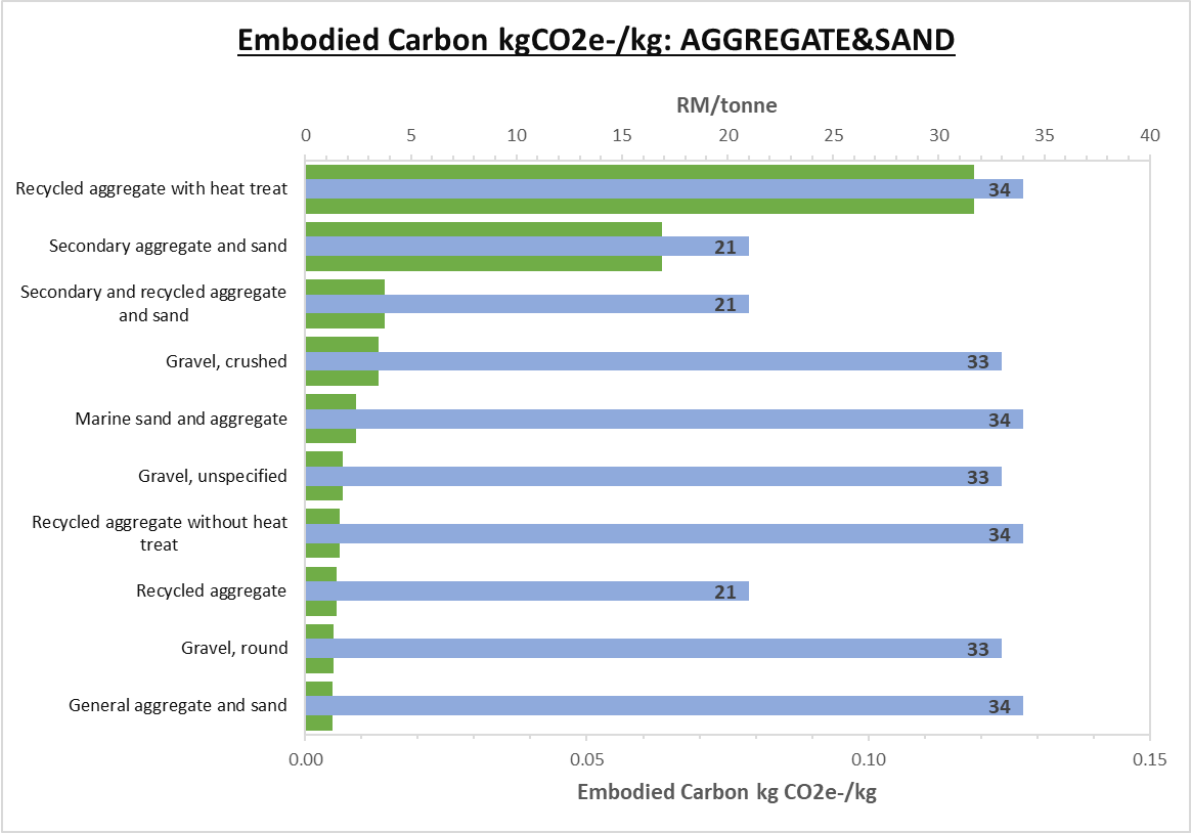
Construction and building materials compiled in the embodied carbon inventory data



Aggregate & Sand

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
General aggregate and sand*	RM 34 / tonne	0.0049	$kgCO_2e/kg$
Marine sand and aggregate	RM 34 / tonne	0.01	$kgCO_2e/kg$
Recycled aggregate without heat treat	RM 34 / tonne	0.01	$kgCO_2e/kg$
Recycled aggregate with heat treat	RM 34 / tonne	0.12	$kgCO_2e/kg$
Secondary aggregate and sand	RM 21 / tonne	0.06	$kgCO_2e/kg$
Secondary and recycled aggregate and sand	RM 21 / tonne	0.01	$kgCO_2e/kg$
Gravel, crushed	RM 33 / tonne	0.01	$kgCO_2e/kg$
Gravel, unspecified	RM 33 / tonne	0.01	$kgCO_2e/kg$
Gravel, round	RM 33 / tonne	0.01	$kgCO_2e/kg$
Recycled aggregate	RM 21 / tonne	0.01	$kgCO_2e/kg$

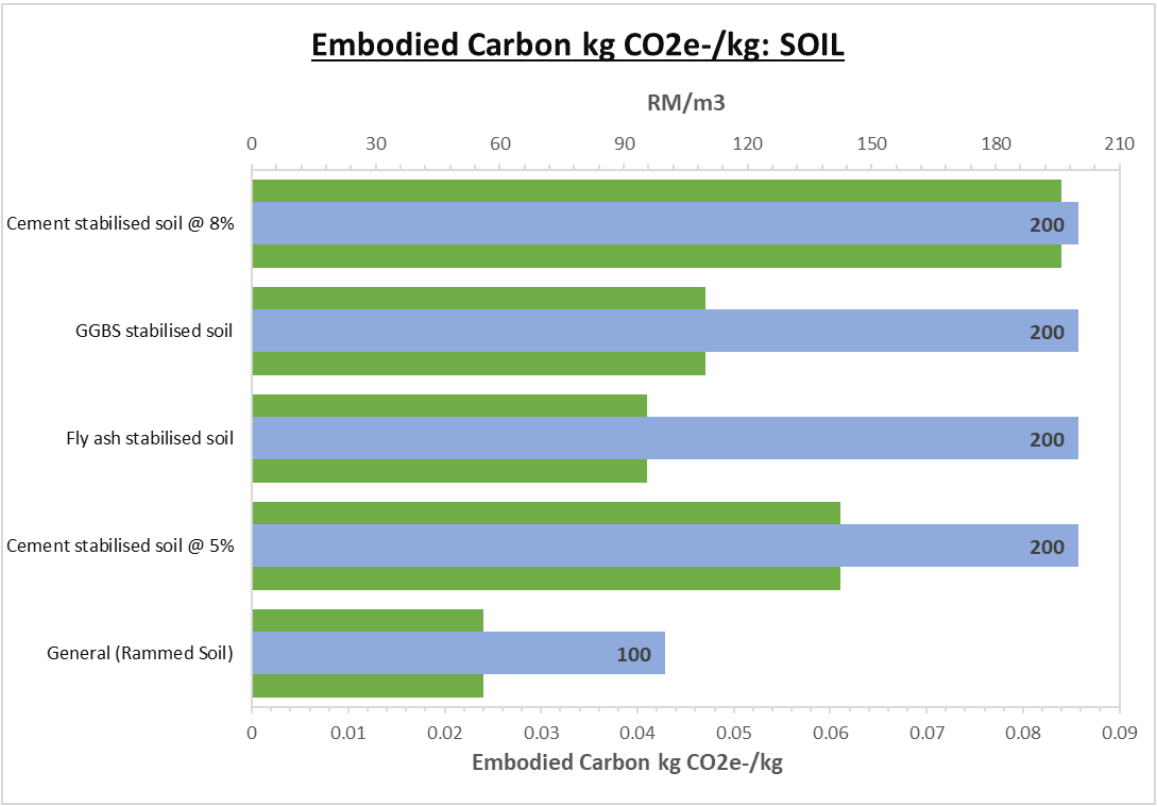
*Commonly used/ traditional material



Soil

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
General (Rammed Soil)*	RM 50 - 100 / m3	0.02	$kgCO_2e/kg$
Cement stabilised soil @ 5%	RM 120 - 200 / m3	0.06	$kgCO_2e/kg$
Cement stabilised soil @ 8%	RM 120 - 200 / m3	0.08	$kgCO_2e/kg$
GGBS stabilised soil	RM 120 - 200 / m3	0.05	$kgCO_2e/kg$
Fly ash stabilised soil	RM 120 - 200 / m3	0.04	$kgCO_2e/kg$

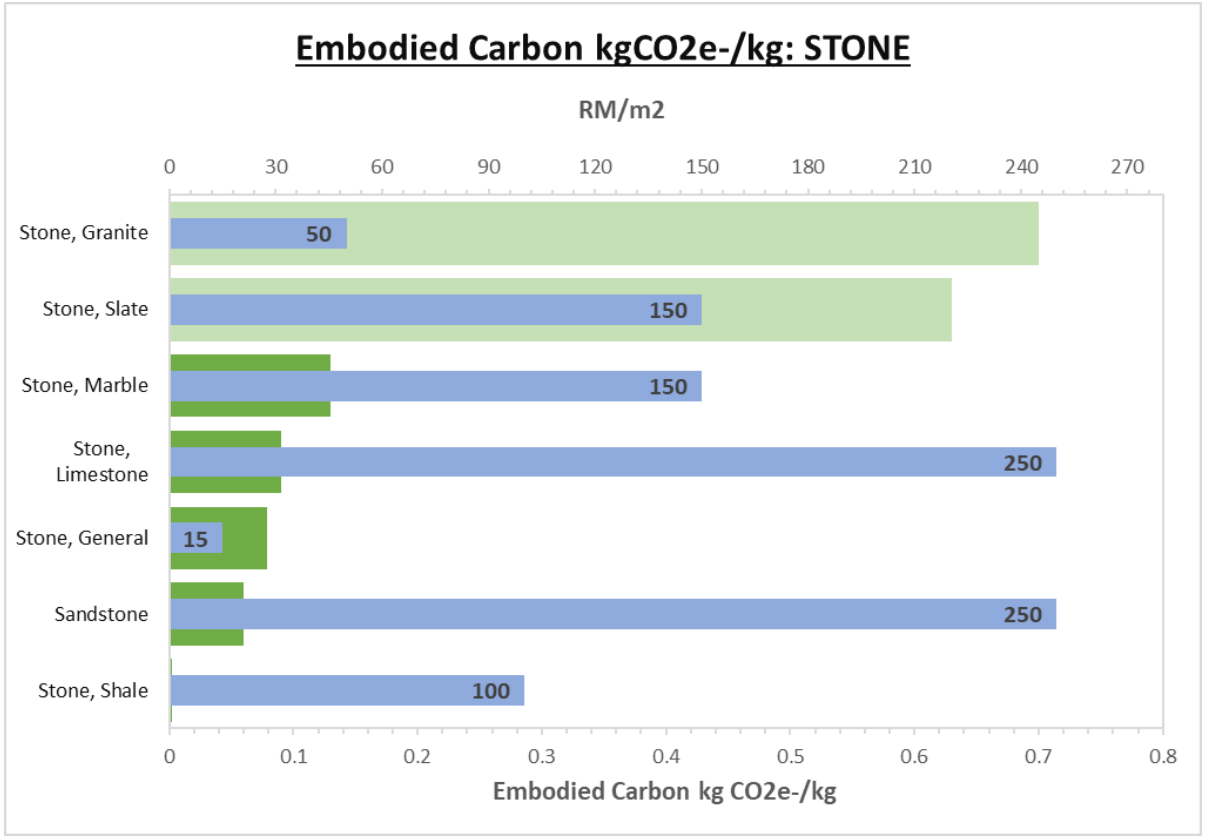
*Commonly used/ traditional material



Stone

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Stone, Shale	RM 100 - 150 / m2	0.002	$kgCO_2e/kg$
Sandstone	RM 100 - 150 / m2	0.06	$kgCO_2e/kg$
Stone, General*	RM 50 - 100 / m2	0.08	$kgCO_2e/kg$
Stone, Limestone	RM 5 - 15 / m2	0.09	$kgCO_2e/kg$
Stone, Marble	RM 150 - 250 / m2	0.13	$kgCO_2e/kg$
Stone, Slate	RM 50 / m2	0.63	$kgCO_2e/kg$
Stone, Granite	RM 150 - 250 / m2	0.70	$kgCO_2e/kg$

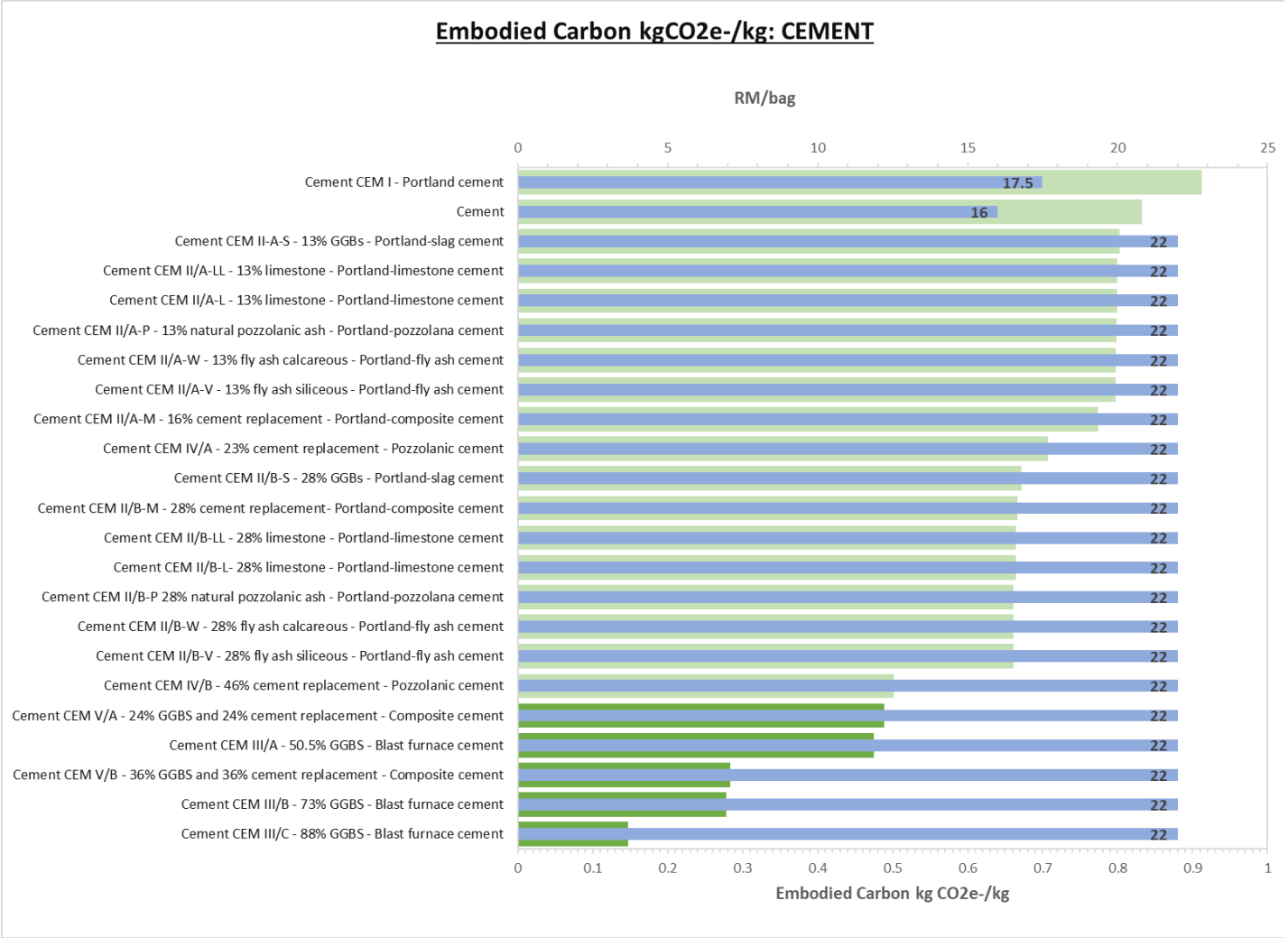
*Commonly used/ traditional material



Cement

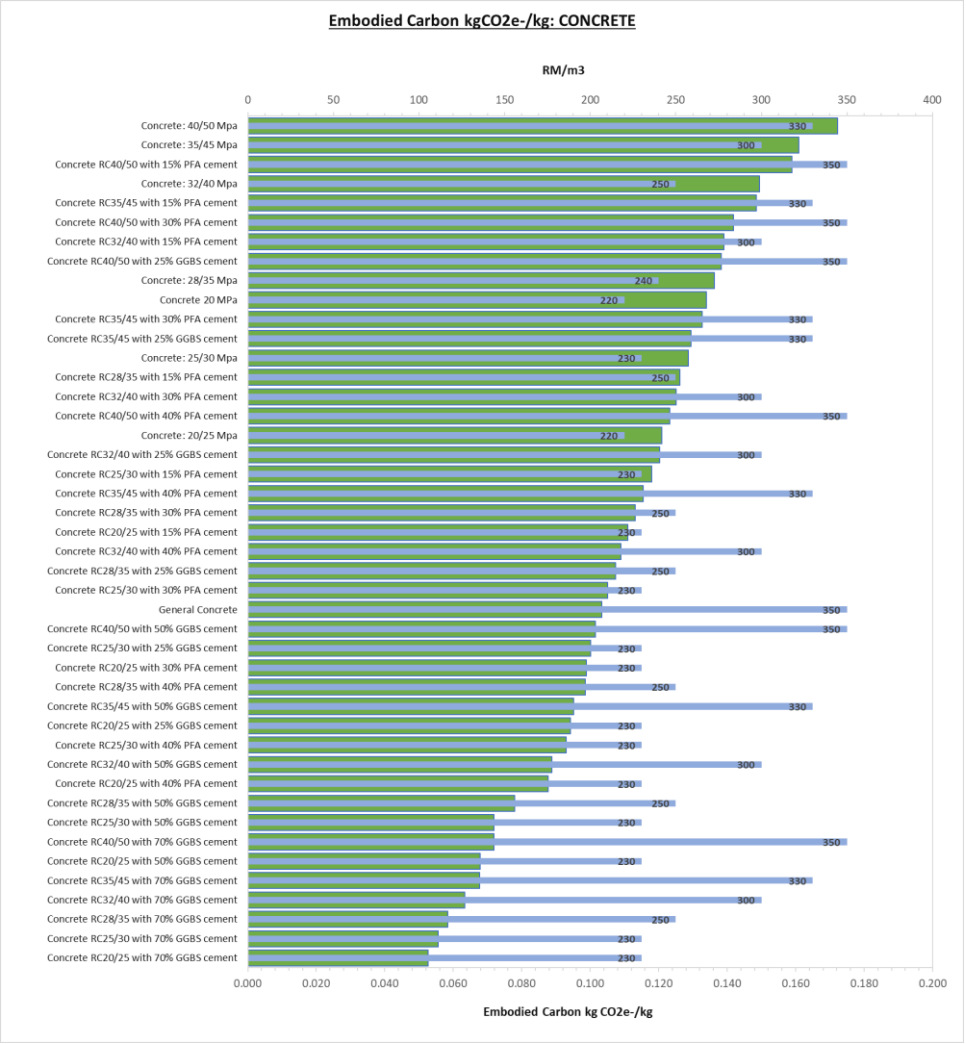
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Cement CEM III/C - 88% GGBS - Blast furnace cement	RM 17.5 - 22 / bag	0.15	$kgCO_2e/kg$
Cement CEM III/B - 73% GGBS - Blast furnace cement	RM 17.5 - 22 / bag	0.28	$kgCO_2e/kg$
Cement CEM V/B - 36% GGBS and 36% cement replacement - Composite cement	RM 17.5 - 22 / bag	0.28	$kgCO_2e/kg$
Cement CEM III/A - 50.5% GGBS - Blast furnace cement	RM 17.5 - 22 / bag	0.47	$kgCO_2e/kg$
Cement CEM V/A - 24% GGBS and 24% cement replacement - Composite cement	RM 17.5 - 22 / bag	0.49	$kgCO_2e/kg$
Cement CEM IV/B - 46% cement replacement - Pozzolanic cement	RM 17.5 - 22 / bag	0.50	$kgCO_2e/kg$
Cement CEM II/B-V - 28% fly ash siliceous - Portland-fly ash cement	RM 17.5 - 22 / bag	0.66	$kgCO_2e/kg$
Cement CEM II/B-W - 28% fly ash calcareous - Portland-fly ash cement	RM 17.5 - 22 / bag	0.66	$kgCO_2e/kg$
Cement CEM II/B-P 28% natural pozzolanic ash - Portland-pozzolana cement	RM 17.5 - 22 / bag	0.66	$kgCO_2e/kg$
Cement CEM II/B-L- 28% limestone - Portland-limestone cement	RM 17.5 - 22 / bag	0.66	$kgCO_2e/kg$
Cement CEM II/B-LL - 28% limestone - Portland-limestone cement	RM 17.5 - 22 / bag	0.66	$kgCO_2e/kg$
Cement CEM II/B-M - 28% cement replacement- Portland-composite cement	RM 17.5 - 22 / bag	0.67	$kgCO_2e/kg$
Cement CEM II/B-S - 28% GGBs - Portland-slag cement	RM 17.5 - 22 / bag	0.67	$kgCO_2e/kg$
Cement CEM IV/A - 23% cement replacement - Pozzolanic cement	RM 17.5 - 22 / bag	0.71	$kgCO_2e/kg$
Cement CEM II/A-M - 16% cement replacement - Portland-composite cement	RM 17.5 - 22 / bag	0.77	$kgCO_2e/kg$
Cement CEM II/A-V - 13% fly ash siliceous - Portland-fly ash cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement CEM II/A-W - 13% fly ash calcareous - Portland-fly ash cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement CEM II/A-P - 13% natural pozzolanic ash - Portland-pozzolana cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement CEM II/A-L - 13% limestone - Portland-limestone cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement CEM II/A-LL - 13% limestone - Portland-limestone cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement CEM II-A-S - 13% GGBs - Portland-slag cement	RM 17.5 - 22 / bag	0.80	$kgCO_2e/kg$
Cement*	RM 16 / bag	0.83	$kgCO_2e/kg$
Cement CEM I - Portland cement	RM 17.5 / bag	0.91	$kgCO_2e/kg$

*Commonly used/ traditional material



Concrete

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
General Concrete*	RM 220-350 / m3	0.10	$kgCO_2e/kg$
Concrete 20 MPa	RM 220 per m3	0.13	$kgCO_2e/kg$
Concrete: 20/25 Mpa	RM 220 per m3	0.12	$kgCO_2e/kg$
Concrete: 25/30 Mpa	RM 230 per m3	0.13	$kgCO_2e/kg$
Concrete: 28/35 Mpa	RM 240 per m3	0.14	$kgCO_2e/kg$
Concrete: 32/40 Mpa	RM 250 per m3	0.15	$kgCO_2e/kg$
Concrete: 35/45 Mpa	RM 300 per m3	0.16	$kgCO_2e/kg$
Concrete: 40/50 Mpa	RM 330 per m3	0.17	$kgCO_2e/kg$
Concrete RC20/25 with 15% PFA cement	RM 230 per m3	0.11	$kgCO_2e/kg$
Concrete RC25/30 with 15% PFA cement	RM 230 per m3	0.12	$kgCO_2e/kg$
Concrete RC28/35 with 15% PFA cement	RM 250 per m3	0.13	$kgCO_2e/kg$
Concrete RC32/40 with 15% PFA cement	RM 300 per m3	0.14	$kgCO_2e/kg$
Concrete RC35/45 with 15% PFA cement	RM 330 per m3	0.15	$kgCO_2e/kg$
Concrete RC40/50 with 15% PFA cement	RM 350 per m3	0.16	$kgCO_2e/kg$
Concrete RC20/25 with 30% PFA cement	RM 230 per m3	0.10	$kgCO_2e/kg$
Concrete RC25/30 with 30% PFA cement	RM 230 per m3	0.11	$kgCO_2e/kg$
Concrete RC28/35 with 30% PFA cement	RM 250 per m3	0.11	$kgCO_2e/kg$
Concrete RC32/40 with 30% PFA cement	RM 300 per m3	0.13	$kgCO_2e/kg$
Concrete RC35/45 with 30% PFA cement	RM 330 per m3	0.13	$kgCO_2e/kg$
Concrete RC40/50 with 30% PFA cement	RM 350 per m3	0.14	$kgCO_2e/kg$
Concrete RC20/25 with 40% PFA cement	RM 230 per m3	0.09	$kgCO_2e/kg$
Concrete RC25/30 with 40% PFA cement	RM 230 per m3	0.09	$kgCO_2e/kg$
Concrete RC28/35 with 40% PFA cement	RM 250 per m3	0.10	$kgCO_2e/kg$
Concrete RC32/40 with 40% PFA cement	RM 300 per m3	0.11	$kgCO_2e/kg$
Concrete RC35/45 with 40% PFA cement	RM 330 per m3	0.12	$kgCO_2e/kg$
Concrete RC40/50 with 40% PFA cement	RM 350 per m3	0.12	$kgCO_2e/kg$
Concrete RC20/25 with 25% GGBS cement	RM 230 per m3	0.09	$kgCO_2e/kg$
Concrete RC25/30 with 25% GGBS cement	RM 230 per m3	0.10	$kgCO_2e/kg$
Concrete RC28/35 with 25% GGBS cement	RM 250 per m3	0.11	$kgCO_2e/kg$
Concrete RC32/40 with 25% GGBS cement	RM 300 per m3	0.12	$kgCO_2e/kg$
Concrete RC35/45 with 25% GGBS cement	RM 330 per m3	0.13	$kgCO_2e/kg$
Concrete RC40/50 with 25% GGBS cement	RM 350 per m3	0.14	$kgCO_2e/kg$
Concrete RC20/25 with 50% GGBS cement	RM 230 per m3	0.07	$kgCO_2e/kg$
Concrete RC25/30 with 50% GGBS cement	RM 230 per m3	0.07	$kgCO_2e/kg$
Concrete RC28/35 with 50% GGBS cement	RM 250 per m3	0.08	$kgCO_2e/kg$
Concrete RC32/40 with 50% GGBS cement	RM 300 per m3	0.09	$kgCO_2e/kg$
Concrete RC35/45 with 50% GGBS cement	RM 330 per m3	0.10	$kgCO_2e/kg$
Concrete RC40/50 with 50% GGBS cement	RM 350 per m3	0.10	$kgCO_2e/kg$
Concrete RC20/25 with 70% GGBS cement	RM 230 per m3	0.05	$kgCO_2e/kg$
Concrete RC25/30 with 70% GGBS cement	RM 230 per m3	0.06	$kgCO_2e/kg$
Concrete RC28/35 with 70% GGBS cement	RM 250 per m3	0.06	$kgCO_2e/kg$
Concrete RC32/40 with 70% GGBS cement	RM 300 per m3	0.06	$kgCO_2e/kg$
Concrete RC35/45 with 70% GGBS cement	RM 330 per m3	0.07	$kgCO_2e/kg$
Concrete RC40/50 with 70% GGBS cement	RM 350 per m3	0.07	$kgCO_2e/kg$

