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International Finance Corporation (IFC)

MAGC Research - Study of Embodied Carbon in New Building Materials

Methodology and Findings Report

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Figures

Glossary of Terms and Abbreviations

Term or abbreviation	Meaning
BF	Blast furnace (for iron production)
BOF	Basic oxygen furnace (for steel production)
CC	Calcined clay
CCS	Carbon capture and storage
CLT	Cross-laminated timber
DESNZ	Department for Energy Security and Net Zero
DRI	Direct reduced iron (for iron production)
EAF	Electric arc furnace (for steel production)
EDGE	Excellence in Design for Greater Efficiencies
EDGE V4	EDGE Version 4
EN 15804	EN 15804:2012+A2:2019 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products
EN 206	BS EN 206:2013+A2:2021 Concrete. Specification, performance, production and conformity
EPD	Environmental Product Declaration
FA	Fly ash
GGBS	Ground-granulated blast furnace slag
GHG	Greenhouse gas
GIA	Gross internal area
GLEC	Global Logistics Emissions Council
Glulam	Glue laminated timber
GWP	Global warming potential
HGV	Heavy goods vehicle
IEA	International Energy Agency
LC3	Limestone calcined clay cement
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LPG	Liquified petroleum gas
LS	Limestone / ground limestone
MAGC	Market Accelerator for Green Construction

Term or abbreviation	Meaning
MDF	Medium Density Fibreboard
MENA	Middle East and North Africa
MEP	Mechanical, electric and public health equipment, a.k.a., building services.
ODCi	Open Data for Climate initiative
OPC	Ordinary Portland Cement, which is typically comprised of around 95% Portland cement clinker and 5% gypsum.
PC	Portland cement, a term often used interchangeably with OPC.
RDF	Refuse derived fuel
RICS PS / RICS PS 2nd Edition	Royal Institution of Chartered Surveyors Professional Standard on *Whole life carbon assessment for the built environment*, 2nd edition (2023).
RSP	Reference study period
SCM	Supplementary cementitious material
TDUK	Timber Development UK
TTW	Tank-to-wheel emissions, i.e., the greenhouse gases and pollutants released directly from a vehicle while it is in operation, often known as "tailpipe emissions". It covers the combustion of fuel in the engine but excludes upstream emissions from fuel production.
WLCA	Whole life carbon assessment
WTT	Well-to-tank emissions, i.e., the greenhouse gas (GHG) emissions generated during the production, processing, and distribution of a fuel—from the point of extraction or generation (the "well") to the point it is stored in a vehicle's tank.
UN COMTRADE	United Nations Commodity Trade Statistics Database

Executive Summary

This report summarises work on Tasks 2 (selection of materials) and 3 (embodied carbon and energy estimates) of the project titled *MAGC Research – Study of Embodied Carbon in New Building Materials* for the International Finance Corporation (IFC).

Context

Excellence in Design for Greater Efficiencies (EDGE), developed by IFC, is an online application for certifying green buildings in developed and developing countries. EDGE users must demonstrate at least 20% reductions in embodied carbon, water and energy use compared to the base case to achieve certification. This requires robust and regionally relevant estimates of the embodied carbon and energy of conventional and lower carbon building materials, including concrete, steel, timber and bamboo. Hence, the objective of this study was to develop embodied carbon and energy estimates for these four key structural materials, covering all global regions. The estimates developed for this study are to be used to estimate upfront carbon and energy in EDGE V4, due for release in H2 2027.

Methodology

An 'Embodied Carbon and Energy Model' was developed for this study. This parametric model calculates embodied carbon and energy for various material-region combinations (e.g., steel rebar in Africa). The model is fully transparent and updatable. References are presented for all input parameters, assumptions stated explicitly where relevant, and data quality and relevance highlighted throughout.

The model uses publicly available data, ensuring the model and its outputs can be made freely available and used by IFC in EDGE, avoiding reliance on third-party background data providers. The model mainly uses existing data from the literature; however, primary data was also collected from suppliers for bamboo.

Product-level embodied carbon and energy life-cycle analysis (LCA) calculations are aligned with the modular structure presented in EN 15804:2012+A2:2019. EDGE V4 will only include upfront carbon (LCA modules A0-A5), meaning it will not include biogenic carbon. However, datasets developed for this project cover the full life cycle (LCA modules A-C, including biogenic carbon), enabling future EDGE versions to expand to also cover the full life cycle. Building-level calculations are aligned with the Royal Institution of Chartered Surveyors Professional Standard on *Whole life carbon for the built environment* (RICS PS) 2nd edition (2023), which is globally applicable and recognised as best practice.

Over 500 datasets for both conventional and lower carbon materials have been developed for concrete, steel, timber and bamboo. Regional datasets – covering Africa, Middle East, Central and South America, Oceania, Asia, North America and Europe – were developed for virtually all key materials. Additional country-level datasets were also developed for bamboo and calcined clay-based concrete, to reflect the localised nature of production and consumption of these materials.