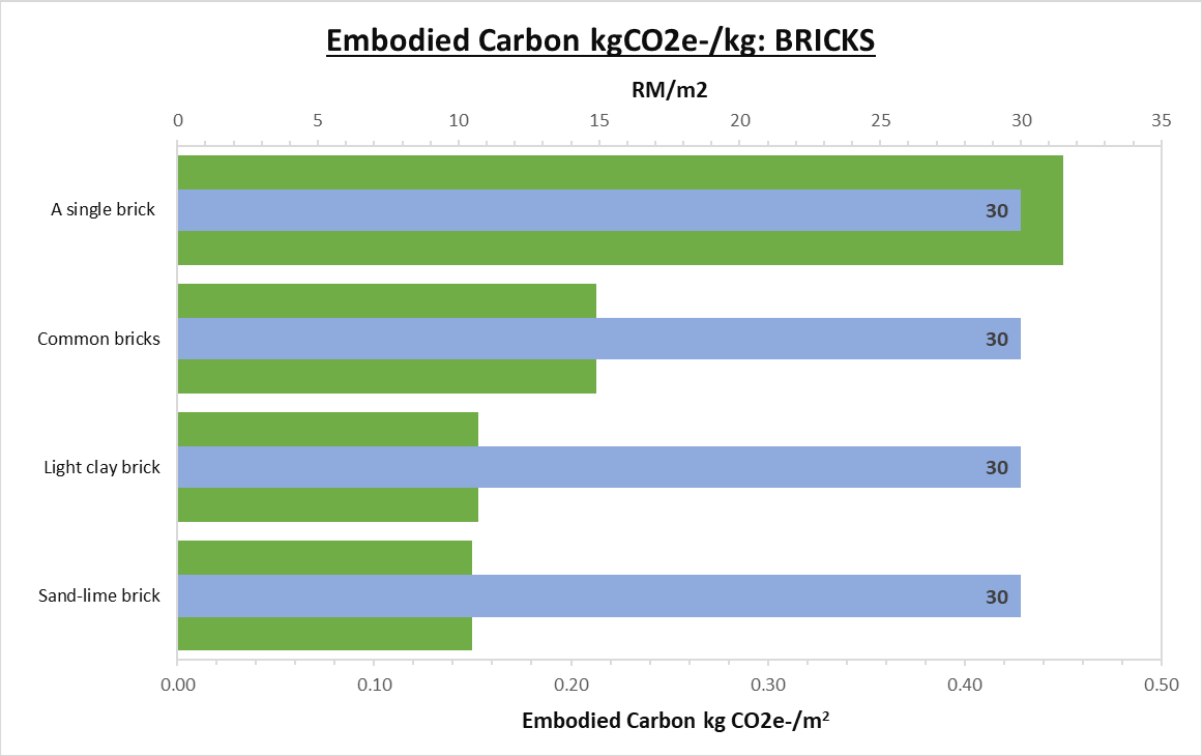


*Commonly used/ traditional material

Bricks

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Common bricks*	RM 25 - 30 / m2	0.21	$kgCO_2e/kg$
A single brick	RM 25 - 30 / m2	0.45	$kgCO_2e/kg$
Sand-lime brick	RM 30 / m2	0.15	$kgCO_2e/kg$
Light clay brick	RM 25 - 30 / m2	0.15	$kgCO_2e/kg$

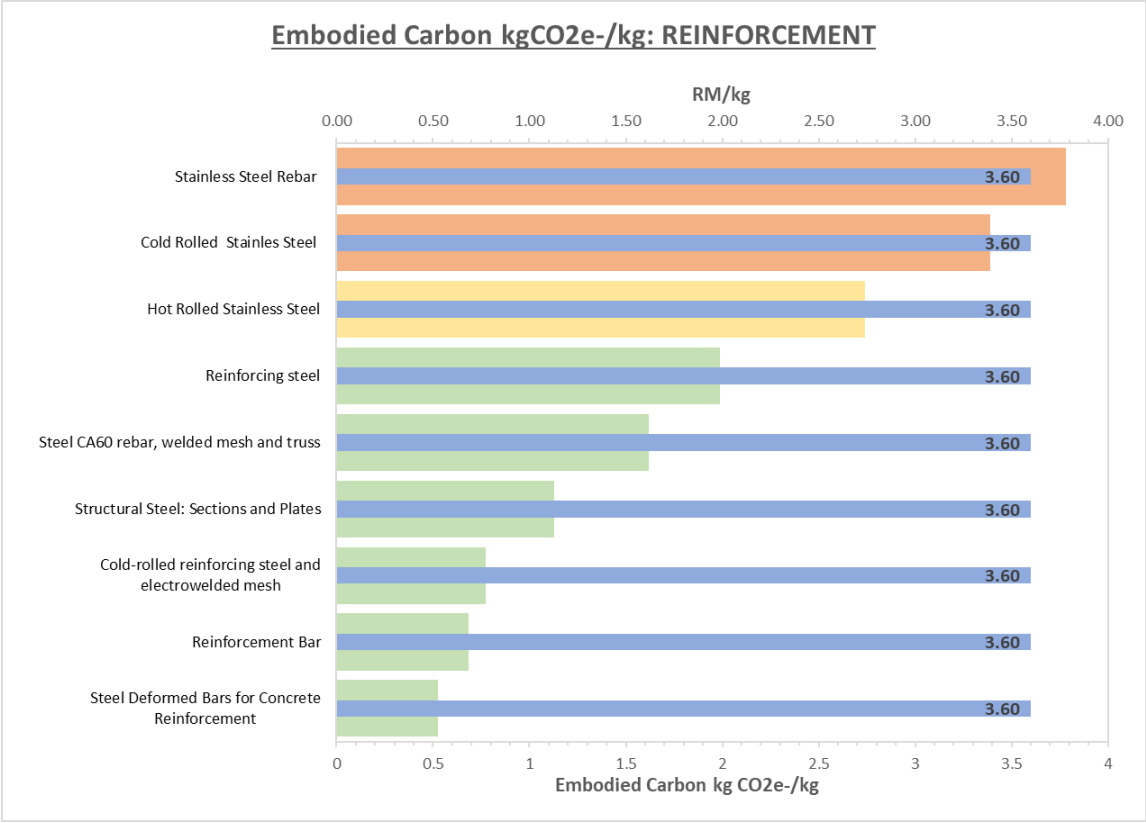
*Commonly used/ traditional material



Reinforcement

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Reinforcing Bar*	RM 3.60 / kg	0.68	$kgCO_2e/kg$
Steel Deformed Bars for Concrete Reinforcement	RM 3.60 / kg	0.53	$kgCO_2e/kg$
Cold-rolled reinforcing steel and electrowelded mesh	RM 3.60 / kg	0.77	$kgCO_2e/kg$
Structural Steel: Sections and Plates	RM 3.60 / kg	1.13	$kgCO_2e/kg$
Steel CA60 rebar, welded mesh and truss	RM 3.60 / kg	1.62	$kgCO_2e/kg$
Reinforcing steel*	RM 3.60 / kg	1.99	$kgCO_2e/kg$
Hot Rolled Stainless Steel	RM 3.60 / kg	2.74	$kgCO_2e/kg$
Cold Rolled Stainles Steel	RM 3.60 / kg	3.39	$kgCO_2e/kg$
Stainless Steel Rebar *	RM 3.60 / kg	3.78	$kgCO_2e/kg$

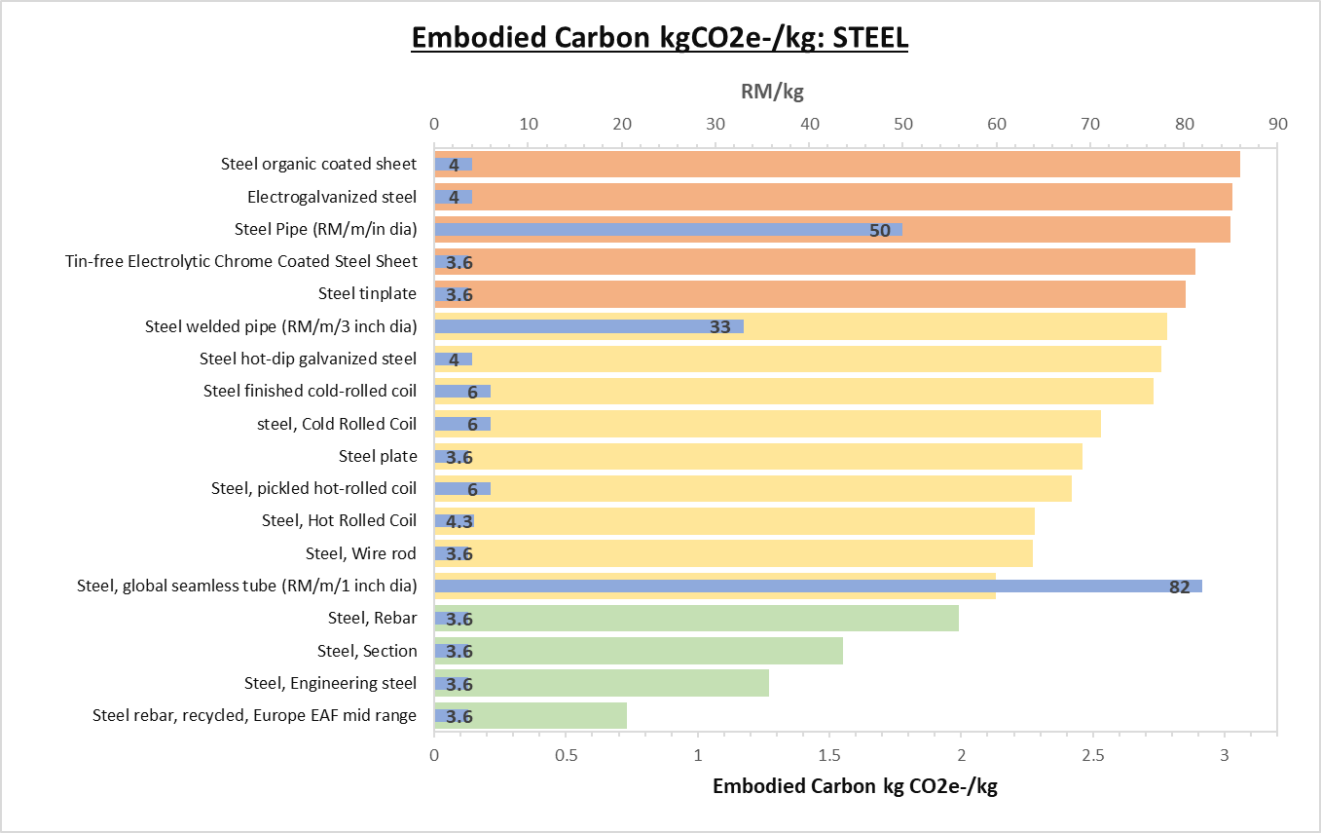
*Commonly used/ traditional material



Steel

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Steel rebar, recycled, Europe EAF mid range	RM 3.60 / kg	0.73	$kgCO_2e/kg$
Steel, Engineering steel	RM 3.60 / kg	1.27	$kgCO_2e/kg$
Steel, Section	RM 3.60 / kg	1.55	$kgCO_2e/kg$
Steel, Rebar*	RM 3.60 / kg	1.99	$kgCO_2e/kg$
Steel, global seamless tube	RM 82 / m / 1 inch dia	2.13	$kgCO_2e/kg$
Steel, Wire rod	RM 3.60 / kg	2.27	$kgCO_2e/kg$
Steel, Hot Rolled Coil	RM 4.3 / kg	2.28	$kgCO_2e/kg$
Steel, pickled hot-rolled coil	RM 6 / kg	2.42	$kgCO_2e/kg$
Steel plate	RM 3.60 / kg	2.46	$kgCO_2e/kg$
steel, Cold Rolled Coil	RM 6/ kg	2.53	$kgCO_2e/kg$
Steel finished cold-rolled coil	RM 6/ kg	2.73	$kgCO_2e/kg$
Steel hot-dip galvanized steel	RM 4 / kg	2.76	$kgCO_2e/kg$
Steel welded pipe	RM 33 / m / 3 inch dia	2.78	$kgCO_2e/kg$
Steel tinplate	RM 3.60 / kg	2.85	$kgCO_2e/kg$
Tin-free Electrolytic Chrome Coated Steel Sheet	RM 3.60 / kg	2.89	$kgCO_2e/kg$
Steel Pipe*	RM 25 - 50 / m / 2 inch	3.02	$kgCO_2e/kg$
Electrogalvanized steel	RM 2-4 / kg	3.03	$kgCO_2e/kg$
Steel organic coated sheet	RM 2-4 / kg	3.06	$kgCO_2e/kg$

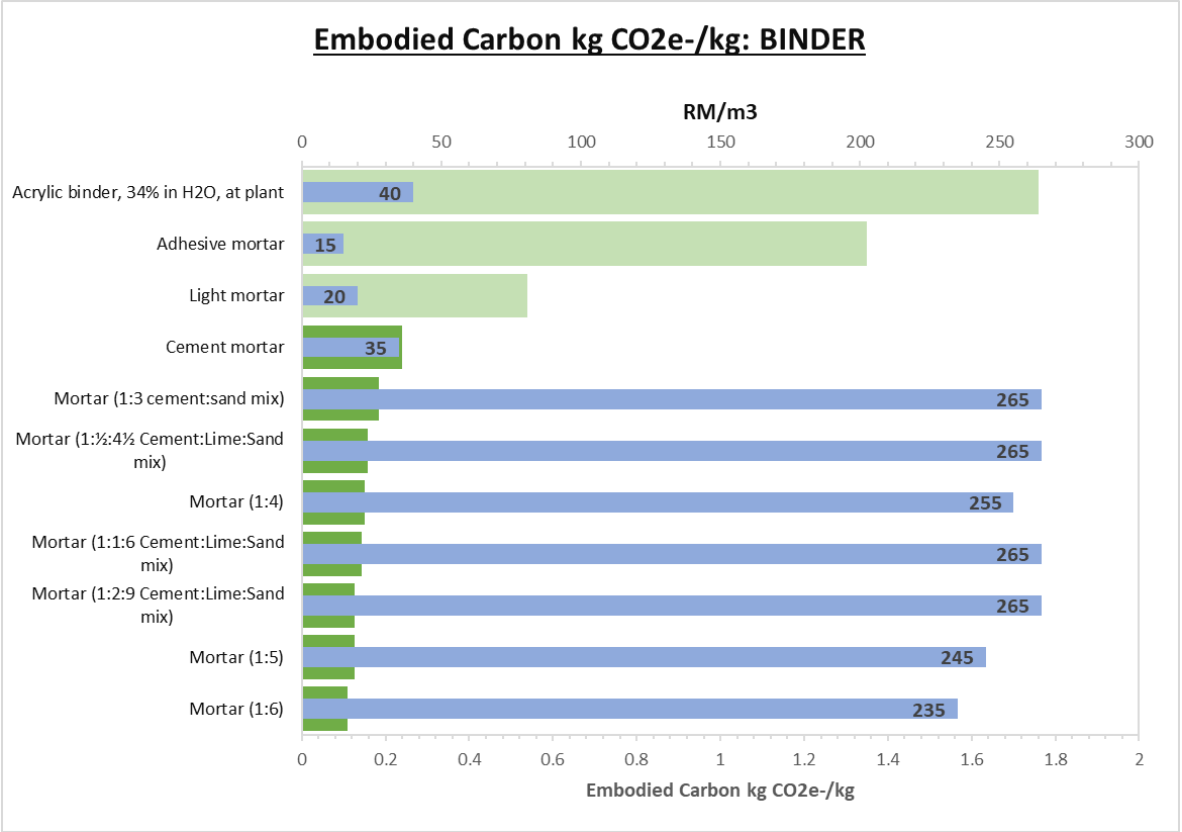
*Commonly used/ traditional material



Binder

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Mortar (1:6)	RM 235 / m3	0.11	$kgCO_2e/kg$
Mortar (1:5)	RM 245 / m3	0.13	$kgCO_2e/kg$
Mortar (1:2:9 Cement:Lime:Sand mix)	RM 265 / m3	0.13	$kgCO_2e/kg$
Mortar (1:1:6 Cement:Lime:Sand mix)	RM 265 / m3	0.14	$kgCO_2e/kg$
Mortar (1:4)	RM 255 / m3	0.15	$kgCO_2e/kg$
Mortar (1:½:4½ Cement:Lime:Sand mix)	RM 265 / m3	0.16	$kgCO_2e/kg$
Mortar (1:3 cement:sand mix)	RM 265 / m3	0.18	$kgCO_2e/kg$
Cement mortar*	RM 35 / m3	0.24	$kgCO_2e/kg$
Light mortar	RM 20 / m3	0.54	$kgCO_2e/kg$
Adhesive mortar	RM 15 / m3	1.35	$kgCO_2e/kg$
Acrylic binder, 34% in H2O, at plant	RM 40 / m3	1.76	$kgCO_2e/kg$

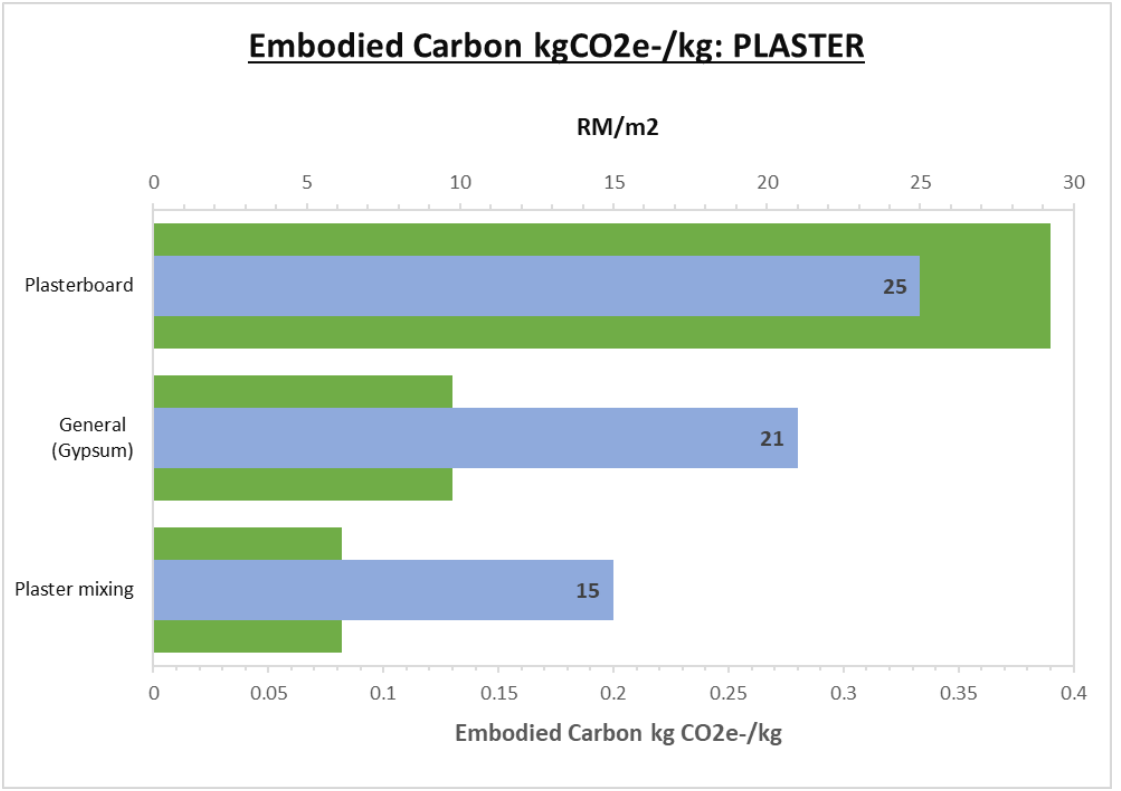
*Commonly used/ traditional material



Plaster

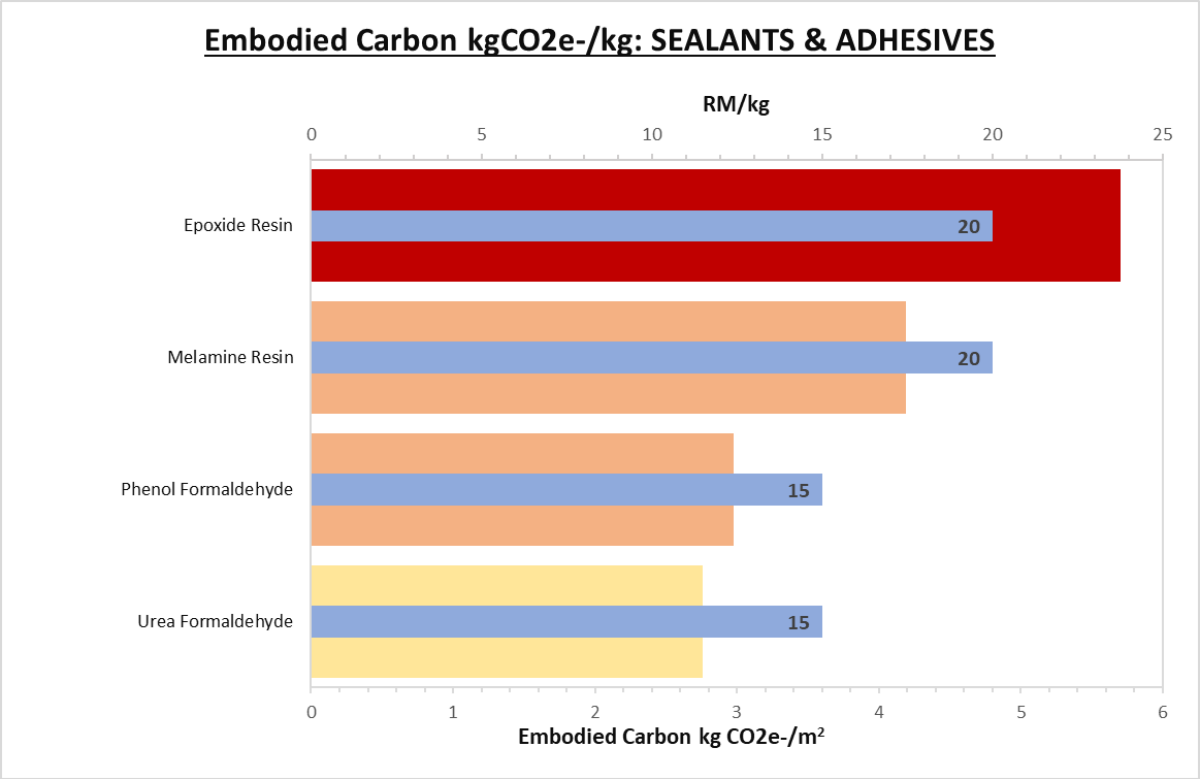
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
General (Gypsum)*	RM 21 / m2	0.13	$kgCO_2e/kg$
Plasterboard	RM 20 - 25 / m2	0.39	$kgCO_2e/kg$
Plaster mixing	RM 10 - 15 / m2	0.08	$kgCO_2e/kg$

*Commonly used/ traditional material



Sealants and Adhesives

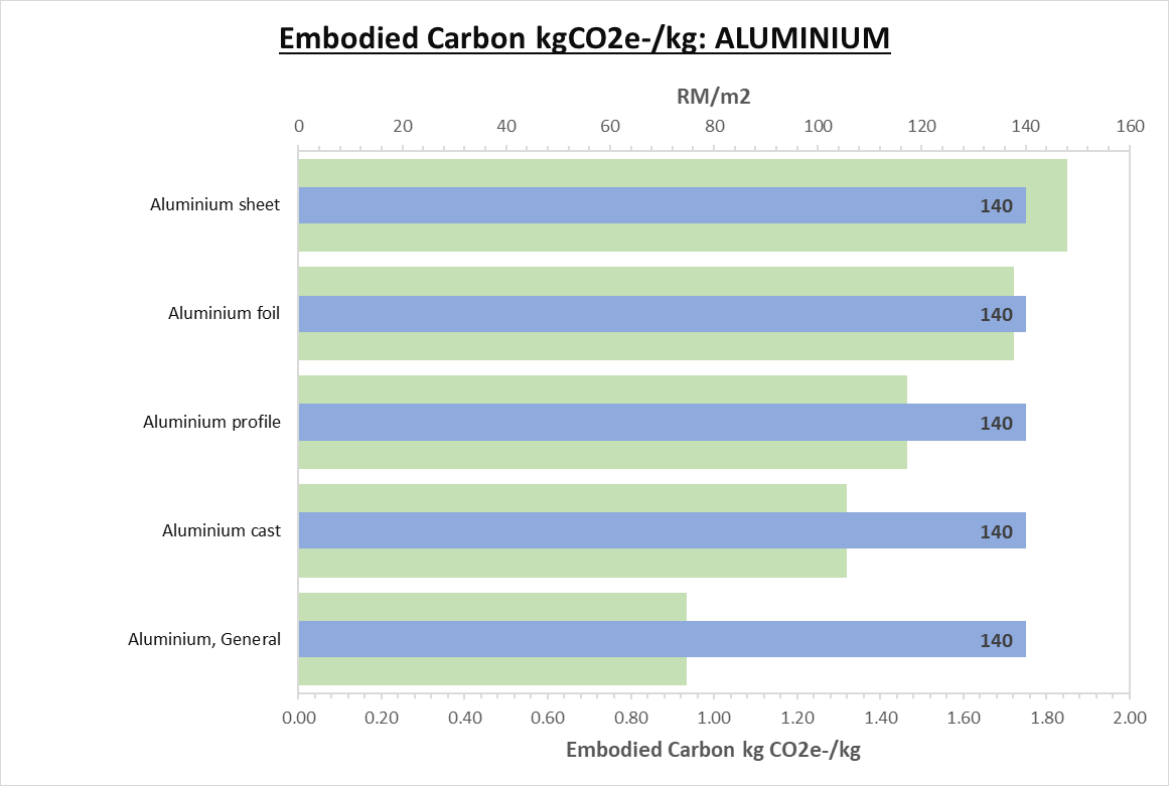
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Urea Formaldehyde	RM 15 / kg	2.76	$kgCO_2e/kg$
Phenol Formaldehyde	RM 15 / kg	2.98	$kgCO_2e/kg$
Melamine Resin	RM 20 / kg	4.19	$kgCO_2e/kg$
Epoxide Resin	RM 20 / kg	5.70	$kgCO_2e/kg$



Aluminium

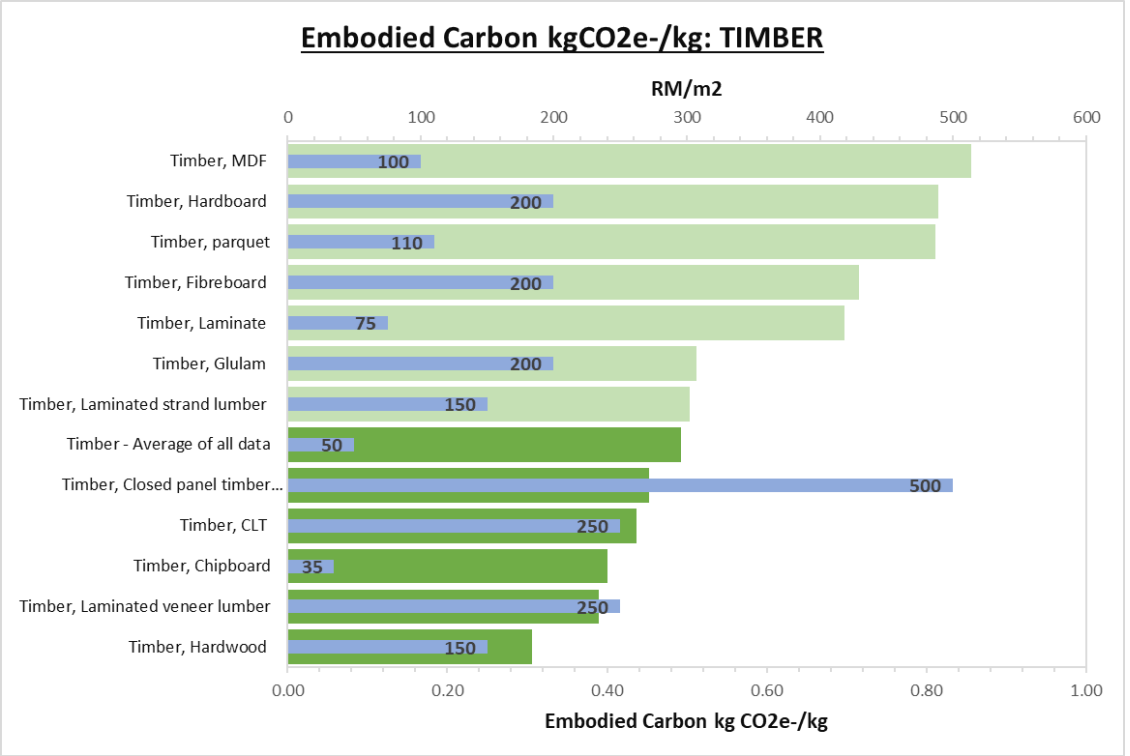
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Aluminium, General*	RM 120 - 140 / m2	0.93	$kgCO_2e/kg$
Aluminium profile	RM 120 - 140 / m2	1.46	$kgCO_2e/kg$
Aluminium cast	RM 120 - 140 / m2	1.32	$kgCO_2e/kg$
Aluminium sheet	RM 120 - 140 / m2	1.85	$kgCO_2e/kg$
Aluminium foil	RM 120 - 140 / m2	1.72	$kgCO_2e/kg$

*Commonly used/ traditional material



Timber

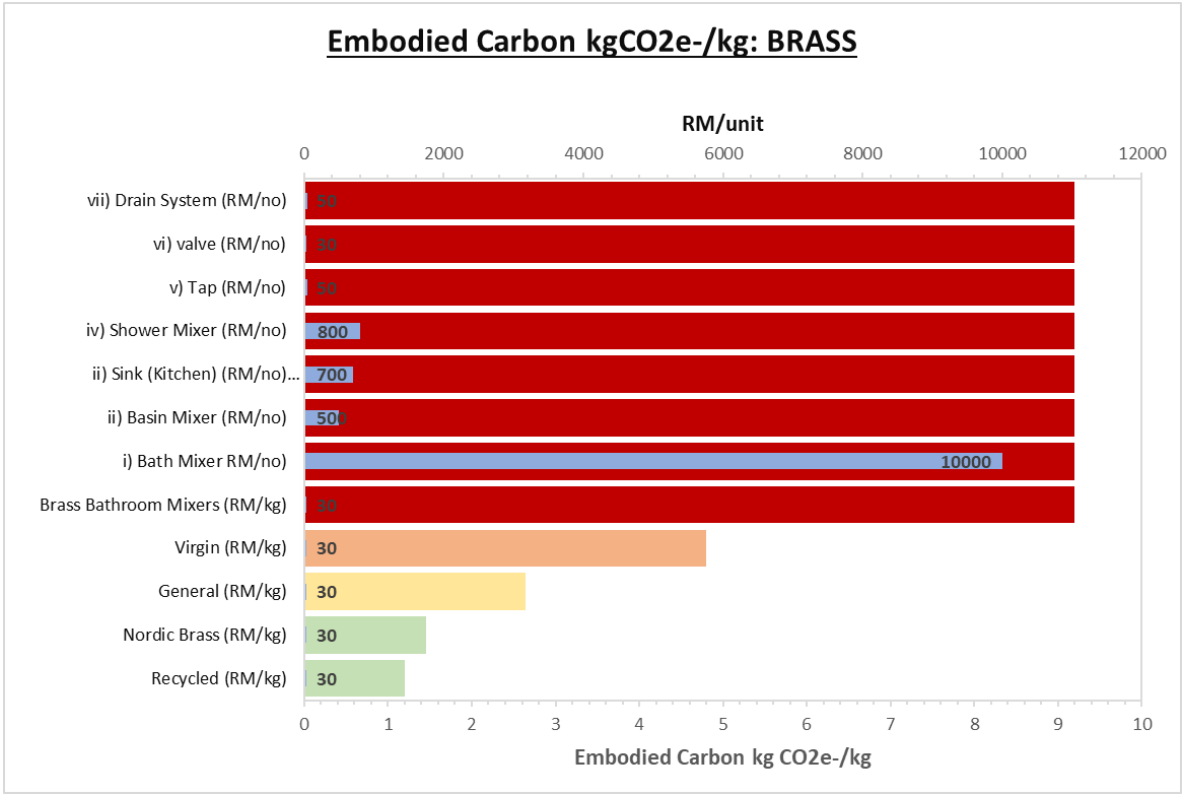
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Timber, Hardwood	RM 150 / m2	0.31	$kgCO_2e/kg$
Timber, Laminated veneer lumber	RM 100 - 250 / m2	0.39	$kgCO_2e/kg$
Timber, Chipboard	RM 35 / m2	0.40	$kgCO_2e/kg$
Timber, CLT	RM 200 - 250 / m2	0.44	$kgCO_2e/kg$
Timber, Closed panel timber frame system	RM 350 - 500 / m2	0.45	$kgCO_2e/kg$
Timber - Average of all data	RM 35 - 50 / m2	0.49	$kgCO_2e/kg$
Timber, Laminated strand lumber	RM 50 - 150 / m2	0.50	$kgCO_2e/kg$
Timber, Glulam	RM 200 / m2	0.51	$kgCO_2e/kg$
Timber, Laminate	RM 35 - 75 / m2	0.70	$kgCO_2e/kg$
Timber, Fibreboard	RM 200 / m2	0.72	$kgCO_2e/kg$
Timber, parquet	RM 80 - 110 / m2	0.81	$kgCO_2e/kg$
Timber, Hardboard	RM 200 / m2	0.82	$kgCO_2e/kg$
Timber, MDF	RM 45 - 100 / m2	0.86	$kgCO_2e/kg$



Brass

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Recycled	RM 20 - 30 / kg	1.20	$kgCO_2e/kg$
Nordic Brass	RM 20 - 30 / kg	1.46	$kgCO_2e/kg$
General*	RM 20 - 30 / kg	**2.64**	$kgCO_2e/kg$
Virgin	RM 20 - 30 / kg	**4.80**	$kgCO_2e/kg$
Brass Bathroom Mixers	RM 20 - 30 / kg	**9.20**	$kgCO_2e/kg$
i) Bath Mixer	RM 5000 - 10000 / no	**9.20**	$kgCO_2e/kg$
ii) Basin Mixer	RM RM 200 - 500 / no	**9.20**	$kgCO_2e/kg$
ii) Sink (Kitchen) Mixer	RM 500 - 700 / no	**9.20**	$kgCO_2e/kg$
iv) Shower Mixer	RM 500 - 800 / no	**9.20**	$kgCO_2e/kg$
v) Tap	RM 5 - 50 / no	**9.20**	$kgCO_2e/kg$
vi) valve	RM 5 - 30 / no	**9.20**	$kgCO_2e/kg$
vii) Drain System	RM 20 - 50 / no	**9.20**	$kgCO_2e/kg$

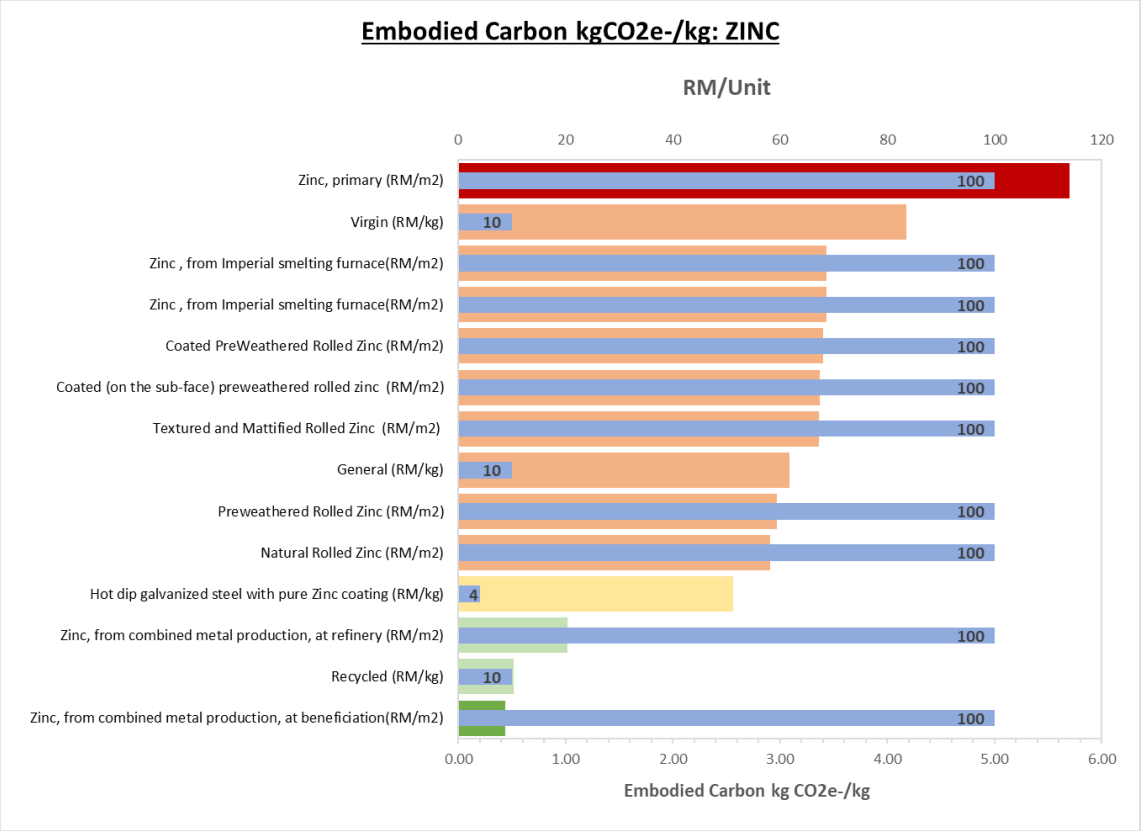
*Commonly used/ traditional material



Zinc

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Zinc, from combined metal production, at beneficiation	RM 100 / m2	0.44	$kgCO_2e/kg$
Recycled	RM 10 / kg	0.52	$kgCO_2e/kg$
Zinc, from combined metal production, at refinery	RM 100 / m2	1.02	$kgCO_2e/kg$
Zinc coating, pieces, adjustment per um	RM 65 / m2	0.088115 *(1.47 kgCO2e/kg, Conv. Factor, thickness 0.25 mm=0.06 kg/m2)	$kgCO_2e/m^2$
Hot dip galvanized steel with pure Zinc coating	RM 4 / kg	**2.56**	$kgCO_2e/kg$
Natural Rolled Zinc	RM 100 / m2	**2.91**	$kgCO_2e/kg$
Preweathered Rolled Zinc	RM 100 / m2	**2.97**	$kgCO_2e/kg$
General*	RM 10 / kg	**3.09**	$kgCO_2e/kg$
Textured and Mattified Rolled Zinc	RM 100 / m2	**3.36**	$kgCO_2e/kg$
Coated (on the sub-face) preweathered rolled zinc	RM 100 / m2	**3.37**	$kgCO_2e/kg$
Coated PreWeathered Rolled Zinc	RM 100 / m2	**3.40**	$kgCO_2e/kg$
Zinc , from Imperial smelting furnace	RM 100 / m2	**3.43**	$kgCO_2e/kg$
Virgin	RM 10 / kg	**4.18**	$kgCO_2e/kg$
Zinc, primary	RM 100 / m2	**5.70**	$kgCO_2e/kg$
Zinc coating, coils	RM 65 / m2	**6.58**	$kgCO_2e/m^2$
Zinc coating, pieces	RM 65 / m2	**9.03**	$kgCO_2e/m^2$

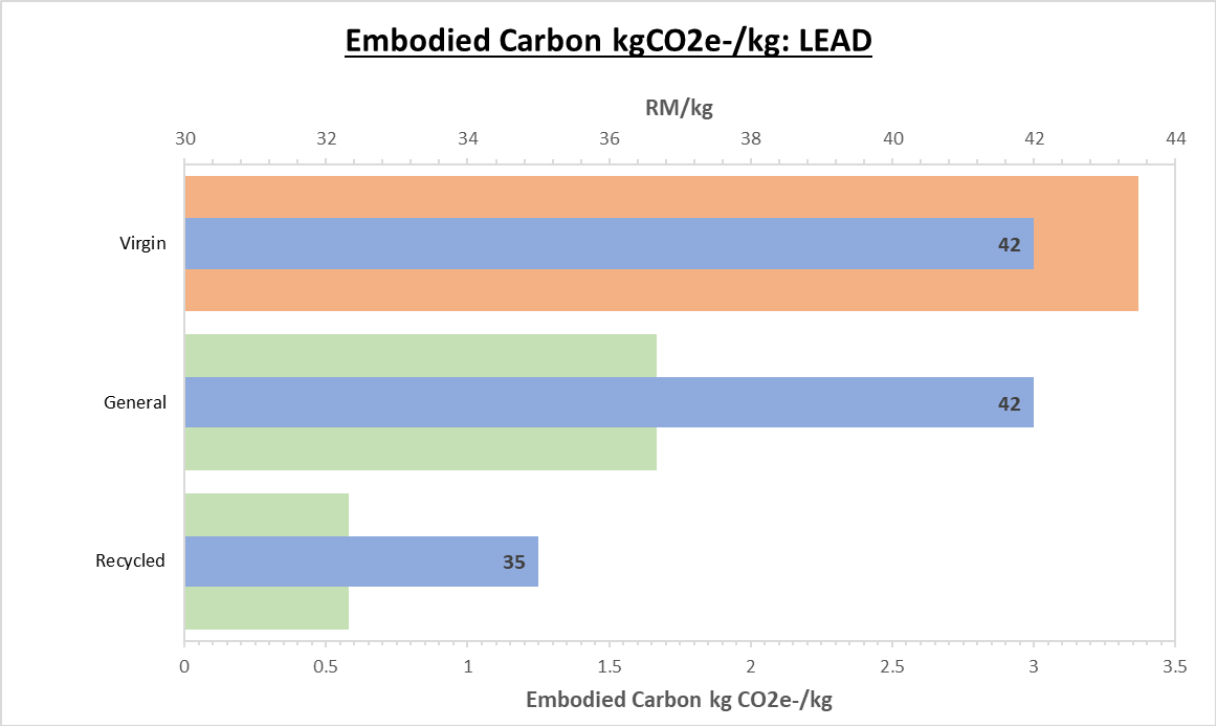
*Commonly used/ traditional material



Lead

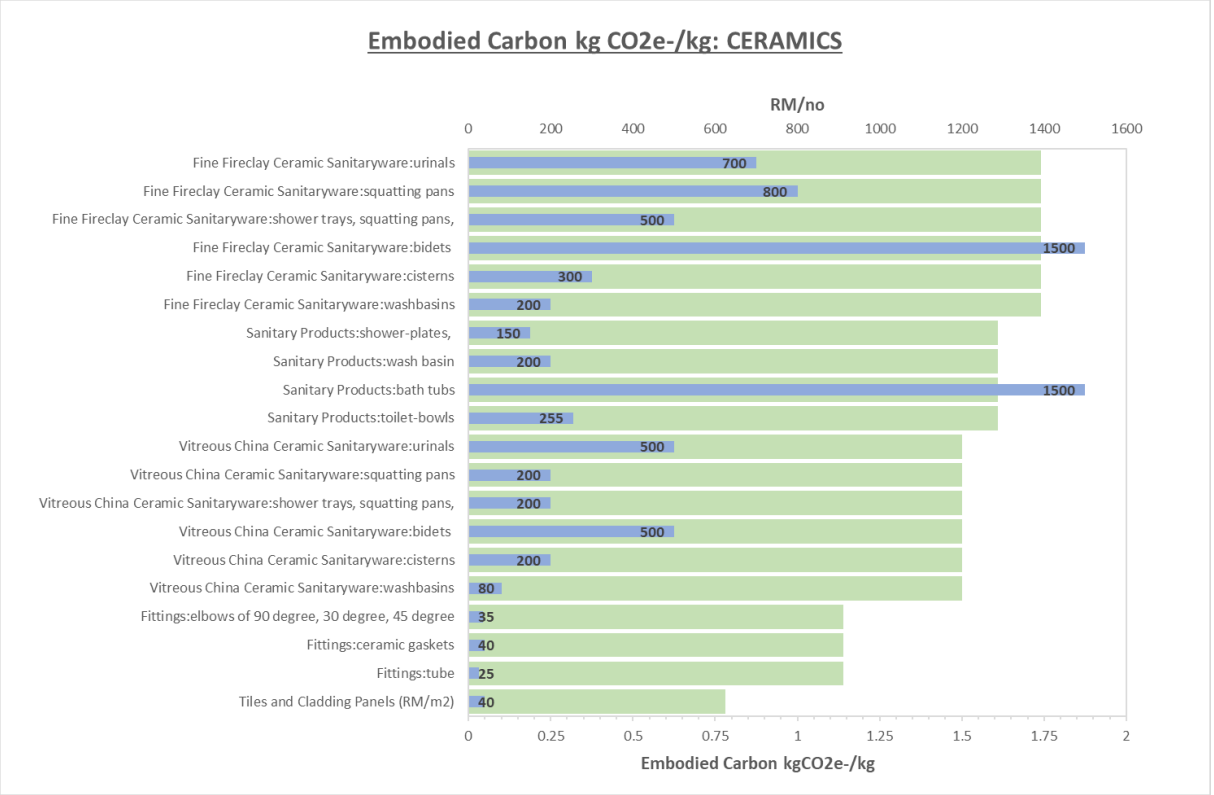
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Recycled	RM 35 / kg	0.58	$kgCO_2e/kg$
General*	RM 42 / kg	1.67	$kgCO_2e/kg$
Virgin	RM 42 / kg	**3.37**	$kgCO_2e/kg$

*Commonly used/ traditional material



Ceramic

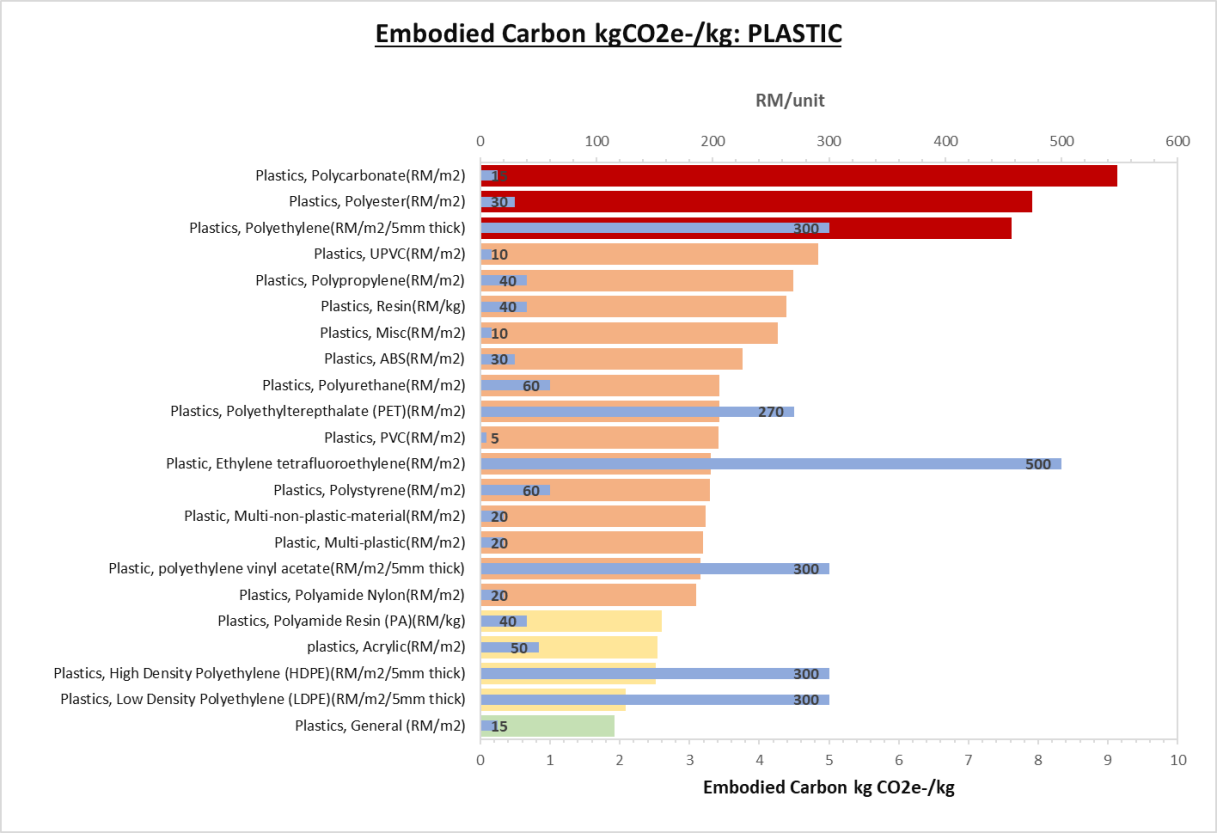
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Fittings:		1.14	kgCO_2e/kg
i) tube	RM12-25 / no	1.14	
ii) ceramic gaskets	RM 30-40 / no	1.14	
iii) elbows of 90 degree, 30 degree, 45 degree	RM 30-35 / no	1.14	
Sanitary Products:			kgCO_2e/kg
i) toilet-bowls	RM 155 - 255 / no	1.61	
ii) bath tubs	RM 550 - 1500 / no	1.61	
iii) wash basin	RM 200 / no	1.61	
iv) shower-plates,	RM 50 - 150 / no	1.61	
Vitreous China Ceramic Sanitaryware:			kgCO_2e/kg
i) washbasins	RM 80 / no	1.50	
ii) cisterns	RM 200 / no	1.50	
iii) bidets	RM 300 - 500 / no	1.50	
iv) shower trays, squatting pans,	RM 200 / no	1.50	
v) squatting pans	RM 200 / no	1.50	
vi) urinals	RM 200 - 500 / no	1.50	
Fine Fireclay Ceramic Sanitaryware			kg CO_2e-/kg
i) washbasins	RM 200 / no	1.74	
ii) cisterns	RM 300 / no	1.74	
iii) bidets	RM 1300 - 1500 / no	1.74	
iv) shower trays, squatting pans,	RM 300 - 500 / no	1.74	
v) squatting pans	RM 800 / no	1.74	
vi) urinals	RM 500 - 700 / no	1.74	
Tiles and Cladding Panels	RM 20 - 40 / m2	0.78	kgCO_2e/kg