Findings

Concrete's embodied carbon is primarily driven by the binder (cement) content, binder type, and region. Emission reductions can be achieved through efficient design to used less concrete, efficient concrete mix design to reduce binder content, and/or use of supplementary cementitious materials (SCMs), such as ground-granulated blast furnace slag (GGBS), fly ash, calcined/activated clay and ground limestone to replace Portland cement clinker. Regional variations in the emissions intensity of concrete are primarily driven by differences in the use of alternative and biomass fuels in Portland cement clinker production, the emissions intensity of electricity generation, and regional trade.

Steel embodied carbon is driven largely by steel's recycled content, the prevalence of electric arc furnace (EAF) versus basic oxygen furnace (BOF) steel production, and emissions intensity of electricity generation. However, since steel scrap is globally resource-constrained, regional LCA datasets for steel contain the regional average recycled content. EDGE users should therefore focus on using steel efficiently on projects to reduce steel-related emissions.

Timber and **bamboo** are both lower carbon structural materials, with the embodied emissions depending primarily on the level of processing of the product. EDGE users should be mindful of transportation distances and associated emissions for these materials, ensure they are sustainably sourced, and check they are disposed of in a way which reduces the risks of methane emissions, to reduce life cycle emissions.

Future developments

Recommended future developments considered highest priority include:

1. Establishing a regular update cycle – e.g., every 5 years – for existing datasets, to capture the latest publicly available production-related data.
2. Expanding the model to include emerging but not yet widely available materials such as Portland cement clinker production with carbon capture and storage (CCS), lower carbon primary steel production methods, and calcined clay concrete and bamboo in countries where they are not yet produced at scale. Country-level datasets can also be added to complement the region-level datasets developed for this study.
3. Using the model as a framework to collect additional product/producer- and region-specific LCA data from EDGE users and collaborators.
4. Expanding the model to include other high-impact materials such as bricks, aluminium and glass.
5. Expanding the scope of LCAs in future EDGE versions to include the whole life cycle, including life cycle biogenic carbon emissions.

1. Introduction

1.1 Background

The Excellence in Design for Greater Efficiencies (EDGE) application, developed by the International Finance Corporation (IFC), is an online application used to certify green buildings in developed and developing countries. Part of the EDGE application's functionality is to estimate the embodied carbon of buildings, i.e. the emissions associated with materials and construction processes throughout the building's life cycle. Buildings can be EDGE Certified if they can demonstrate an embodied carbon reduction of 20% or more compared to the baseline, together with the same 20% reductions in operational energy and water consumption. It is therefore essential that EDGE contain robust embodied carbon data, and calculation methods, for both conventional and lower carbon building materials in all global regions.

1.2 Project details

This project, titled *MAGC Research – Study of Embodied Carbon in New Building Materials* (hereafter referred to as the MAGC Research Project), was undertaken for the IFC over a 27-month period from April 2024 to June 2026, under the research component of the UK-IFC Market Accelerator for Green Construction (MAGC) Program. The project delivery team, led by Arup, also consisted of members from Building Transparency[1], EBP Chile, Sintali and ConstructionLCA.

The project purpose was to develop life-cycle analysis (LCA) datasets for structural materials including concrete, steel, timber and bamboo, covering seven global regions: Asia, Africa, the Middle East, North America, Central and South America, Europe and Oceania. These product-level datasets are to be made available within the EDGE V4 application, to facilitate building-level whole life carbon assessments (WLCAs) as part of the EDGE certification process.

Previous projects have been undertaken to provide product-level LCA datasets for use within EDGE. However, these datasets currently only provide data for LCA modules A1-A3, i.e., raw material supply, transport and manufacturing, as shown in Figure 1. While these 'product stage' emissions typically account for a large proportion of the life cycle emissions of structural materials, construction stage (modules A4-A5), use stage (module B) and end-of-life stage (module C) emissions can also be significant. Therefore, this study aims to expand the LCA scope to include the whole life cycle from cradle to grave (i.e., including LCA modules A-C), and, as needed, to expand the range of lower carbon materials available for selection within EDGE.

This project is divided into six main tasks, as follows.

- Task 1: Workplan.
- Task 2: List of countries and materials to be included in the study.
- Task 3: Embodied carbon and energy estimates for all materials.
- Task 4: Methodology and Findings Report (this report).
- Task 5: Training materials for EDGE users on including less carbon intensive materials on projects.
- Task 6: Updated EDGE Materials Reference Guide.

This report is the output of Task 4 and summarises the methodology adopted for, and findings from, Tasks 2 and 3. The findings outlined in this report also inform and are coordinated with the deliverables for Tasks 5 and 6.

[1] Building Transparency lead the Open Data for Climate Initiative (ODCi), which aims to provide global, freely accessible, verified, and standardised construction materials life-cycle assessment (LCA) data to the public, covering LCA modules A1-A3. However, at the time of writing, the ODCi is yet to complete, with progress stalled due to reliance on third-party background data for the LCAs.

1.3 Scope of this report

The purpose of this report is to outline the methodology adopted for producing the product cradle-to-grave LCA datasets, and for calculating *building-level* embodied carbon and energy in EDGE for LCA modules A5.1 (pre-construction demolition), A5.2 (site activities), B2 (maintenance), B3 (repair) and C1 (deconstruction).