Plastic

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Plastics, General*	RM 5 - 15 / m2	1.93	$kgCO_2e/kg$
Plastics, Low Density Polyethylene (LDPE)	RM 250 - 300 / m2 / 5mm thick	2.08	$kgCO_2e/kg$
Plastics, High Density Polyethylene (HDPE)	RM 250 - 300 / m2 / 5mm thick	2.52	$kgCO_2e/kg$
plastics, Acrylic	RM 30 - 50 / m2	2.54	$kgCO_2e/kg$
Plastics, Polyamide Resin (PA)	RM 20 - 40 / kg	2.60	$kgCO_2e/kg$
Plastics, Polyamide Nylon	RM 10 - 20 / m2	3.10	$kgCO_2e/kg$
Plastic, polyethylene vinyl acetate	RM 250 - 300 / m2 / 5mm thick	3.16	$kgCO_2e/kg$
Plastic, Multi-plastic	RM 10 - 20 / m2	3.19	$kgCO_2e/kg$
Plastic, Multi-non-plastic-material	RM 10 - 20 / m2	3.23	$kgCO_2e/kg$
Plastics, Polystyrene	RM 50 - 60 / m2	3.29	$kgCO_2e/kg$
Plastic, Ethylene tetrafluoroethylene	RM 400 - 500 / m2	3.30	$kgCO_2e/kg$
Plastics, PVC	RM 2-5 / m2	3.42	$kgCO_2e/kg$
Plastics, Polyethylterepthalate (PET)	RM 220 - 270 / m2	3.43	$kgCO_2e/kg$
Plastics, Polyurethane	RM 60 / m2	3.43	$kgCO_2e/kg$
Plastics, ABS	RM 20-30 / m2	3.76	$kgCO_2e/kg$
Plastics, Misc	RM 5-10 / m2	4.26	$kgCO_2e/kg$
Plastics, Resin	RM 20 - 40 / kg	4.39	$kgCO_2e/kg$
Plastics, Polypropylene	RM30 - 40 /m2	4.49	$kgCO_2e/kg$
Plastics, UPVC	RM 5-10 / m2	4.84	$kgCO_2e/kg$
Plastics, Polyethylene	RM 250 - 300 / m2 / 5mm thick	7.62	$kgCO_2e/kg$
Plastics, Polyester	RM 20-30 / m2	7.92	$kgCO_2e/kg$
Plastics, Polycarbonate	RM 5 - 15 / m2	9.14	$kgCO_2e/kg$

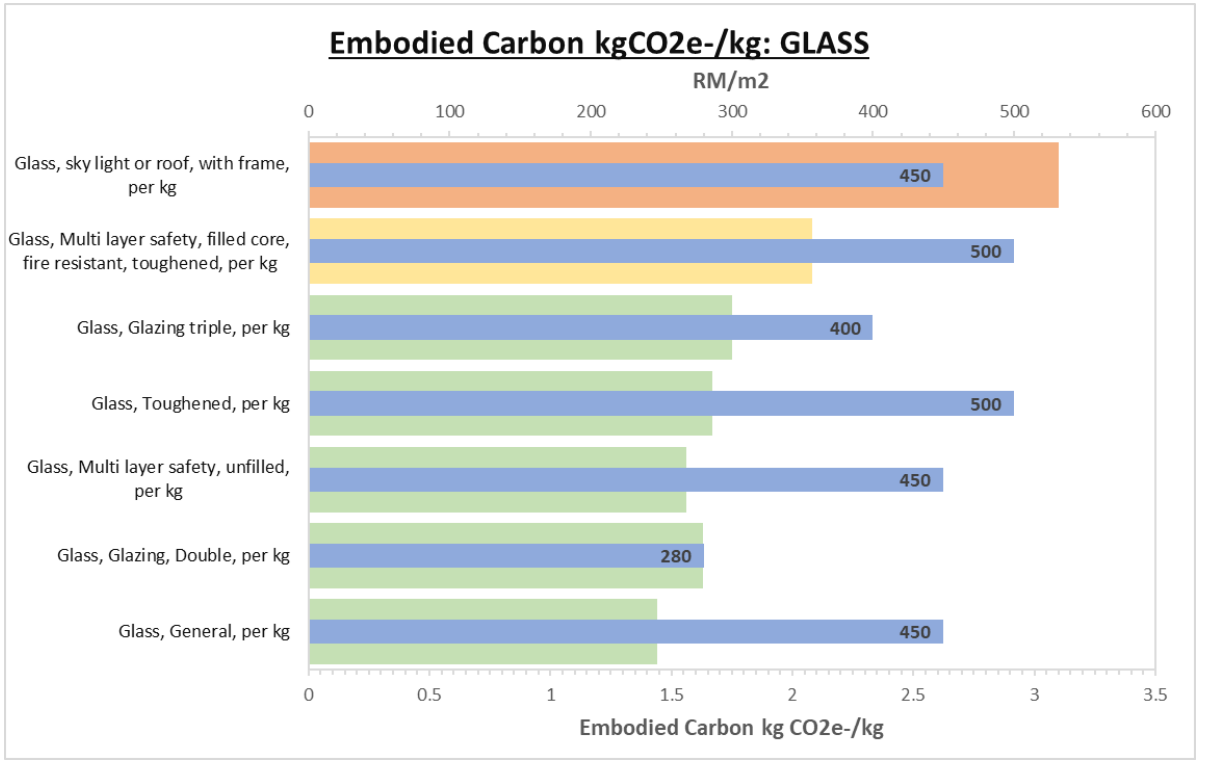
*Commonly used/ traditional material



Glass

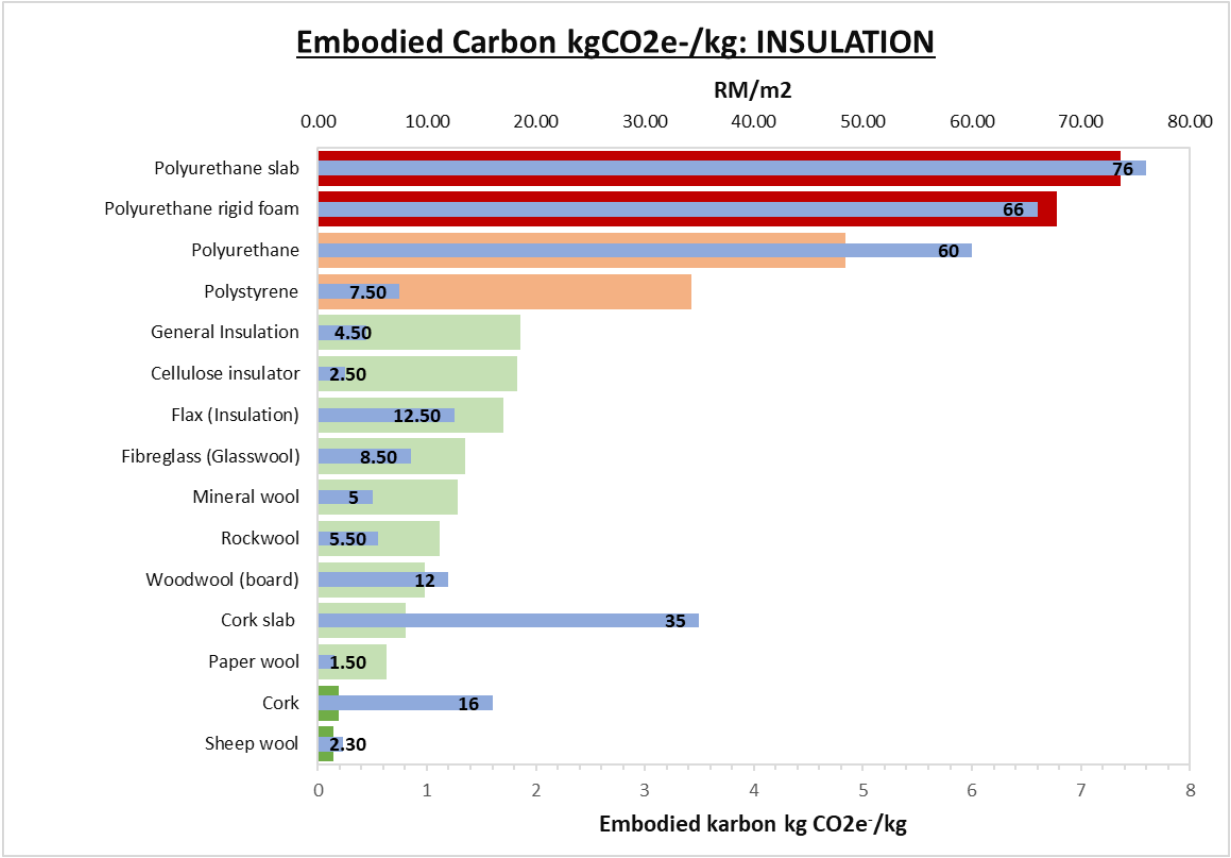
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Glass, General, per kg*	RM 100-150/m2	1.44	$kgCO_2e/kg$
Glass, Multi layer safety, unfilled, per kg	RM 450 / m2	1.56	$kgCO_2e/kg$
Glass, Glazing, Double, per kg	RM 225-280 / m2	1.63	$kgCO_2e/kg$
Glass, Toughened, per kg	RM 500 / m2	1.67	$kgCO_2e/kg$
Glass, Glazing triple, per kg	RM 350 - 400 / m2	1.75	$kgCO_2e/kg$
Glass, Multi layer safety, filled core, fire resistant, toughened, per kg	RM 500 / m2	2.08	$kgCO_2e/kg$
Glass, sky light or roof, with frame, per kg	RM 450 / m2	3.10	$kgCO_2e/kg$

*Commonly used/ traditional material



Insulation

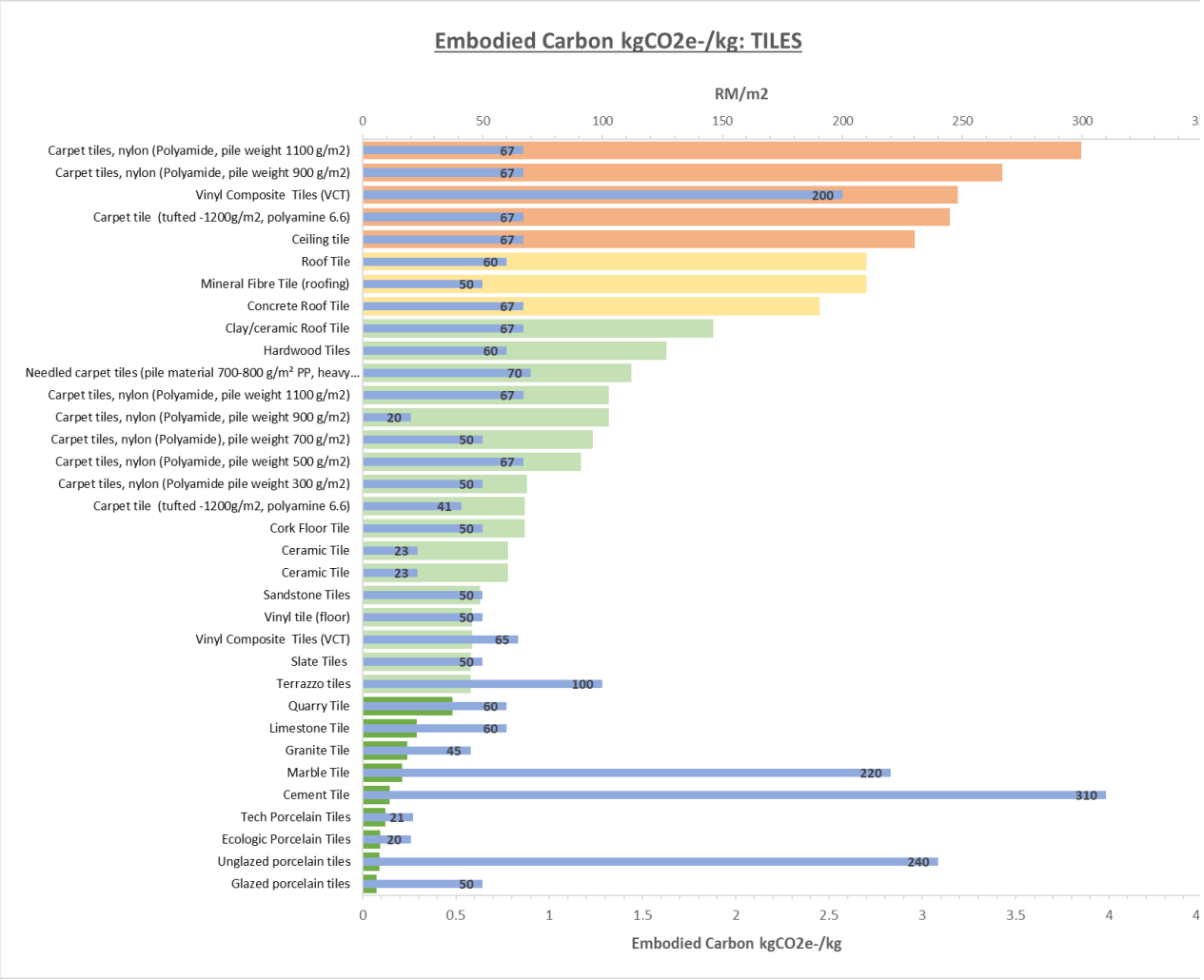
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Sheep wool	RM 2.3/m2	0.14	$kgCO_2e/kg$
Cork	RM 16 /m2	0.19	$kgCO_2e/kg$
Paper wool	RM 1.50/m2	0.63	$kgCO_2e/kg$
Cork slab	RM 35 / m2	0.81	$kgCO_2e/kg$
Woodwool (board)	RM 12 /m2	0.98	$kgCO_2e/kg$
Rockwool	RM 5.5/m2	1.12	$kgCO_2e/kg$
Mineral wool	RM 5 /m2	1.28	kgCO2e/kg
Fibreglass (Glasswool)	RM 8.50 /m2	1.35	$kgCO_2e/kg$
Flax (Insulation)	RM 12.5 /m2	1.70	$kgCO_2e/kg$
Cellulose insulator	RM 2.5/m2	1.83	$kgCO_2e/kg$
General Insulation	RM 4.50/m2	1.86	$kgCO_2e/kg$
Polystyrene	RM 7.50 /m2	3.29 - 3.43	$kgCO_2e/kg$
Polyurethane	RM 60 / m2	4.26-4.84	$kgCO_2e/kg$
Polyurethane rigid foam	RM 66 /m2	6.78	$kgCO_2e/kg$
Polyurethane slab	RM 76/m2	7.36	$kgCO_2e/kg$



Tiles

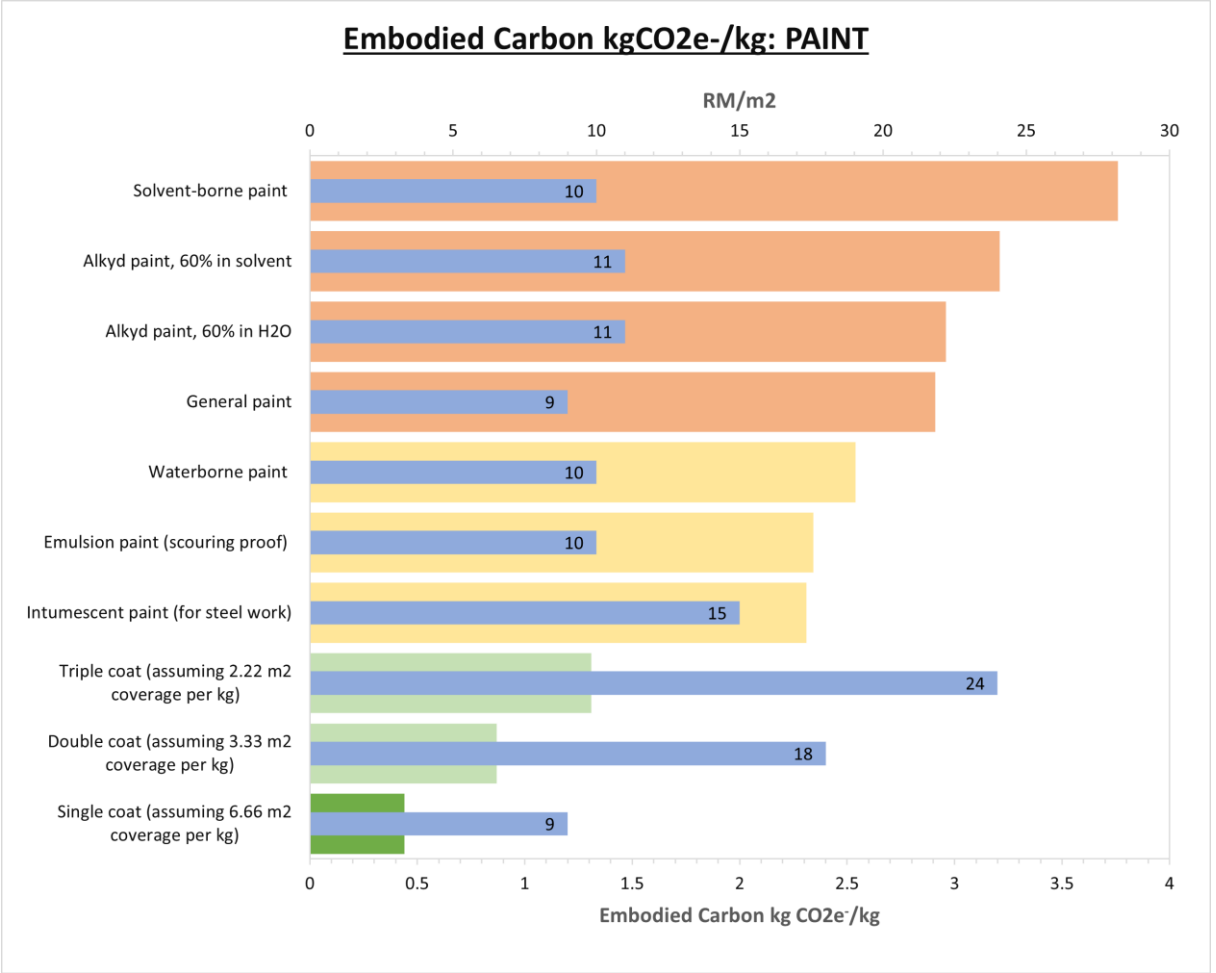
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Slate Tiles	RM 50 / m2	0.08	$kgCO_2e/kg$
Limestone Tile	RM 240 / m2	0.09	$kgCO_2e/kg$
Sandstone Tiles	RM 15-20 / m2	0.10	$kgCO_2e/kg$
Terrazzo tiles	RM 21 /m2	0.12	$kgCO_2e/kg$
Granite Tile	RM 290 - 310 / m2	0.15	$kgCO_2e/kg$
Marble Tile*	RM 180 - 220 / m2	0.21	$kgCO_2e/kg$
Concrete Roof Tile*	RM 45 / m2	0.24	$kgCO_2e/kg$
Quarry Tile	RM 30 - 60 / m2	0.29	$kgCO_2e/kg$
Clay/ceramic Roof Tile	RM 60 / m2	0.48	$kgCO_2e/kg$
Cork Floor Tile	RM 100 / m2	0.58	$kgCO_2e/kg$
Hardwood Tiles	RM 35 / m2	0.59	$kgCO_2e/kg$
Ecologic Porcelain Tiles	RM 50 / m2	0.63	$kgCO_2e/kg$
Ceramic Tile*	RM 23 / m2	0.78	$kgCO_2e/kg$
Glazed porcelain tiles	RM 50 / m2	0.87	$kgCO_2e/kg$
Unglazed porcelain tiles	RM 41 / m2	0.87	$kgCO_2e/kg$
Tech Porcelain Tiles	RM 50 / m2	0.88	$kgCO_2e/kg$
Needled carpet tiles (pile material 700-800 g/m² PP, heavy backing bitumen based)	RM 67 / m2	1.17	$kgCO_2e/kg$
Vinyl tile (floor)*	RM 50 / m2	1.23	$kgCO_2e/kg$
Ceiling tile*	RM 20 / m2	1.32	$kgCO_2e/kg$
Cement Tile*	RM 70 / m2	1.44	$kgCO_2e/kg$
Roof Tile	RM 60 / m2	1.63	$kgCO_2e/kg$
Carpet tiles, nylon (Polyamide pile weight 300 g/m2)	RM 67 / m2	1.88	$kgCO_2e/kg$
Carpet tiles, nylon (Polyamide, pile weight 500 g/m2)	RM 67 / m2	2.45	$kgCO_2e/kg$
Mineral Fibre Tile (roofing)	RM 50	2.70	$kgCO_2e/kg$
Carpet tiles, nylon (Polyamide), pile weight 700 g/m2)	RM 67 / m2	2.96	$kgCO_2e/kg$
Carpet tile (tufted -1200g/m2, polyamine 6.6)	RM 67 / m2	3.15	$kgCO_2e/kg$
Vinyl Composite Tiles (VCT)	RM 100 - 200 / m2	3.19	$kgCO_2e/kg$
Carpet tiles, nylon (Polyamide, pile weight 900 g/m2)	RM 67 / m2	3.43	$kgCO_2e/kg$
Carpet tiles, nylon (Polyamide, pile weight 1100 g/m2)	RM 67 / m2	3.85	$kgCO_2e/kg$

*Commonly used/ traditional material



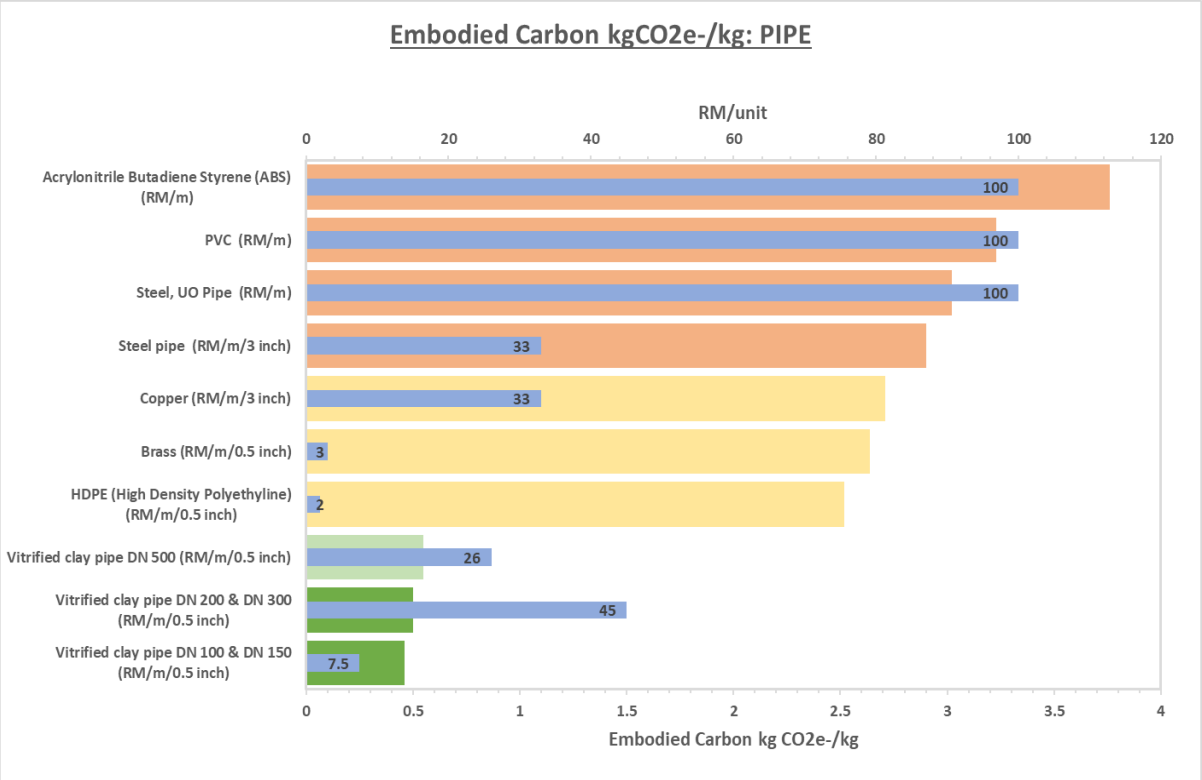
Paint

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Single coat (assuming 6.66 m2 coverage per kg)	RM 9 / m2	0.44	$kgCO_2e/kg$
Double coat (assuming 3.33 m2 coverage per kg)	RM 18 / m2	0.87	$kgCO_2e/kg$
Triple coat (assuming 2.22 m2 coverage per kg)	RM 24 / m2	1.31	$kgCO_2e/kg$
Intumescent paint (for steel work)	RM 15 / m2	2.31	$kgCO_2e/kg$
Emulsion paint (scouring proof)	RM 10 / m2	2.34	$kgCO_2e/kg$
Waterborne paint	RM 10 / m2	2.54	$kgCO_2e/kg$
General paint	RM 6 - 9 / m2	2.91	$kgCO_2e/kg$
Alkyd paint, 60% in H2O	RM 11 / m2	2.96	$kgCO_2e/kg$
Alkyd paint, 60% in solvent	RM 11 / m2	3.21	$kgCO_2e/kg$
Solvent-borne paint	RM 10 / m2	3.76	$kgCO_2e/kg$



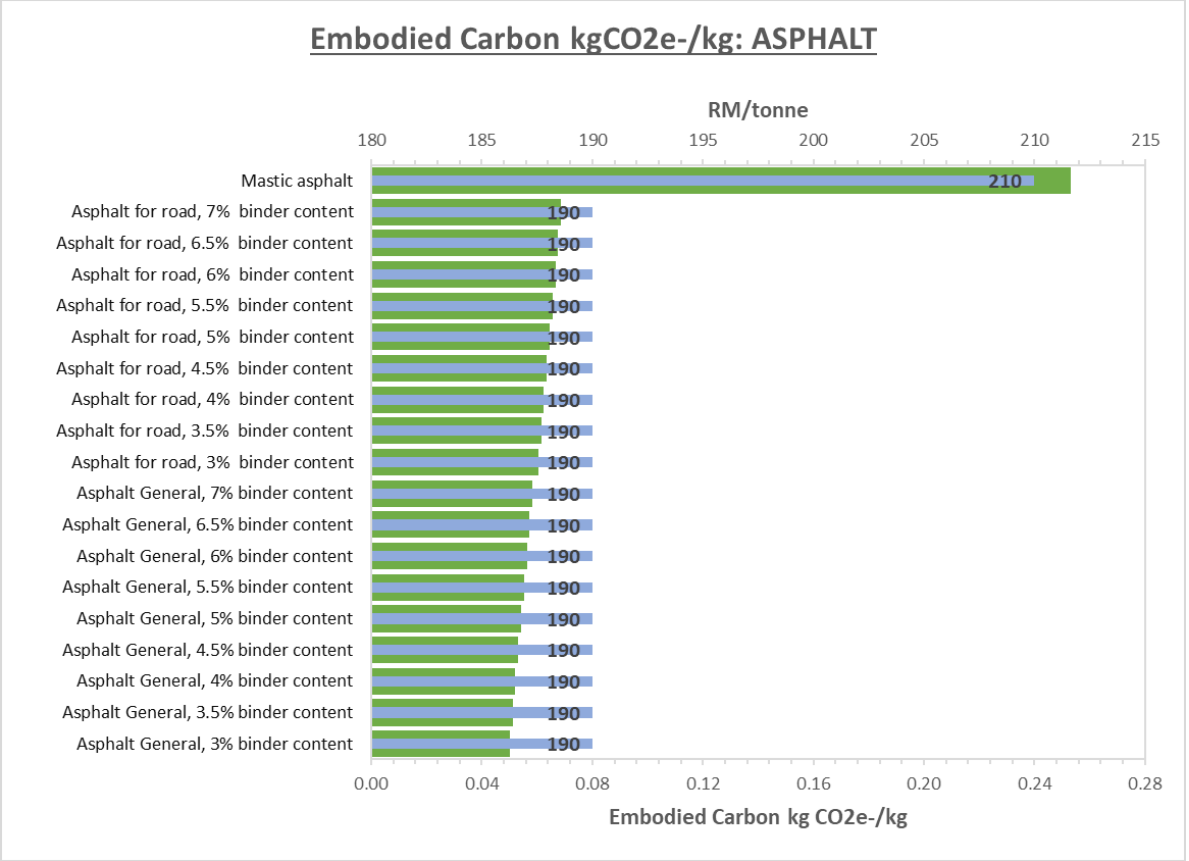
Pipe

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Vitrified clay pipe DN 100 & DN 150	RM 40 - 100 / m	0.46	$kgCO_2e/kg$
Vitrified clay pipe DN 200 & DN 300	RM 40 - 100 / m	0.50	$kgCO_2e/kg$
Vitrified clay pipe DN 500	RM 40 - 100 / m	0.55	$kgCO_2e/kg$
HDPE (High Density Polyethyline)	RM 2 / m / 0.5 inch	2.52	$kgCO_2e/kg$
Brass	RM 45 / m / 0.5 inch	2.64	$kgCO_2e/kg$
Copper	RM 26 / m / 0.5 inch	2.71	$kgCO_2e/kg$
Steel pipe	RM 33 / m / 3 inch	2.90	$kgCO_2e/kg$
Steel, UO Pipe	RM 33 / m / 3 inch	3.02	$kgCO_2e/kg$
PVC	RM 3 / m / 0.5 inch	3.23	$kgCO_2e/kg$
Acrylonitrile Butadiene Styrene (ABS)	RM 7.50 / m / 0.5 inch	3.76	$kgCO_2e/kg$



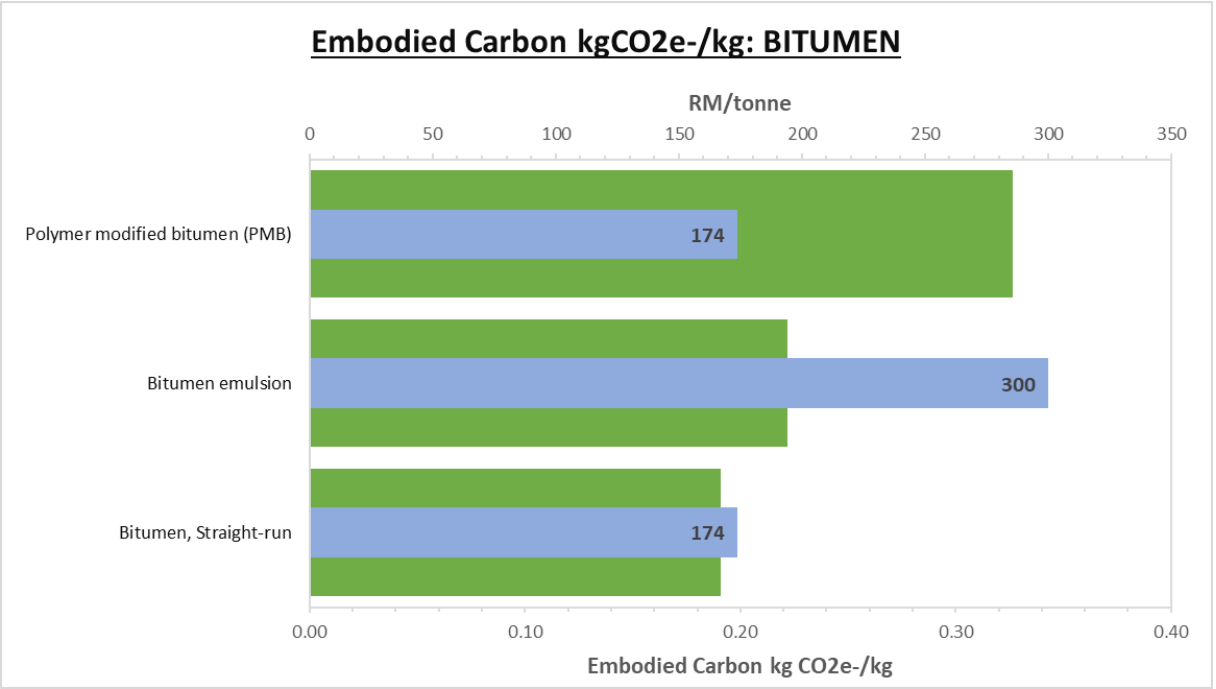
Asphalt

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Asphalt General, 3% binder content	RM 190 / tonne	0.05	$kgCO_2e/kg$
Asphalt General, 3.5% binder content	RM 190 / tonne	0.05	$kgCO_2e/kg$
Asphalt General, 4% binder content	RM 190 / tonne	0.05	$kgCO_2e/kg$
Asphalt General, 4.5% binder content	RM 190 / tonne	0.05	$kgCO_2e/kg$
Asphalt General, 5% binder content	RM 190 / tonne	0.05	$kgCO_2e/kg$
Asphalt General, 5.5% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt General, 6% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt General, 6.5% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt General, 7% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 3% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 3.5% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 4% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 4.5% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 5% binder content	RM 190 / tonne	0.06	$kgCO_2e/kg$
Asphalt for road, 5.5% binder content	RM 190 / tonne	0.07	$kgCO_2e/kg$
Asphalt for road, 6% binder content	RM 190 / tonne	0.07	$kgCO_2e/kg$
Asphalt for road, 6.5% binder content	RM 190 / tonne	0.07	$kgCO_2e/kg$
Asphalt for road, 7% binder content	RM 190 / tonne	0.07	$kgCO_2e/kg$
Mastic asphalt	RM 210 / tonne	0.25	$kgCO_2e/kg$



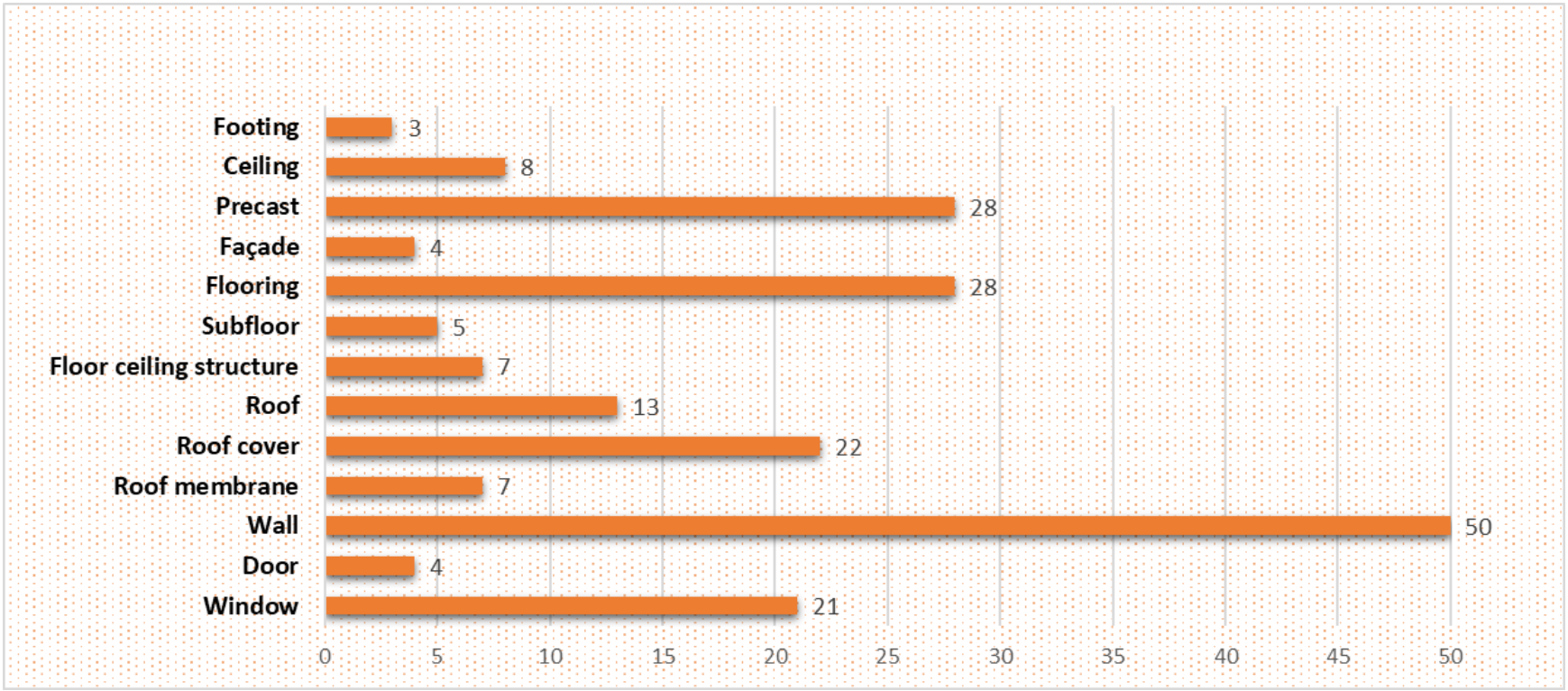
Bitumen

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Bitumen, Straight-run	RM 174 / tonne	0.19	$kgCO_2e/kg$
Polymer modified bitumen (PMB)	RM 174 / tonne	0.33	$kgCO_2e/kg$
Bitumen emulsion	RM 300 / tonne	0.22	$kgCO_2e/kg$



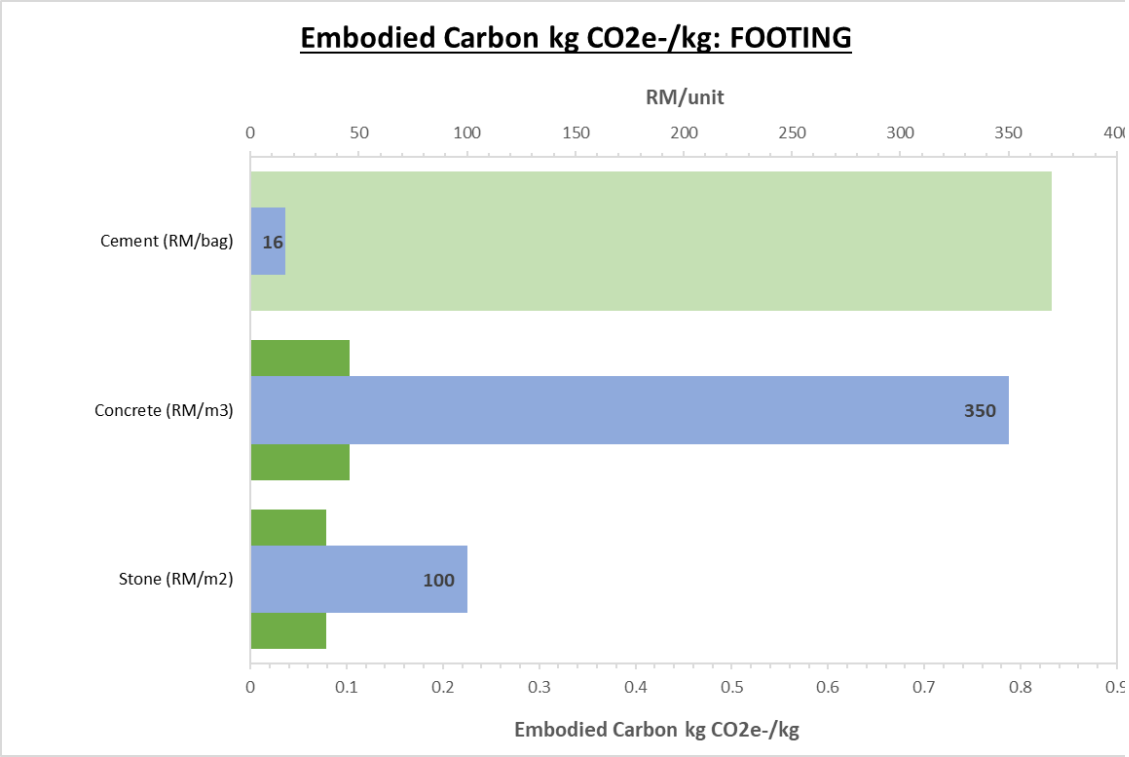
BUILDING ELEMENTS

Building elements compiled in the embodied carbon inventory data



Footing

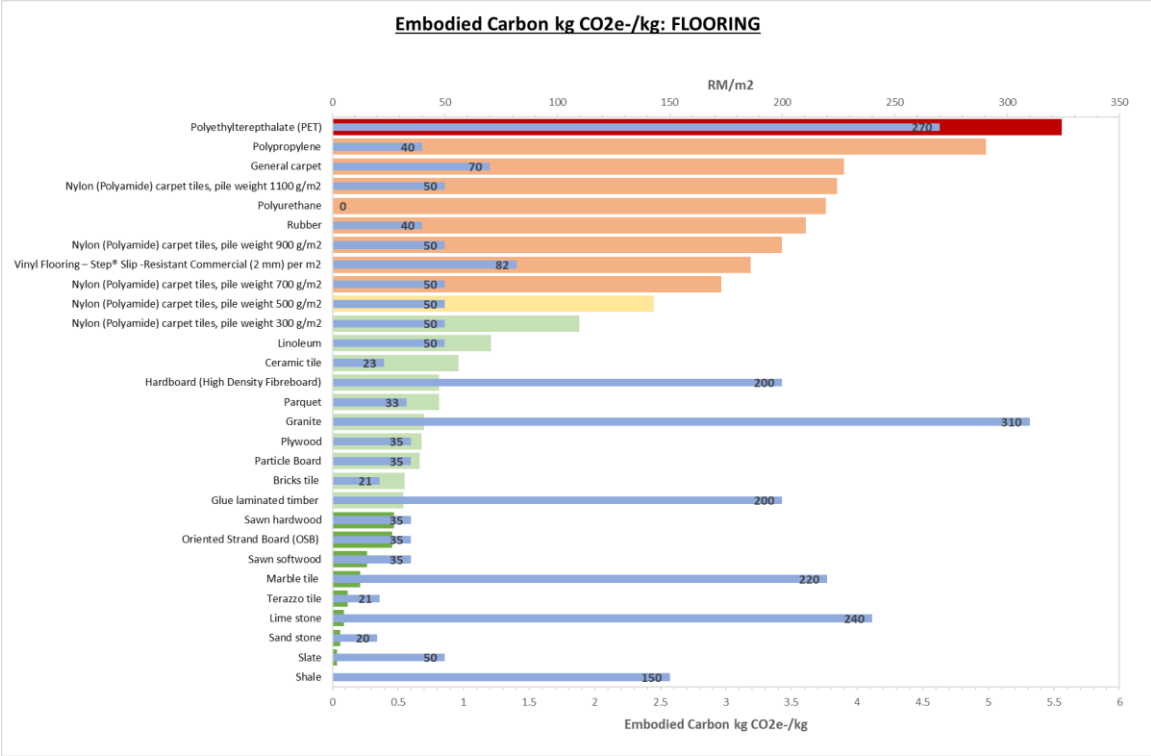
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Stone	RM 50 - 100 / m2	0.08	$kgCO_2e/kg$
Concrete	RM 220-350 / m3	0.10	$kgCO_2e/kg$
Cement	RM 16 / bag	0.83	$kgCO_2e/kg$



Flooring

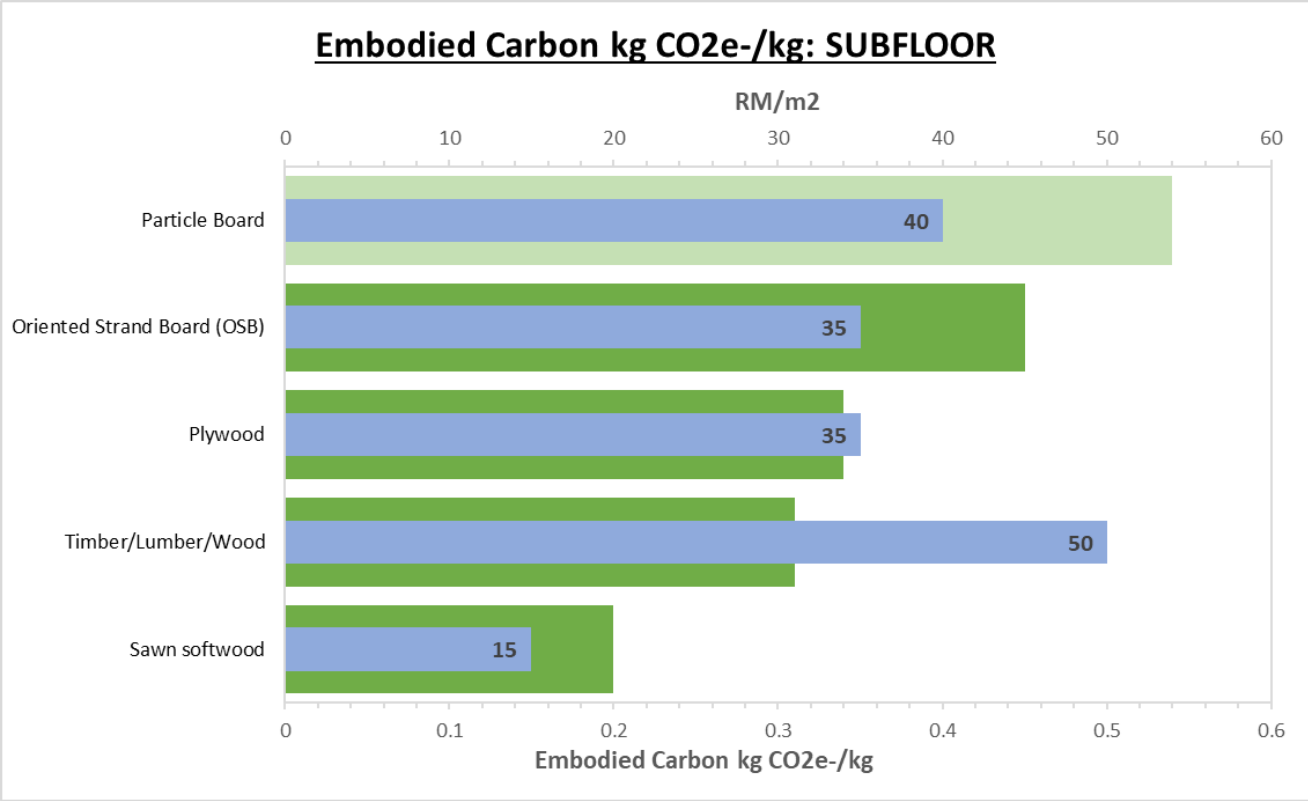
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Shale	RM 100 - 150 / m2	0.002	$kgCO_2e/kg$
Slate	RM 50 / m2	0.04	$kgCO_2e/kg$
Sand stone	RM 15-20 / m2	0.06	$kgCO_2e/kg$
Lime stone*	RM 240 / m2	0.09	$kgCO_2e/kg$
Terazzo tile*	RM 21 /m2	0.118	$kgCO_2e/kg$
Marble tile	RM 180 - 220 / m2	0.21	$kgCO_2e/kg$
Sawn softwood	RM 35 / m2	0.26	$kgCO_2e/kg$
Oriented Strand Board (OSB)	RM 35 / m2	0.46	$kgCO_2e/kg$
Sawn hardwood	RM 35 / m2	0.47	$kgCO_2e/kg$
Glue laminated timber	RM 200 / m2	0.54	$kgCO_2e/kg$
Bricks tile	RM 21 / m2	0.55	$kgCO_2e/kg$
Particle Board	RM 35 / m2	0.66	$kgCO_2e/kg$
Plywood	RM 35 / m2	0.68	$kg\ CO_2e/kg$
Granite	RM 290 - 310 / m2	0.70	$kgCO_2e/kg$
Parquet	RM 33 / m2	0.81	$kgCO_2e/kg$
Hardboard (High Density Fibreboard)	RM 200 / m2	0.82	$kgCO_2e/kg$
Ceramic tile*	RM 23 / m2	0.96	$kgCO_2e/kg$
Linoleum	RM 50 / m2	1.21	$kgCO_2e/kg$
Nylon (Polyamide) carpet tiles, pile weight 300 g/m2	RM30 - 50 /m2	1.88	$kgCO_2e/kg$
Nylon (Polyamide) carpet tiles, pile weight 500 g/m2	RM30 - 50 /m2	2.45	$kgCO_2e/kg$
Nylon (Polyamide) carpet tiles, pile weight 700 g/m2	RM30 - 50 /m2	2.96	$kgCO_2e/kg$
Vinyl Flooring – Step® Slip - Resistant Commercial (2 mm) per m2	RM 82 / m2	3.19	$kgCO_2e/kg$
Nylon (Polyamide) carpet tiles, pile weight 900 g/m2	RM30 - 50 /m2	3.43	$kgCO_2e/kg$
Rubber	RM 40 / m2	3.61	$kgCO_2e/kg$
Polyurethane	RM 60 / m2	3.76	$kgCO_2e/kg$
Nylon (Polyamide) carpet tiles, pile weight 1100 g/m2	RM30 - 50 /m2	3.85	$kg\ CO_2e/kg$
General carpet*	RM 70 / m2	3.90	$kgCO_2e/kg$
Polypropylene	RM30 - 40 /m2	4.98	$kgCO_2e/kg$
Polyethylterepthalate (PET)	RM 220 - 270 / m2	5.56	$kgCO_2e/kg$

*Commonly used/ traditional material



Subfloor

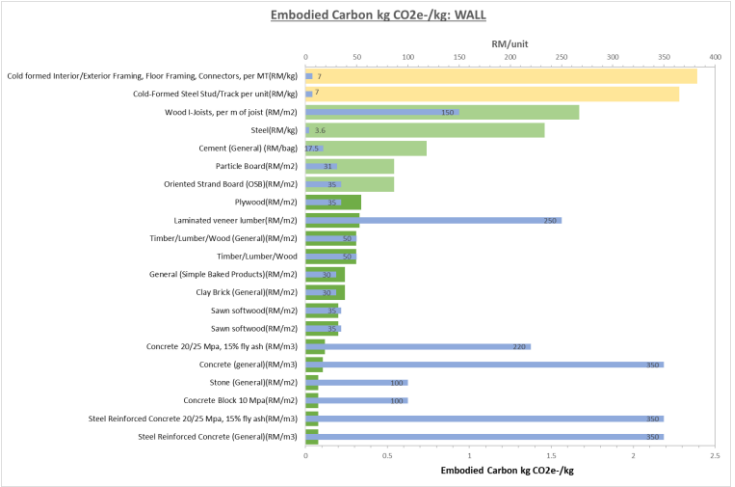
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Sawn softwood	RM 8-15 / m	0.20	$kgCO_2e/kg$
Timber/Lumber/Wood	RM 35 - 50 / m2	0.31	$kgCO_2e/kg$
Plywood	RM 35 / m2	0.34	$kgCO_2e/kg$
Oriented Strand Board (OSB)	RM 35 / m2	0.45	$kgCO_2e/kg$
Particle Board	RM 30-40 / m2	0.54	$kgCO_2e/kg$

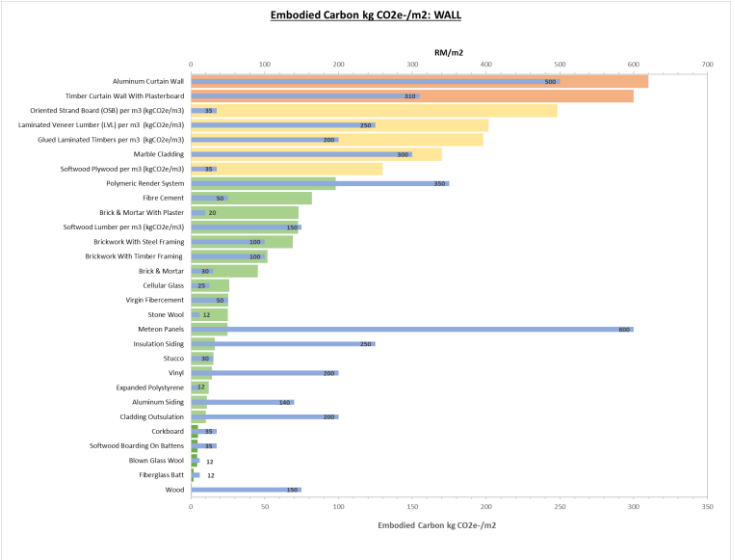


Wall

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Steel Reinforced Concrete (General)*	RM 300-350 / m3	0.08	$kgCO_2e/kg$
Steel Reinforced Concrete 20/25 Mpa, 15% fly ash	RM 300-350 / m3	0.08	$kgCO_2e/kg$
Concrete Block 10 Mpa	RM 70 - 100 / m2	0.0781	$kgCO_2e/kg$
Stone (General)*	RM 50 - 100 / m2	0.079	$kgCO_2e/kg$
Concrete (general)*	RM 220-350 / m3	0.107	$kgCO_2e/kg$
Concrete 20/25 Mpa, 15% fly ash	RM 220 per m3	0.12	$kgCO_2e/kg$
Sawn softwood	RM 35 / m2	0.20	$kgCO_2e/kg$
Sawn softwood	RM 35 / m2	0.20	$kgCO_2e/kg$
Clay Brick (General)*	RM 25 - 30 / m2	0.24	$kgCO_2e/kg$
General (Simple Baked Products)	RM 25 - 30 / m2	0.24	$kgCO_2e/kg$
Timber/Lumber/Wood	RM 35 - 50 / m2	0.31	$kgCO_2e/kg$
Timber/Lumber/Wood (General)*	RM 35 - 50 / m2	0.31	$kgCO_2e/kg$
Laminated veneer lumber	RM 100 - 250 / m2	0.33	$kgCO_2e/kg$
Plywood	RM 35 / m2	0.34	$kgCO_2e/kg$
Oriented Strand Board (OSB)	RM 35 / m2	0.45	$kgCO_2e/kg$
Particle Board	RM 31 / m2	0.54	$kgCO_2e/kg$
Cement (General)*	RM 15.5-RM17.5 / bag	0.74	$kgCO_2e/kg$
Steel	RM 3.60 / kg	1.46	$kgCO_2e/kg$
Wood I-Joists, per m of joist	RM 50 - 150 / m2	1.67	$kgCO_2e/kg$
Cold formed Interior/Exterior Framing, Floor Framing, Connectors, per MT	RM 7 / kg	2.39	$kgCO_2e/kg$
Corkboard	RM 27 - 35 / m2	0.60	kgCO2e/m2
Wood	RM 50 - 150 / m2	1.90	kgCO2e/m2
Fiberglass Batt	RM 7 - 12 / m2	2.28	kgCO2e/kg
Cladding Outsulation	RM 100 - 200 / m2	4.20	kgCO2e/m2
Aluminum Siding	RM 120 - 140 / m2	4.60	kgCO2e/m2
Expanded Polystyrene	RM 50 - 60 / m2	4.70	kgCO2e/m2
Softwood Plywood per m3	RM 35 / m2	10.20	kgCO2e/m2
Vinyl	RM 100 - 200 / m2	10.80	kgCO2e/m2
Stucco	RM 20 - 30 / m2	12.00	kgCO2e/m2
Insulation Siding	RM 100 - 250 / m2	14.20	kgCO2e/m2
Marble Cladding	RM 150 - 300 / m2	15.30	kgCO2e/m2
Glued Laminated Timbers per m3	RM 200 / m2	16.20	kgCO2e/m2
Cold-Formed Steel Stud/Track per unit	RM 7 / kg	24.90	kgCO2e/m2
Laminated Veneer Lumber (LVL) per m3	RM 100 - 250 / m2	25.00	kgCO2e/m2
Meteon Panels	RM 350 - 600 / m2	25.30	kgCO2e/m2
Oriented Strand Board (OSB) per m3	RM 35 / m2	26.00	kgCO2e/m2
Stone Wool	RM 7 - 12 / m2	45.20	kgCO2e/m2
Virgin Fibercement	RM 25 - 50 / m2	52.00	kgCO2e/m2
Cellular Glass	RM 12 - 25 / m2	69.00	kgCO2e/m2
Timber Curtain Wall With Plasterboard	RM 110 - 310 / m2	72.64	kgCO2e/m3
Aluminum Curtain Wall	RM 250 - 500 / m2	73.00	kgCO2e/m2
Blown Glass Wool	RM 7 - 12 / m2	82.00	kgCO2e/m2
Softwood Boarding On Battens	RM 35 / m2	98.00	kgCO2e/m2
Brick & Mortar	RM 25 - 30 / m2	129.77	kgCO2e/m3
Brickwork With Timber Framing	RM 50 - 100 / m2	170.00	kgCO2e/m2
Brickwork With Steel Framing	RM 50 - 100 / m2	197.97	kgCO2e/m3
Softwood Lumber per m3	RM 50 - 150 / m2	201.80	kgCO2e/m3
Brick & Mortar With Plaster	RM 25 - 30 / m2	248.30	kgCO2e/m3
Fibre Cement	RM 25 - 50 / m2	300.00	kgCO2e/m2
Polymeric Render System	RM 250 - 350 / m2	310.00	kgCO2e/m2

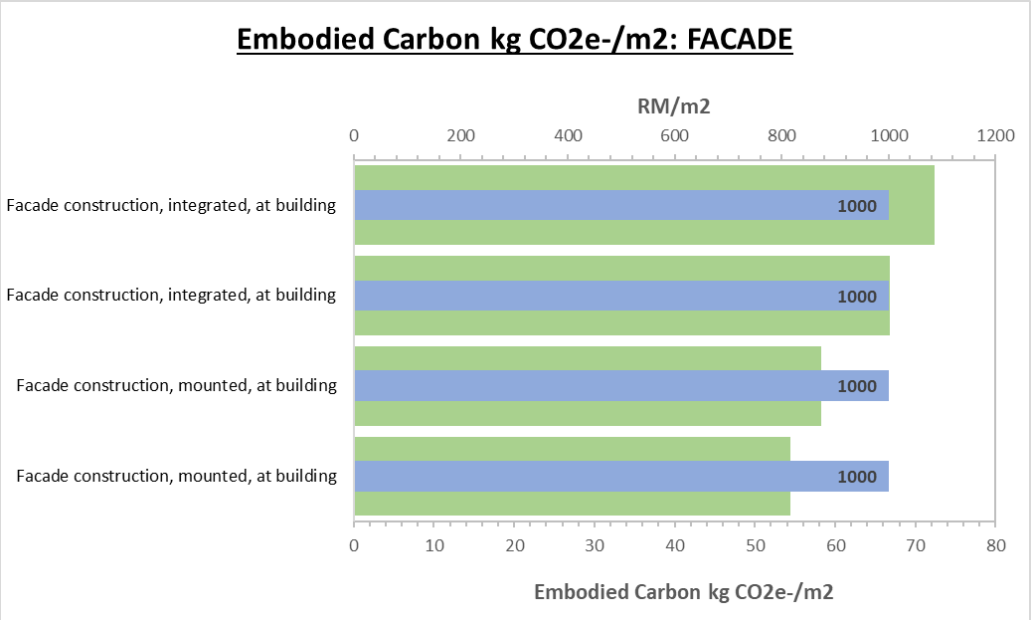
*Commonly used/ traditional material





Façade

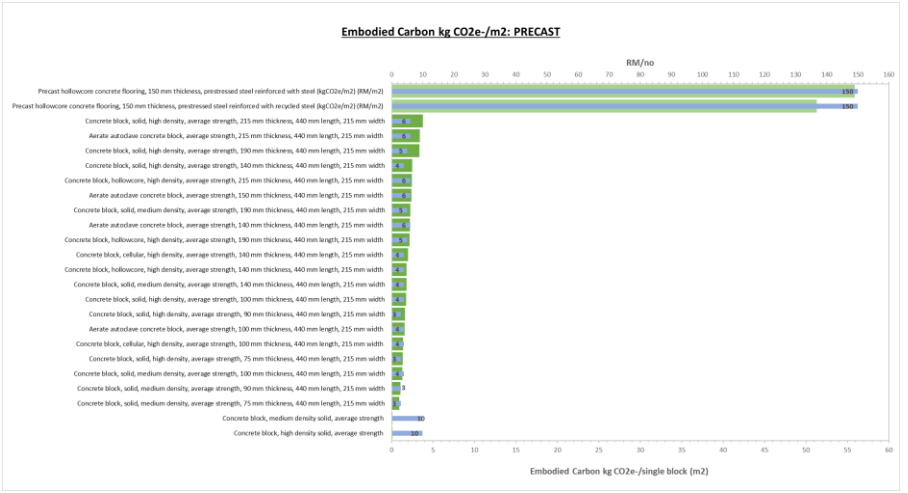
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Facade construction, integrated, at building	RM 800 - 1000 / m2	72.42	$kgCO_2e/m^2$
Facade construction, integrated, at building		66.75	$kgCO_2e/m^2$
Facade construction, mounted, at building		54.47	$kgCO_2e/m^2$
Facade construction, mounted, at building		58.24	$kgCO_2e/m^2$

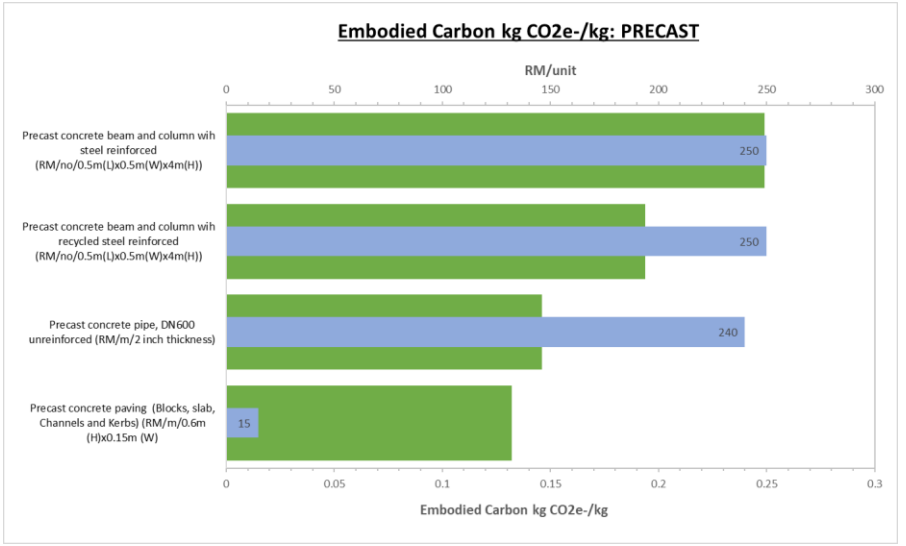


Precast

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Concrete block, high density solid, average strength	RM 3 - 10 / no	0.09	kgCO2e/Single block
Precast concrete paving (Blocks, slab, Channels and Kerbs)*	RM 12 - 15 / m / 0.6m(H) x 0.15m(W)	0.13	$kgCO_2e/kg$
Precast concrete pipe, DN600 unreinforced	RM 220 - 240 / m / 2 inch thickness	0.15	$kgCO_2e/kg$
Precast concrete beam and column wih recycled steel reinforced	RM 250 / no / 0.5m(L) x 0.5m(W) x 4m(H)	0.19	$kgCO_2e/kg$
Precast concrete beam and column wih steel reinforced	RM 250 / no / 0.5m(L) x 0.5m(W) x 4m(H)	0.25	$kgCO_2e/kg$
Concrete block, medium density solid, average strength	RM 3 - 10 / no	0.0931	$kgCO_2e$/Single block
Concrete block, solid, medium density, average strength, 75 mm thickness, 440 mm length, 215 mm width	RM 3 / no	0.931	$kgCO_2e$/Single block
Concrete block, solid, medium density, average strength, 90 mm thickness, 440 mm length, 215 mm width	RM 3 / no	1.07	$kgCO_2e$/Single block
Concrete block, solid, medium density, average strength, 100 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.28	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 75 mm thickness, 440 mm length, 215 mm width	RM 3 / no	1.33	$kgCO_2e$/Single block
Concrete block, cellular, high density, average strength, 100 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.38	$kgCO_2e$/Single block
Aerate autoclave concrete block, average strength, 100 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.59	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 90 mm thickness, 440 mm length, 215 mm width	RM 3 / no	1.6	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 100 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.75	$kgCO_2e$/Single block
Concrete block, solid, medium density, average strength, 140 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.8	$kgCO_2e$/Single block
Concrete block, hollowcore, high density, average strength, 140 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.82	$kgCO_2e$/Single block
Concrete block, cellular, high density, average strength, 140 mm thickness, 440 mm length, 215 mm width	RM 4 / no	1.98	$kgCO_2e$/Single block
Concrete block, hollowcore, high density, average strength, 190 mm thickness, 440 mm length, 215 mm width	RM 5 / no	2.19	$kgCO_2e$/Single block
Aerate autoclave concrete block, average strength, 140 mm thickness, 440 mm length, 215 mm width	RM 6 / no	2.22	$kgCO_2e$/Single block
Concrete block, solid, medium density, average strength, 190 mm thickness, 440 mm length, 215 mm width	RM 5 / no	2.28	$kgCO_2e$/Single block
Aerate autoclave concrete block, average strength, 150 mm thickness, 440 mm length, 215 mm width	RM 6 / no	2.38	$kgCO_2e$/Single block
Concrete block, hollowcore, high density, average strength, 215 mm thickness, 440 mm length, 215 mm width	RM 6 / no	2.42	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 140 mm thickness, 440 mm length, 215 mm width	RM 4 / no	2.48	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 190 mm thickness, 440 mm length, 215 mm width	RM 5 / no	3.35	$kgCO_2e$/Single block
Aerate autoclave concrete block, average strength, 215 mm thickness, 440 mm length, 215 mm width	RM 6 / no	3.42	$kgCO_2e$/Single block
Concrete block, solid, high density, average strength, 215 mm thickness, 440 mm length, 215 mm width	RM 6 / no	3.77	$kgCO_2e$/Single block
Precast hollowcore concrete flooring, 150 mm thickness, prestressed steel reinforced with recycled steel	RM 100 - 150 / m2	51.3	$kgCO_2e/m^2$
Precast hollowcore concrete flooring, 150 mm thickness, prestressed steel reinforced with steel	RM 100 - 150 / m2	55.9	$kgCO_2e/m^2$

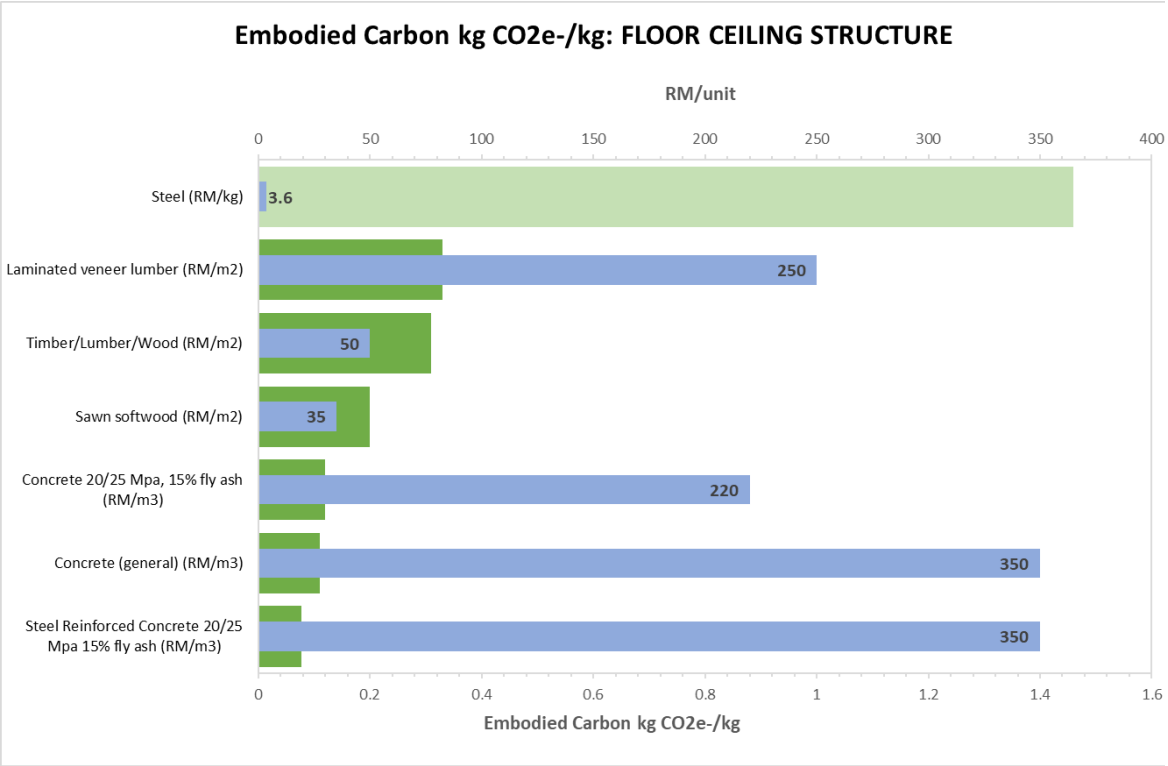
*Commonly used/ traditional material





Floor Ceiling Structure

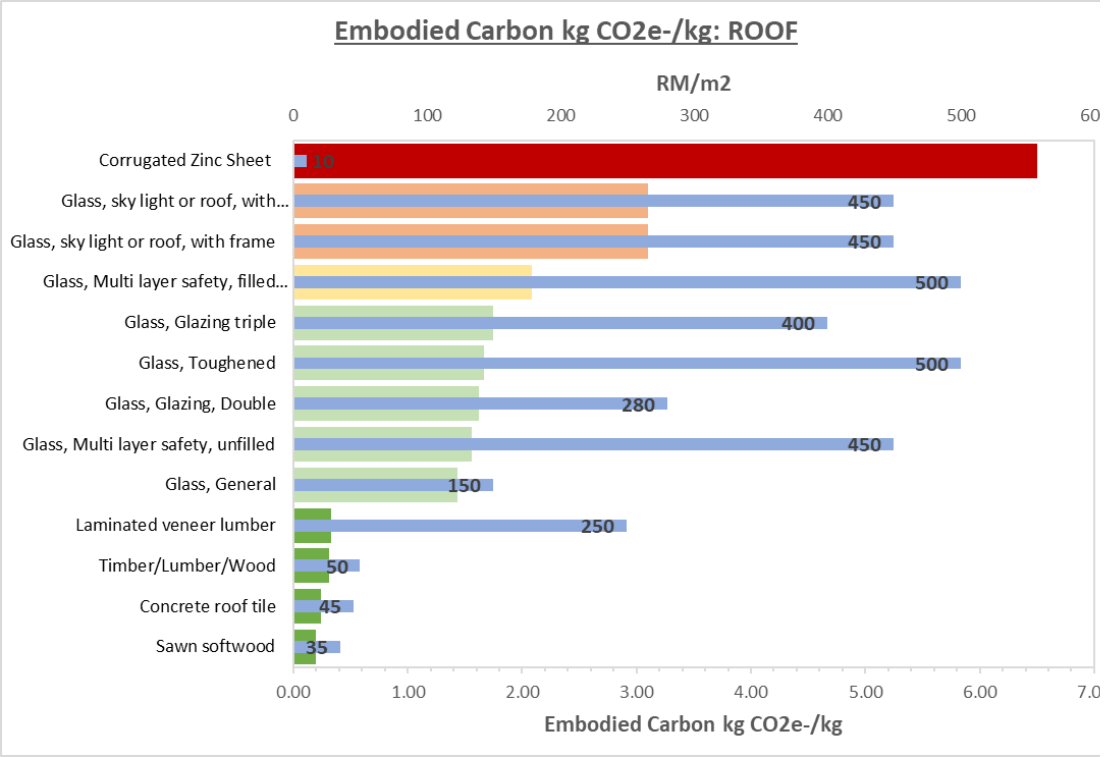
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Steel Reinforced Concrete 20/25 Mpa 15% fly ash	RM 300-350 / m3	0.08	$kgCO_2e/kg$
Concrete (general)	RM 220-350 / m3	0.11	$kgCO_2e/kg$
Concrete 20/25 Mpa, 15% fly ash	RM 220 per m3	0.12	$kgCO_2e/kg$
Sawn softwood	RM 35 / m2	0.20	$kgCO_2e/kg$
Timber/Lumber/Wood	RM 35 - 50 / m2	0.31	$kgCO_2e/kg$
Laminated veneer lumber	RM 100 - 250 / m2	0.33	$kgCO_2e/kg$
Steel	RM 3.60 / kg	1.46	$kgCO_2e/kg$



Roof

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Sawn softwood	RM 35 / m2	0.20	$kgCO_2e/kg$
Concrete roof tile*	RM 45 / m2	0.24	$kgCO_2e/kg$
Timber/Lumber/Wood*	RM 35 - 50 / m2	0.31	$kgCO_2e/kg$
Laminated veneer lumber	RM 100 - 250 / m2	0.33	$kgCO_2e/kg$
Glass, General*	RM 100-150/m2	1.44	$kgCO_2e/kg$
Glass, Multi layer safety, unfilled	RM 450 / m2	1.56	$kgCO_2e/kg$
Glass, Glazing, Double	RM 225-280 / m2	1.63	$kgCO_2e/kg$
Glass, Toughened	RM 500 / m2	1.67	$kgCO_2e/kg$
Glass, Glazing triple	RM 350 - 400 / m2	1.75	$kgCO_2e/kg$
Glass, Multi layer safety, filled core, fire resistant, toughened	RM 500 / m2	2.08	$kgCO_2e/kg$
Glass, sky light or roof, with frame (General)	RM 450 / m2	3.10	$kgCO_2e/kg$
Glass, sky light or roof, with frame	RM 450 / m2	3.10	$kgCO_2e/kg$
Corrugated Zinc Sheet*	RM 10 / m2	6.50	$kgCO_2e/kg$

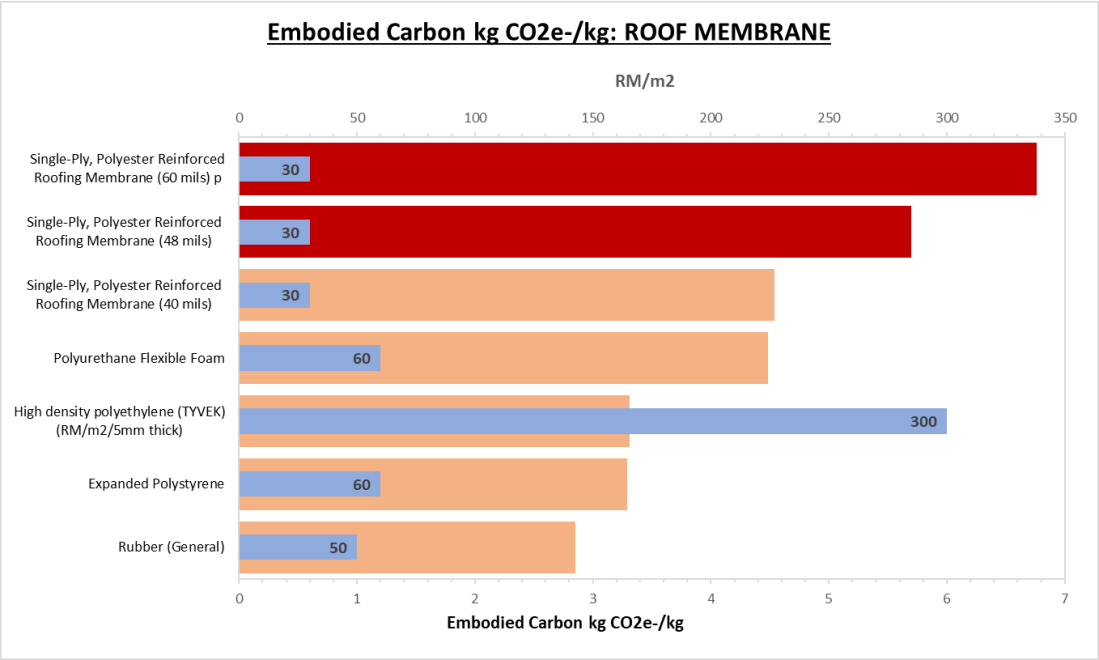
*Commonly used/ traditional material



Roof Membrane

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Rubber (General)*	RM 35 - 50 / m2	2.85	$kgCO_2e/kg$
Expanded Polystyrene	RM 50 - 60 / m2	3.29	$kgCO_2e/kg$
High density polyethylene (TYVEK)	RM 250 - 300 / m2 / 5mm thick	3.31	$kgCO_2e/kg$
Polyurethane Flexible Foam	RM 60 / m2	4.84	$kgCO_2e/kg$
Single-Ply, Polyester Reinforced Roofing Membrane (40 mils)	RM 20-30 / m2	4.54	$kgCO_2e/kg$
Single-Ply, Polyester Reinforced Roofing Membrane (48 mils)	RM 20-30 / m2	5.70	$kgCO_2e/kg$
Single-Ply, Polyester Reinforced Roofing Membrane (60 mils)	RM 20-30 / m2	6.76	$kgCO_2e/kg$

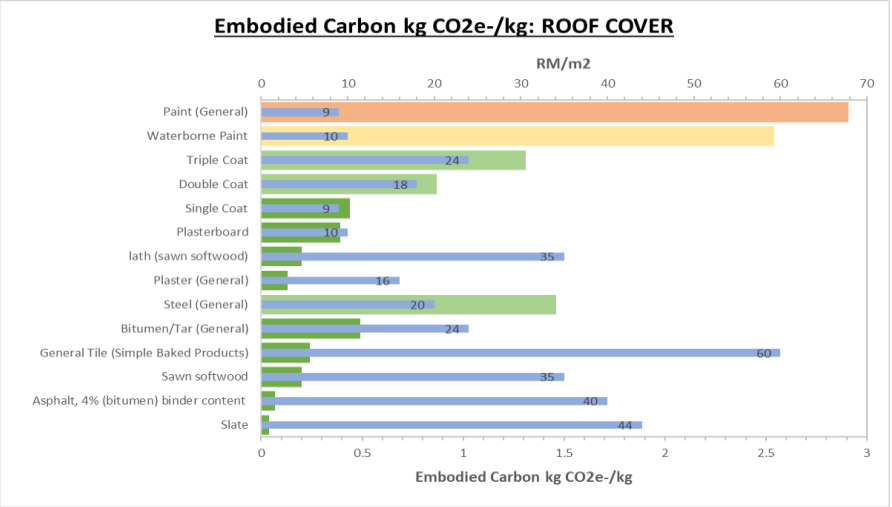
*Commonly used/ traditional material

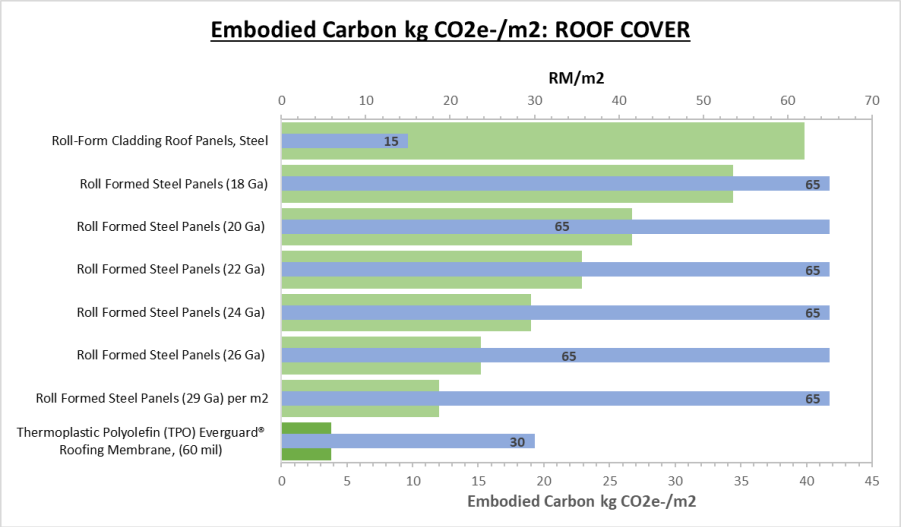


Roof Cover

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Slate	RM 44 / m2	0.04	$kgCO_2e/kg$
Asphalt, 4% (bitumen) binder content	RM 35 - 40 / m2	0.07	$kgCO_2e/kg$
Plaster (General)*	RM 12 - 16 / m2	0.13	$kgCO_2e/kg$
Sawn softwood	RM 35 / m2	0.20	$kgCO_2e/kg$
lath (sawn softwood)	RM 35 / m2	0.20	$kgCO_2e/kg$
General Tile (Simple Baked Products)*	RM 60 / m2	0.24	$kgCO_2e/kg$
Plasterboard	RM 7 - 10 / m2	0.39	$kgCO_2e/kg$
Single Coat	RM 9 / m2	0.44	$kgCO_2e/kg$
Bitumen/Tar (General)*	RM 24 / m2	0.49	$kgCO_2e/kg$
Double Coat	RM 18 / m2	0.87	$kgCO_2e/kg$
Triple Coat	RM 24 / m2	1.31	$kgCO_2e/kg$
Steel (General)*	RM 20 / m2	1.46	$kgCO_2e/kg$
Waterborne Paint	RM 10 / m2	2.54	$kgCO_2e/kg$
Paint (General)*	RM 6 - 9 / m2	2.91	$kgCO_2e/kg$
Roll Formed Steel Panels (29 Ga) per m2	RM 65 / m2	12.04	$kgCO_2e/m^2$
Roll Formed Steel Panels (26 Ga)	RM 65 / m2	15.2	$kgCO_2e/m^2$
Roll Formed Steel Panels (24 Ga)	RM 65 / m2	19.04	$kgCO_2e/m^2$
Roll Formed Steel Panels (22 Ga)	RM 65 / m2	22.9	$kgCO_2e/m^2$
Roll Formed Steel Panels (20 Ga)	RM 65 / m2	26.7	$kgCO_2e/m^2$
Thermoplastic Polyolefin (TPO) Everguard® Roofing Membrane, (60 mil)	RM 15 -30 / m2	3.8	$kgCO_2e/m^2$
Roll Formed Steel Panels (18 Ga)	RM 65 / m2	34.4	$kgCO_2e/m^2$
Roll-Form Cladding Roof Panels, Steel	RM 12 - 15 / m2	39.87	$kgCO_2e/m^2$

*Commonly used/ traditional material

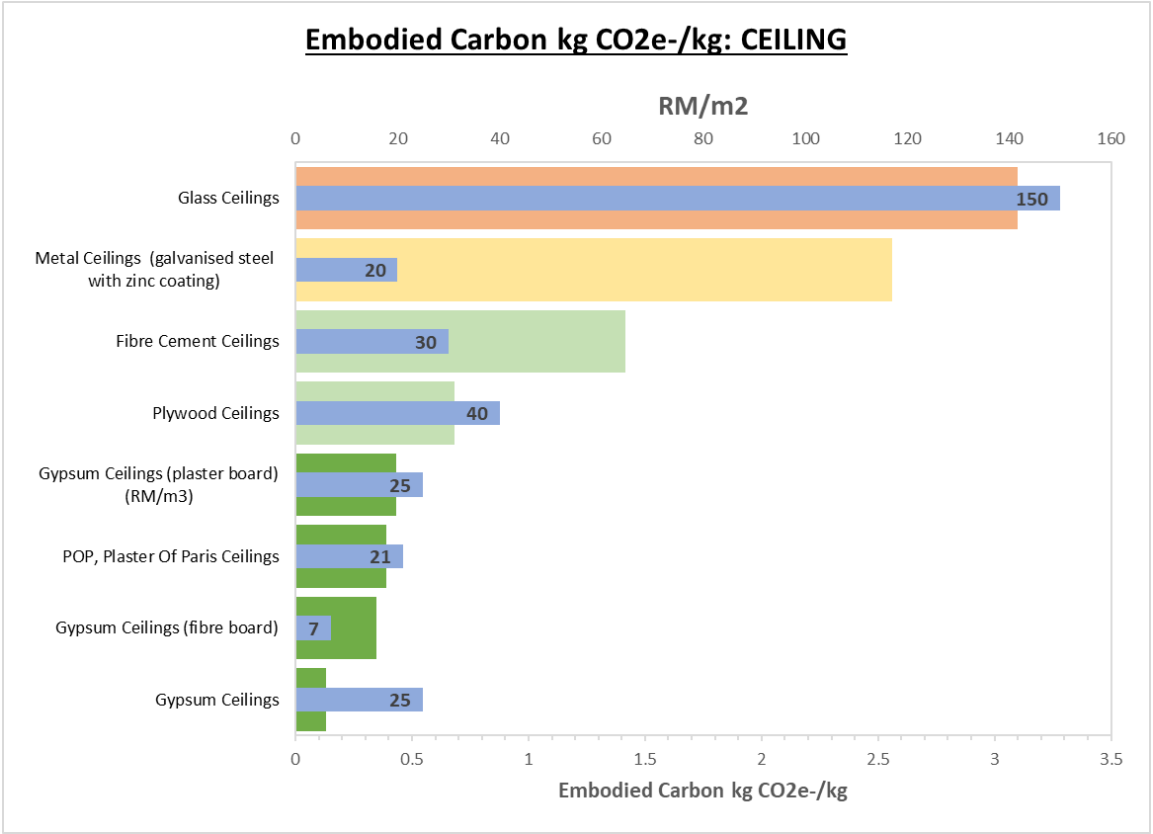




Ceiling

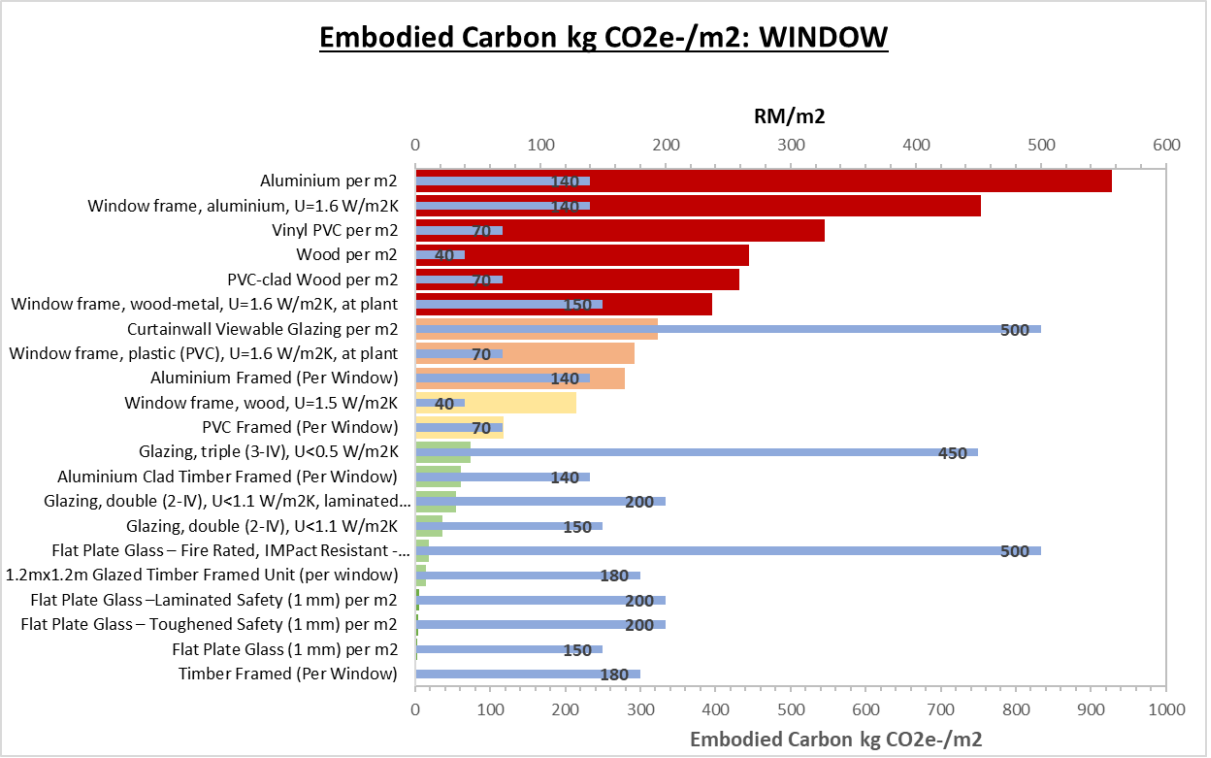
TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Gypsum Ceilings	RM 20 - 25 / m2	0.13	$kgCO_2e/kg$
Gypsum Ceilings (fibre board)*	RM 5 - 7 / m2	0.35	$kgCO_2e/kg$
POP, Plaster Of Paris Ceilings	RM 21 / m2	0.39	$kgCO_2e/kg$
Gypsum Ceilings (plaster board)*	RM 20 - 25 / m3	0.43	$kgCO_2e/kg$
Plywood Ceilings	RM 36 - 40 / m2	0.68	$kgCO_2e/kg$
Metal Ceilings (galvanised steel with zinc coating)	RM 20 / m2	2.56	$kgCO_2e/kg$
Glass Ceilings	RM 50 - 150 / m2	3.10	$kgCO_2e/kg$
Fibre Cement Ceilings*	RM 25 - 30 / m2	12.02	$kgCO_2e/m3$

*Commonly used/ traditional material



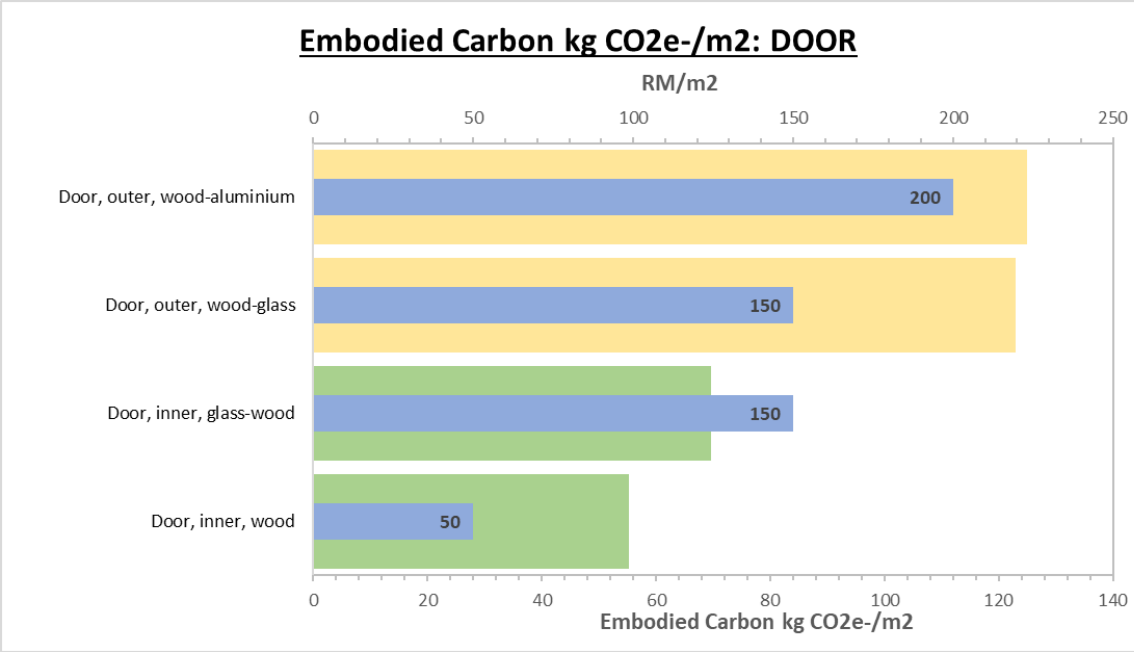
Window

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Timber Framed (Per Window)	RM 150-180 / m2	1.68	$kgCO_2$/window
Flat Plate Glass (1 mm) per m2	RM 50-150 / m2	2.67	kg CO_2e/m^2
Flat Plate Glass – Toughened Safety (1 mm) per m2	RM 150-200 / m2	3.65	$kgCO_2e/m^2$
Flat Plate Glass –Laminated Safety (1 mm) per m2	RM 150-200 / m2	5.42	kg CO_2e/m^2
1.2mx1.2m Glazed Timber Framed Unit (per window)	RM 150-180 / m2	14.60	$kgCO_2$/window
Flat Plate Glass – Fire Rated, IMPact Resistant - Keralite® F, per MT or per 81.3 m2	RM 300-500 / m2	18.45	kg CO_2e/m^2
Glazing, double (2-IV), U<1.1 W/m2K	RM 50-150 / m2	36.70	kg CO_2e/m^2
Glazing, double (2-IV), U<1.1 W/m2K, laminated safety glass	RM 150-200 / m2	54.70	kg CO_2e/m^2
Aluminium Clad Timber Framed (Per Window)	RM 120 - 140 / m2	61.50	$kgCO_2$/window
Glazing, triple (3-IV), U<0.5 W/m2K	RM 450 / m2	74.20	kg CO_2e/m^2
PVC Framed (Per Window)	RM 50 - 70 / m2	118.00	$kgCO_2$/window
Window frame, wood, U=1.5 W/m2K	RM 40 / m2	215.00	kg CO_2e/m^2
Aluminium Framed (Per Window)	RM 120 - 140 / m2	279.00	$kgCO_2$/window
Window frame, plastic (PVC), U=1.6 W/m2K, at plant	RM 50 - 70 / m2	292.00	kg CO_2e/m^2
Curtainwall Viewable Glazing per m2	RM 250 - 500 / m2	323.00	kg CO_2e/m^2
Window frame, wood-metal, U=1.6 W/m2K, at plant	RM 100 - 150 / m2	395.00	kg CO_2e/m^2
PVC-clad Wood per m2	RM 50 - 70 / m2	431.50	kg $CO_2e/m2$
Wood per m2	RM 40 / m2	444.20	kg CO_2e/m^2
Vinyl PVC per m2	RM 50 - 70 / m2	545.80	kg CO_2e/m^2
Window frame, aluminium, U=1.6 W/m2K	RM 120 - 140 / m2	754.00	kg CO_2e/m^2
Aluminium per m2	RM 120 - 140 / m2	928.50	kg CO_2e/m^2



Door

TYPES	MARKET PRICE	EMBODIED CARBON FACTOR	FUNCTIONAL UNIT
Door, inner, glass-wood	RM 100-150/m2	69.6	kg CO_2e/m^2
Door, inner, wood	RM 20-50/m2	55.2	kg CO_2e/m^2
Door, outer, wood-aluminium	RM 150-200 / m2	125	kg CO_2e/m^2
Door, outer, wood-glass	RM 100-150/m2	123	kg CO_2e/m^2



Case Study

4.1 Introduction

There is a need to calculate the embodied carbon of our work at the design stage, giving designers/engineers the ability to target carbon reductions of structures and other building elements through material selection, specification, efficiency and reuse. This section provides a very brief overview of calculating embodied carbon, focusing on building elements and construction materials.

4.2 Example of Case Study Calculation

Description of the Case Study A

The three commercial building is located at Jalan Kuchai Lama, Kuala Lumpur.

Description of the Case Study

The functional unit in this study is 1 m^2 of built-up area for the building material and construction phase with 2403 m^2 consisting of office room, meeting room, lobby, utility room, toilet, etc. The calculation example focused on the substructure, frame, external wall, internal wall, staircase, upper floor, roof and finishes.

Table 4.1 shows quantity of materials for typical structural element while **Table 4.2** presents embodied carbon factors that will be used for this Case Study.

Table 4.1: Quantity of materials for typical structural elements in Case Study A

Item	Materials	Quantity	Qty/m² (GFA)	Unit
A	*Substructure*			
	Concrete	284.37	0.11	**m³**
	Reinforcement	380139	158.2	**kg**
	Plywood	13.55	0.006	**m³**
B	*Frame*			
	Concrete	260	0.11	**m³**
	Steel section	163089	67.87	**kg**
C	*External Wall*			
	Pre-cast concrete	421419.5	175.37	**kg**
	Brick	63773.05	26.54	**kg**
	Steel rectangular hollow section	178300	74.2	**kg**
D	*Internal Wall*			
	Pre-cast concrete	170261.99	70.85	**kg**
	Dry wall partition	1711.5	0.71	**kg**
E	*Staircase*			
	Concrete	94.78	0.04	**m³**
	Reinforcement	64502	26.84	**kg**
F	*Upper Floor*			
	Pre-cast concrete	939629.64	391.02	**kg**
G	*Roof*			
	Pre-cast concrete	318383.92	132.5	**kg**
	Metal Deck	101.92	0.04	**kg**
	Fibre glass	101.92	0.04	**kg**
F	*Finishes*			
	Ceramic tiles	1819.34	0.76	**kg**
	Cement mortar	7200.34	3.0	**kg**
	Painting	**1126.25**	**0.47**	**kg**

Table 4.2: Embodied carbon coefficient factor for different types of materials in Case Study A (EC factor taken from Inventory)

Materials	ENVIRONMENTALLY SCALE	EMBODIED CARBON COEFFICIENT	FUNCTIONAL UNIT	BOUNDARY	SOURCES
Concrete RC32/40 with 30% PFA cement		0.12	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Reinforcement Bar		0.684	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	BRC 2019
Plywood		0.681	kg CO_2e/kg	Cradle to gate (Extraction to Manufacturing)	ICE (2019), SIRIM
Reinforcing steel		1.99	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Precast concrete		0.178	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Common bricks		0.21	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Steel, Section		1.55	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Plasterboard		0.39	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Ceramic Tile		0.78	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Waterborne paint		2.54	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Mortar (1:6)		0.110	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)
Glass, sky light or roof, with frame (General)		3.102	$kgCO_2e/kg$	Cradle to gate (Extraction to Manufacturing)	ICE (2019)

Embodied Carbon Calculation

The user needs to be familiar with lifecycle stages (in accordance with BS EN 15978 (2011)4 and BS EN 15804 (2019)5, which are used to define the amount of carbon released at the different stages of a material or product's life (**Figure 4.1**).

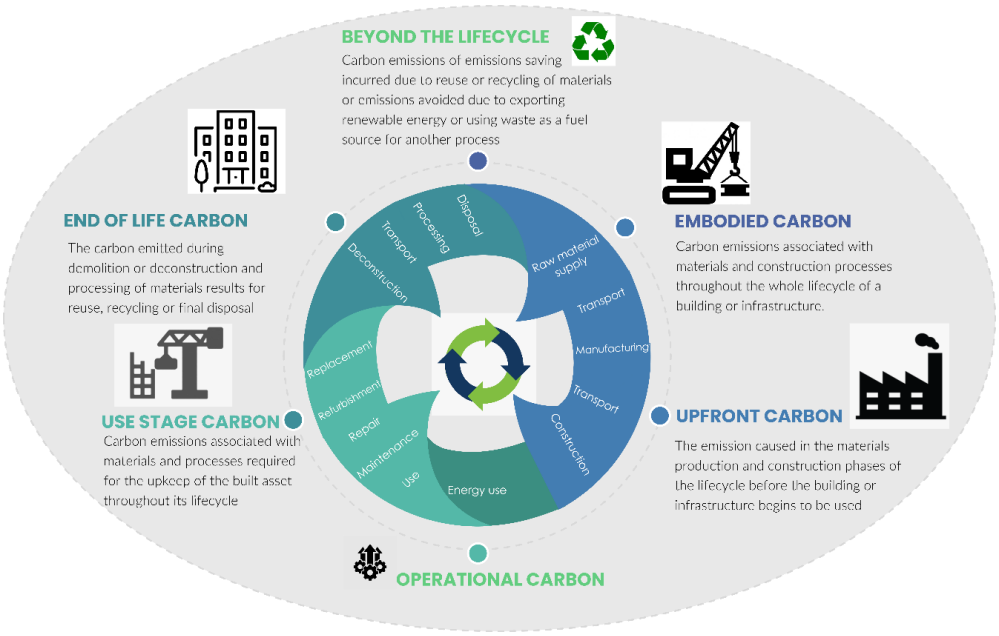


Figure 4.1: Life cycle of carbon emissions

This report only contains information on calculating carbon for the most typical structural materials during the production (A1–A3) and construction (A4–A5) stages, as these are likely to make up the vast majority of the embodied carbon and are therefore the emissions that must be addressed most urgently to respond to the climate emergency. **Table 4.3** presents lifecycles stages for the production (A1–A3) and construction (A4–A5) stages.

Table 4.3: Lifecycle stages

Lifecycle stage	Description
Production stage (A1–A3)	The extraction, processing, transportation and manufacture of materials and products up to the point where they leave the factory gate to be taken to site.
Transport (A4)	The transportation of materials and products from the factory gate to site.

Construction installation – material waste (A5w)	Extraction, processing, manufacture, transportation and end-of-life processing associated with materials wasted on site.

- Data in **Table 4.4, Table 4.5**, and **Table 4.6** have been adopted from published resources in order to perform the calculation of the Case Study. It is worth noting that real data obtained that consider the geographical, temporal, and locality context of the Case study is preferred for the accuracy of emissions estimation. In an event of the local data is absent, then the emissions factor from the published resources could be used to estimate the emissions.

- Embodied carbon for transportation within cradle-to-gate boundary should calculated based on the transportation of 1kg repair materials, mode and kg km emission factors of transport (in this case, should indicate all average mode of transportation used either tonnage, HGV and etc. and their respective tonnage, in Malaysian context). Info/data on body type, gross vehicle weight, and carbon emission gCO_2 per tonne km, and the shortest and most direct distance (travelled for material transportation from resourcing location to building site (in km) should be collected.

-Due to the absence of local data, the transport emissions factors are adopted from BEIS, 2020. *Greenhouse gas reporting: conversion factors 2020.* London, BEIS. Available online at https://carbon.tips/cf2020.

Table 4.4: Transport emissions factors for different modes of transport

Mode	TEFmode ($gCO_2e/kg/km$)	Descriptions
Road transport emissions	0.10650	*For HGV (all diesel)*
Sea transport emissions	0.01614	For cargo ship, container ship
Freight flight emissions	0.59943	International
Rail transport emissions	0.02556	Freight train

Source: (BEIS,2020)

Table 4.5: Transport emissions coefficient factors (TECF)

Transport Details	Emissions coefficient factors (ECF)
A4 Transport for locally manufactured with average distance travelled by road 50km	0.005 $kgCO_2e/kg$
A4 Transport for national with average distance travelled by road 300km	0.032 $kgCO_2e/kg$

Source: (BEIS,2020)

Table 4.6: Waste rate (WR) and waste factor (WF)

Waste	Waste rate (WR)	waste factor (WF)
Concrete in situ	5%	0.053
Precast concrete	1%	0.010
Steel reinforcement	5%	0.053
Brick	20%	0.250
Plasterboard	22.5%	0.290

Source: istructure.org

A4 Transport carbon factors

A4 emissions mainly concern the transport of materials and products from factory to site and constitute of <10% of the total embodied carbon of a structure. The A4 ECF depends on the mode of transport and distance travelled.

The A4 ECF is multiplied by the material quantity in the same way A1–A3 ECFs are.

Transport default emission factors are given in **Table 4.4** for different modes of transport, and default ECFs for the UK are given in **Table 4.5**. A more accurate estimate can be made once the material or product source has been identified.

A5w Material wastage

The A5w emissions factor accounts for the carbon emissions released during production, transportation, and disposal of wasted material. The factor itself represents the percentage estimate of how much of the material brought to site is

wasted (using a waste factor, WF) so that *the A5w factor can be multiplied by the same material quantity used for the A1–A3 calculations.*

The A5w factor is derived by multiplying the WF by the sum of the relevant ECFs:

A5w = WF × (A13 + A4 + C2 + C34)

where:

- WF is the waste factor, based on expected % waste rate **(Table 4.6)**

-A13 is A1–A3 emissions for production of the wasted material, **(Table 4.2)**

-A4 for transporting the wasted material to site **(Table 4.5)**

- C2 for transporting the wasted material away from site (in the absence of better data, assume 50km by road to the nearest reuse/recycling location = **0.005kgCO_2e/kg**)

- C34 is C3–C4 emissions for processing and disposal of the waste material (in the absence of better data, assume **1.77kgCO_2e/kg** for timber products and **0.013kgCO_2e/kg** for all other materials.

A. <u>Substructure</u>

1. Inputs	2. Calculations	3. Results
1.1 Quantities	<u>Concrete</u>	Embodied carbon per material:
Concrete = 284.37 x 2400kg/m^3 = 682.5t	A1–A3 (production) = 682.5t x 0.12 = 81.9tCO_2e	Concrete = 81.9 + 4.6 + 0.9 = 87.4tCO_2e
Reinforcement = 158.2 kg/m^2 x 2403 m^2 = 380.1t	A4 (transport) = 922.5t x 0.005 = 4.6tCO_2e	Reinforcement = 260 + 3.1 + 4.3 = 267.4tCO_2e
Plywood = 13.55 x 600 kg/m^3 = 8.1t	A5w (waste) = 109.7t x 0.008 = 0.9tCO_2e	Plywood = 5.5 + 0.005 + 0.76 = 6.27tCO_2e
1.2 Carbon factors	<u>Reinforcement</u>	Estimate of overall carbon footprint for sub structure element:
<u>Concrete</u>	A1–A3 (production) = 380.1t x 0.684 = 260tCO_2e	87.4tCO_2e + 267.4tCO_2e + 6.27 tCO_2e = **361.07tCO_2e**
A1–A3 (production) = 0.12kgCO_2e/kg	A4 (transport) = 97.1t x 0.032 = 3.1tCO_2e	
(from Table 4, RC32/40 with 25% GGBS as cement replacement)	A5w (waste) = 109.7t x 0.039 = 4.3tCO_2e	
A4 (transport) = 0.005kgCO_2e/kg	<u>Plywood</u>	

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.053 × (0.12 + 0.005 + 0.005 + 0.013)

= 0.008kgCO_2e/kg

(WF from Table 8, concrete in situ, and default C2 and C3–C4 values)

Reinforcement

A1–A3 (production) = 0.684kgCO_2e/kg

(from Table 4, typical K Specific Rebar)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.053 × (0.684 + 0.032 + 0.005 + 0.013) = 0.039kgCO_2e/kg

Plywood

A1–A3 (production) = 0.681kgCO_2e/kg

(from Table 4, typical Plywood 100% FSC/PEFC)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.010 × (0.681 + 0.032 + 0.005 + 0.013) = 0.007kgCO_2e/kg

A1–A3 (production) = 8.1t x 0.681 = 5.5tCO_2e

A4 (transport) = 0.16t x 0.032 = 0.005tCO_2e

A5w (waste) = 109.7t x 0.007 = 0.76tCO_2e

B. Frame

1. Inputs

1.1 Quantities

Concrete = 260 x 2400kg/m^3 = 624t

Steel section = 2403 x 30 kg/m^2 = 72.1t

1.2 Carbon factors

Concrete

A1–A3 (production) = 0.12kgCO_2e/kg

(from Table 4, RC32/40 with 25% GGBS as cement replacement)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.053 × (0.12 + 0.005 + 0.005 + 0.013)

= 0.008kgCO_2e/kg

(WF from Table 8, concrete in situ, and default C2 and C3–C4 values)

Steel section

A1–A3 (production) = 1.99kgCO_2e/kg

(from Table 4, Steel)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

2. Calculations

Concrete

A1–A3 (production) = 624t x 0.12 = 74.9tCO_2e

A4 (transport) = 771.1t x 0.005 = 3.9tCO_2e

A5w (waste) = 78.8t x 0.008 = 0.6tCO_2e

Steel section

A1–A3 (production) = 72.1t x 1.99 = 143.5tCO_2e

A4 (transport) = 17.1t x 0.032 = 0.54tCO_2e

A5w (waste) = 78.8t x 0.025 = 1.97tCO_2e

3. Results

Embodied carbon per material:

Concrete = 74.9 + 3.9 + 0.6 = 79.4tCO_2e

Steel section = 143.5 + 0.54 + 1.97 = 146.01tCO_2e

Estimate of overall carbon footprint for frame element:

79.4tCO_2e + 146.01tCO_2e = **225.41tCO_2e**

A5w (waste) = 0.010 × (2.45 + 0.032 + 0.005

+ 0.013) = 0.025kgCO_2e/kg

(WF from Table 8, steel frame, and default C2 and C3–C4 values)

C. External Wall

1. Inputs

1.1 Quantities

Pre-cast concrete = 175.4 kg/m^2 x 2403 m^2 = 421.4t

Brick = 26.54 kg/m^2 x 2403 m^2 = 63.8t

Steel rectangular hollow section = 74.2 kg/m^2 x 2403 m^2 = 178.3t

1.2 Carbon factors

Pre-cast concrete

A1–A3 (production) = 0.178kgCO_2e/kg

(from Table 4, Unreinforced, C40/50 with average cement mix)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.010 × (0.178 + 0.005 + 0.005 + 0.013)

2. Calculations

Pre-cast concrete

A1–A3 (production) = 421.4t x 0.178 = 75tCO_2e

A4 (transport) = 119.6t x 0.005 = 0.6tCO_2e

A5w (waste) = 71.4t x 0.002 = 0.14tCO_2e

Brick

A1–A3 (production) = 63.8t x 0.213 = 13.6tCO_2e

A4 (transport) = 0.98t x 0.032 = 0.03tCO_2e

A5w (waste) = 71.4t x 0.065 = 4.6tCO_2e

Steel rectangular hollow section

A1–A3 (production) = 178.3t x 1.55 = 276.4tCO_2e

A4 (transport) = 20.2t x 0.032 = 0.64tCO_2e

A5w (waste) = 71.4t x 0.010 = 0.71tCO_2e

3. Results

Embodied carbon per material:

Pre-cast Concrete = 75 + 0.6 + 0.14 = 75.7tCO_2e

Brick = 13.6 + 0.03 + 4.6 = 18.2tCO_2e

Steel rectangular hollow section = 276.4 + 0.64 + 0.71 = 277.8tCO_2e

Estimate of overall carbon footprint for external wall element:

75.7tCO_2e + 18.2tCO_2e + 277.8tCO_2e = **371.7tCO_2e**

= 0.002kgCO_2e/kg

(WF from Table 8, precast, and default C2 and C3–C4 values)

Brick

A1–A3 (production) = 0.213kgCO_2e/kg

(from Table 4)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 4, assume Nationally manufactured)

A5w (waste) = 0.25 × (0.213 + 0.032 + 0.005

+ 0.013) = 0.065kgCO_2e/kg

Steel rectangular hollow section

A1–A3 (production) = 1.55kgCO_2e/kg

(from Table 4, Steel section)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.010 × (1.55 + 0.032 + 0.005

+ 0.013) = 0.016kgCO2e/kg

D. Internal Wall

1. Inputs	2. Calculations	3. Results
1.1 Quantities	Pre-cast concrete	Embodied carbon per material:
Pre-cast concrete = 70.85 kg/m^2 x 2403 m^2 = 170t	A1–A3 (production) = 170t x 0.178 = 30.26tCO_2e	Pre-cast Concrete = 30.3 + 0.09 + 0.03 = 30.42tCO_2e
Dry wall partition = 0.71 kg/m^2 x 2403 m^2 = 1.7t	A4 (transport) = 19.3t x 0.005 = 0.09tCO_2e	Dry wall partition = 0.66 + 0.0002 + 2.2 = 2.86tCO_2e

1.2 Carbon factors

Pre-cast concrete

A1–A3 (production) = 0.178kgCO_2e/kg

(from Table 4, Unreinforced, C40/50 with average cement mix)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.010 × (0.178 + 0.005 + 0.005 + 0.013)

= 0.002kgCO_2e/kg

(WF from Table 8, precast, and default C2 and C3–C4 values)

Dry wall partition/plasterboard

A1–A3 (production) = 0.39kgCO_2e/kg

(from Table 4, Minimum 60% recycled content)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.29 × (0.39 + 0.032 + 0.005

+ 0.013) = 0.13kgCO_2e/kg

A5w (waste) = 17.2t x 0.002 = 0.03tCO_2e

Dry wall partition

A1–A3 (production) = 1.7t x 0.39 = 0.66tCO_2e

A4 (transport) = 0.006t x 0.032 = 0.0002tCO_2e

A5w (waste) = 17.2t x 0.13 = 2.2tCO_2e

Estimate of overall carbon footprint for internal wall element:

30.42tCO_2e + 2.86tCO_2e = **33.28tCO_2e**

E. Staircase

1. Inputs

1.1 Quantities

Concrete = 94.78 x 2400kg/m^3 = 227.4t

Reinforcement = 26.84 kg/m^2 x 2403 m^2 = 64.5t

1.2 Carbon factors

Concrete

A1–A3 (production) = 0.12kgCO_2e/kg

(from Table 4, RC32/40 with 25% GGBS replacement)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.053 × (0.12 + 0.005 + 0.005 + 0.013)

= 0.008kgCO2e/kg

(WF from Table 8, concrete in situ, and default C2 and C3–C4 values)

Reinforcement

A1–A3 (production) = 0.684kgCO_2e/kg

(from Table 4, typical Specific Rebar)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.053 × (0.684 + 0.032 + 0.005

+ 0.013) = 0.039kgCO_2e/kg

2. Calculations

Concrete

A1–A3 (production) = 227.4t x 0.12 = 27.3tCO_2e

A4 (transport) = 103.6t x 0.005 = 0.51tCO_2e

A5w (waste) = 29.2t x 0.008 = 0.23tCO_2e

Reinforcement

A1–A3 (production) = 64.5t x 0.684 = 44.1tCO_2e

A4 (transport) = 3.66t x 0.032 = 0.12tCO_2e

A5w (waste) = 29.2t x 0.039 = 1.14tCO_2e

3. Results

Embodied carbon per material:

Concrete = 27.3 + 0.51 + 0.23 = 28.04tCO_2e

Reinforcement = 44.1 + 0.12 + 1.14 = 45.4tCO_2e

Estimate of overall carbon footprint for staircase element:

28.04tCO_2e + 45.4tCO_2e = **73.44tCO_2e**

F. UPPER FLOOR

1. Inputs

1.1 Quantities

Pre-cast concrete = 391.02 kg/m^2 x 2403 m^2 = 939.6t

1.2 Carbon factors

Pre-cast concrete

A1–A3 (production) = 0.178kgCO_2e/kg

(from Table 4, Unreinforced, C40/50 with average cement mix)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.010 × (0.178 + 0.005 + 0.005 + 0.013)

= 0.002kgCO_2e/kg

(WF from Table 8, precast, and default C2 and C3–C4 values)

2. Calculations

Pre-cast concrete

A1–A3 (production) = 939.6t x 0.178 = 167.3tCO_2e

A4 (transport) = 560.4t x 0.005 = 2.8tCO_2e

A5w (waste) = 93.9t x 0.002 = 1.9tCO_2e

3. Results

Embodied carbon per material:

Pre-cast Concrete = 167.3 + 2.8 + 1.9 = 172tCO_2e

Estimate of overall carbon footprint for upper floor element:

172tCO_2e

G. ROOF

1. Inputs

1.1 Quantities

Pre-cast concrete = 132.5 kg/m^2 x 2403 m^2 = 318.4t

Roof sky light glass with frame = 0.04 kg/m^2 x 2403 m^2 = 0.1t

2. Calculations

Pre-cast concrete

A1–A3 (production) = 318.4t x 0.178 = 56.67tCO_2e

A4 (transport) = 19.3t x 0.005 = 0.09tCO_2e

A5w (waste) = 17.2t x 0.002 = 0.03tCO_2e

3. Results

Embodied carbon per material:

Pre-cast Concrete = 56.67 + 0.09 + 0.03 = 56.79tCO_2e

Roof sky light glass with frame = 0.31 + 0.0002 + 15.7 = 16.01tCO_2e

1.2 Carbon factors

Pre-cast concrete

A1–A3 (production) = 0.178kgCO_2e/kg

(from Table 4, Unreinforced, C40/50 with average cement mix)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 7, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.010 × (0.178 + 0.005 + 0.005 + 0.013)

= 0.002kgCO_2e/kg

(WF from Table 8, precast, and default C2 and C3–C4 values)

Roof sky light glass with frame

A1–A3 (production) = 3.102kgCO_2e/kg

(from Table 4, Roof sky light glass with frame)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.29 × (3.102 + 0.032 + 0.005

+ 0.013) = 0.914kgCO2e/kg

Roof sky light glass with frame

A1–A3 (production) = 0.1t x 3.102 = 0.3102tCO_2e

A4 (transport) = 0.006t x 0.032 = 0.0002tCO_2e

A5w (waste) = 17.2t x 0.914 = 15.7tCO_2e

Estimate of overall carbon footprint for roof element:

56.79tCO_2e + 16.01tCO_2e = **72.8tCO_2e**

H. FINISHES

1. Inputs

1.1 Quantities

Ceramic tiles = 0.76 kg/m^2 x 2403 m^2 = 1.8t

Cement mortar = 3.0 kg/m^2 x 2403 m^2 = 7.2t

Painting = 0.47 kg/m^2 x 2403 m^2 = 1.1t

1.2 Carbon factors

Ceramic

A1–A3 (production) = 0.78kgCO_2e/kg

(from Table 4, Unreinforced, C40/50 with average cement mix)

A4 (transport) = 0.005kgCO_2e/kg

(from Table 4, assume locally manufactured)

A5w (waste)

= WF × (A1–A3 + A4 + C2 + C3–C4)

= 0.010 × (0.78 + 0.005 + 0.005 + 0.013)

= 0.008kgCO_2e/kg

(WF from Table 5, precast, and default C2 and C3–C4 values)

Painting

A1–A3 (production) = 2.54kgCO_2e/kg

(from Table 4, Waterborne paint)

A4 (transport) = 0.032kgCO_2e/kg

(from Table 7, assume Nationally manufactured)

A5w (waste) = 0.111 × (2.54 + 0.032 + 0.005

+ 0.013) = 0.29kgCO2e/kg

2. Calculations

Ceramic Tiles

A1–A3 (production) = 1.8t x 0.78 = 1.4tCO_2e

A4 (transport) = 0.003t x 0.005 = 0.0000tCO_2e

A5w (waste) = 1.0t x 0.008 = 0.008tCO_2e

Ceramic Mortar

A1–A3 (production) = 7.2t x 0.78 = 5.6tCO_2e

A4 (transport) = 0.12t x 0.005 = 0.0006tCO_2e

A5w (waste) = 1.0t x 0.008 = 0.008tCO_2e

Painting

A1–A3 (production) = 1.1t x 2.54 = 2.79tCO_2e

A4 (transport) = 0.12t x 0.032 = 0.004tCO_2e

A5w (waste) = 1.0t x 0.26 = 0.26tCO_2e

3. Results

Embodied carbon per material:

Ceramic = 1.4 + 5.6 + 0.0006 + 0.016 = 7.02tCO_2e

Painting = 2.79 + 0.004 + 0.26 = 3.1tCO_2e

Estimate of overall carbon footprint for finishes element:

7.02tCO_2e + 3.1tCO_2e = **10.12tCO_2e**

Estimate of overall carbon footprint for the commercial building, based on eight (8) elements (A–H), based on building area of 2,403m^2:

Table 4.7: Overall carbon footprint according to building element

No.	Building Element	Carbon footprint value (tCO_2e)
A	Sub Structure	361.07
B	Frame	99.3
C	External Wall	371.7
D	Internal wall	33.28
E	Staircase	73.44
F	Upper Floor	172
G	Roof	72.8
H	Finishes	10.12

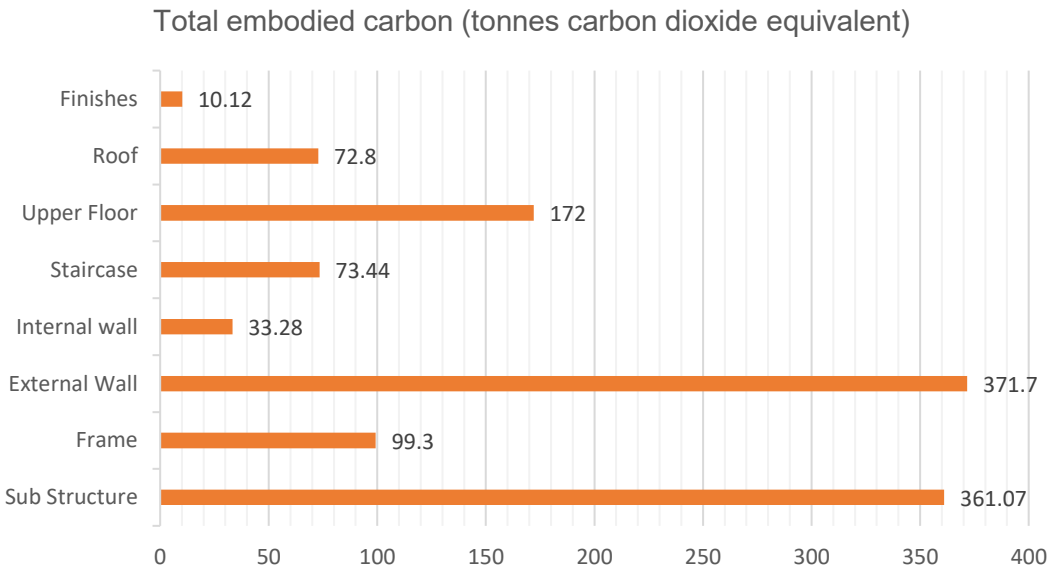


Figure 4.2: Total embodied carbon (tCO_2e) in Case Study A

Embodied Carbon Reduction Strategies

This report aims to provide clear and practical guidelines on how to proceed with assessing embodied carbon in buildings. This may be beneficial to the targeted audience who recognize the relevance of embodied carbon and seek to conduct an embodied carbon assessment but are unclear where to begin. Several carbon mitigation initiatives worth considering include the following:

- Avoid or minimise the use of materials with a high embodied energy. Unless they assist in lowering operational energy, this may comprise sourcing materials locally and saving on the transportation energy.
- Reuse materials. Anytime necessary, seek to recover resources like brick, metals, fractured concrete, or wood. Salvaged resources often have a significantly smaller embodied carbon footprint than freshly made materials since they have consumed the carbon to produce them. Using recovered wood for instance, users conserve the energy that would have been wasted in chopping down the tree, moving it to the mill, and processing it, but the tree that never chopped down still does the task of carbon sequestration.
- Develop a lifelong and persistent structure. As deconstruction permits for simple reuse and recycling. Low-carbon design features comprise exposed concrete ceilings, aerated blockwork, rotational piles, and voided biaxial slabs, as well as low-carbon substitutes to typical building supplies. This necessitates direct parallels of possible measures to choose the optimum carbon-efficient one.
- Utilise materials with a high recyclable composition. This is especially relevant for metals. For instance, virgin steel might have a fivefold greater embodied carbon footprint than steel with high recycled content. Select supplies with high recycled content, like cement substitutes such as GGBS (ground granulated blast furnace slag) or PFA (pulverised fuel ash), have been the quickest easy solutions on certain projects.
- Reuse existing infrastructures rather than developing new ones. Compared to new construction, renovation and reuse projects mainly conserve approximately 50% and 75% of the embodied carbon emissions. This is notably important if the substructure and framework are intact, as it retains the majority of embodied carbon.

- Imply the usage of low-carbon concrete compositions. While emissions per tonne are not extremely significant, concrete's mass and prevalence make it the primary generator of embodied carbon in every project. Collaborating with structural engineers to develop low-carbon concrete compositions that combine fly ash, slag, calcined clays, and even lower-strength concrete could be the solution. While access to these components varies by region, there are practical steps that may be taken to reduce the concrete blend's carbon footprint.
- Boost structural efficiency to the maximum. Since the majority of embodied carbon in the construction, explore strategies to optimise structural efficiency. Applying optimal value engineering approaches for wood framing, efficient structural components, and slabs ultimately maximizes efficiency and minimize material use.
- Reduce the reliance on carbon-intensive materials. Responsible use is crucial for materials with a large carbon footprint, like aluminium, polymers, and foam insulation. For example, while aluminium may enhance the appearance of the building, it is vital to use it sparingly given its enormous carbon footprint.
- Consider carbon-neutral approaches. Contemplate the alternatives. If a wood structure can replace steel and concrete, or if wood siding can be used in a vinyl substitute, the embodied carbon project can be lessened. While it is unlikely that it would be practicable to entirely eschew carbon-intensive products—metals, plastics, and aluminium—it is essential to opt for lower-carbon replacements.
- Reducing the waste. Module design enables lower waste in wood-framed home construction. Consider 4x8 plywood, 12-foot gypsum boards, 2-foot wood framing increments, and pre-cut structural elements.
- Employ carbon sequestering materials. Implementing carbon-sequestering agricultural products can substantially lower a project's embodied carbon. Whilst wood is a natural choice, explore alternatives such as straw or hemp insulation, which, unlike wood, are continuously renewable.
- Use lesser finish materials. Using structural materials as finishing is one method. Finished polished concrete slabs cut embodied carbon versus carpet or vinyl, and unfinished ceilings can also decrease embodied carbon.

GLOSSARY

Building component
A prefabricated assembly of materials that form a product with a specific function, e.g., a precast concrete floor unit, a facade unit.

Building element
A major physical part of a building that fulfils a specific function, or functions, irrespective of its design, specification, or construction, e.g., floors, frame, external walls.

Carbon factor
Normally measured in kgCO2e per unit of product e.g., kgCO2e/kg.

Cradle-to-gate
Carbon emissions between the confines of the 'cradle' (earth) up to the factory gate of the final processing operation. This includes mining, raw materials extraction, processing and manufacturing.

Cradle-to-site
Cradle-to-gate emissions plus delivery to the site of use (construction/installation site).
Cradle-to-end of construction
Cradle-to-site plus construction and assembly on site.

Cradle-to-grave
Cradle-to-end of construction plus maintenance, refurbishments, demolition, waste treatment and disposals ('grave').

Cradle-to-cradle
The process of making a component or product and then, at the end of its life, converting it into a new component of a) the same quality (e.g., recycling of aluminium cans) or b) a lesser quality (downcycling of a computer plastic case into a plastic container, which is then turned into a building insulation board, eventually becoming waste).

Embodied carbon
Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or

products. Embodied carbon can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typically embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO2e per kilogram of product or material.

Global Warming Potential (GWP)
A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO2e, which has a GWP of 1.

kgCO2e
Carbon dioxide equivalent emissions. This can also be referred to as 'global warming potential' (GWP).

Life Cycle Assessment
Systematic analysis of the potential environmental impacts of products or services during their entire life cycle.

Life Cycle Inventory
Life cycle inventory (LCI) is the methodology step that involves creating an inventory of input and output flows for a product system.

Operational carbon
Carbon emissions association with energy consumption (operational energy) while the building is occupied. This includes the so-called regulated load (e.g., heating, cooling, ventilation, lighting) and unregulated/plug load (e.g., ICT equipment, cooking and refrigeration appliances).

Recycled Content
The portion of a product that contains materials that have been recovered or otherwise diverted from the solid waste stream.

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Datuk Ir. Ahmad 'Asri Abdul Hamid
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Ir. M. Ramuseren
Ts Fuhairah Binti Ahmad Fuad
Afiq Shazwan Mukhtar

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Dato' Ir Rohaizi bin Mohd Jusoh
Mohammad Faizal bin Abdul Hamid
Ts Dr Mohd Khairolden Bin Ghani
Mhd.Jumain Bin Mapplati

The working team from Universiti Teknologi MARA (UiTM);

Lead Author:
Ts. Dr. Nur Kamaliah Mustaffa

Working Team:
Dr. Sakhiah Abdul Kudus
Dr. Zadariana Jamil @Osman
Assoc. Prof. Ts. Dr. Che Khairil Izam Che Ibrahim

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