Section 2 of the report outlines the methodology adopted for this project, including the LCA scope adopted (section 2.1), how material-region combinations were selected (section 2.2), the approach to resource-constrained materials (section 2.3) and data sources used for the project (section 2.4). Section 2.5 then sets out, module-by-module, the approach adopted or recommended for calculating embodied carbon and energy, either at the product level in the LCA datasets, at the product level in EDGE, or at the building level in EDGE.

Section 3 of the report then presents the embodied carbon and energy results from the product LCA study.

Separately to this report, guidance and training materials have been developed outlining:

1. How LCA data for individual building products (e.g., rebar) should be processed and combined in EDGE to estimate the embodied carbon and energy of building assemblies (e.g., reinforced concrete floor slab, made up of several individual building products) (output of Task 6).
2. How EDGE users can include lower embodied carbon materials on their projects (output of Task 5).

2. Methodology

The EDGE application is used to estimate (among other parameters) the embodied carbon emissions of new and refurbished buildings. To facilitate these building-level calculations, product-level information is needed, quantifying the embodied carbon and energy of individual construction products (e.g., steel rebar).

The primary purpose of this project is to provide product-level LCA datasets for individual materials covering all global regions. Considering the limited availability of product-specific or industry average LCA data in some regions, these generic, region-level datasets can help fill the data gap, enabling WLCAs to be undertaken. However, the project also provides guidance on how embodied carbon and energy can be calculated at the building-level in EDGE for LCA modules A5.1 (pre-construction demolition), A5.2 (site activities), B2 (maintenance), B3 (repair), and C1 (deconstruction), which are typically estimated at the building-level rather than at the product-level.

It is widely understood that embodied carbon differs by material (e.g., steel rebar versus plywood). However, embodied carbon is also geography-specific, meaning it changes from region to region, depending on factors such as the carbon intensity of electricity production, material production efficiency, and regional trade relationships. Product-level LCA datasets are therefore used to represent use/consumption of a given material (e.g., plywood), within a defined region (either one of the global regions listed in section 2.2.1, or individual countries). In other words, each LCA dataset produced for this project represents one material-region combination (e.g., plywood used in North America).

For this project, product-level LCA datasets were developed in alignment with EN 15804:2012+A2:2019 *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products* (hereafter referred to as EN 15804) [1]. Guidance on building-level assessment of embodied carbon is aligned with the Royal Institution of Chartered Surveyors Professional Standard (RICS PS) 2nd edition on *Whole life carbon assessment for the built environment* (hereafter referred to as RICS PS) [2] which has been endorsed by the International Cost Measurement Standard Coalition. Both standards are considered best practice and are widely used in industry to conduct WLCAs for buildings and infrastructure.

This section outlines the methodology, adopted for this study, used to:

1. Determine the material-region combinations, for which product-level LCA datasets would be developed (Task 2).
2. Develop the cradle-to-grave product-level LCA datasets to be included in EDGE (part of Task 3).
3. Provide guidance on how building-level embodied carbon and energy can be calculated in EDGE for LCA modules A5.1, A5.2, B2, B3, and C1 (part of Task 3).

It is understood that benchmarking in the EDGE application will be based primarily on embodied carbon, and therefore embodied carbon is the focus of this report. However, embodied energy values have been calculated for all materials alongside embodied carbon and included in the LCA datasets developed for the project. Guidance will be provided for estimating embodied energy at the building level, although it should be noted that detailed guidance on calculating embodied energy is not part of RICS PS, which focuses on embodied carbon.

2.1 LCA scope

The LCA scope adopted in the development of LCA datasets for this project includes modules A-C (i.e., cradle-to-grave), as per the definitions set out in EN 15804 and RICS PS. This scope was agreed based on IFCs requirements, set out in the project terms of reference.

Prior to this project being undertaken, LCA datasets in EDGE included LCA modules A1-A3 only, i.e., raw material supply, transport and manufacturing, as shown in Figure 1. While product stage emissions typically account for most of the life cycle emissions of structural materials, construction (module A4-A5), in use (module B) and end-of-life stage (module C) emissions can also be significant. The LCA scope was therefore extended for this project, helping to improve the completeness of future WLCAs undertaken using EDGE.

Modules B6 (operational energy use) and B7 (operational water use) are not considered further herein because they account for the emissions associated with energy and water used to operate the building, including heating, hot water, cooling, ventilation, lighting systems, equipment and lifts (operational carbon). Module B8 (user carbon) captures emissions associated with user activities, e.g., vehicle emissions from a new road, and is therefore also excluded. This project focuses solely on embodied carbon (and embodied energy), while other parts of the EDGE application are used to estimate operational carbon. ‘User carbon’ for buildings accounts for user activities such as commuting to the building, electric vehicle charging and consumables and is similarly excluded from this project but could be calculated separately in EDGE. Hence, the LCA modules considered in-scope for this project include A0-A5, B1-B5 and C1-C4, labelled ‘Embodied carbon/life cycle embodied carbon’ in Figure 1.

As shown in Figure 1, LCA module D represents ‘benefits and loads beyond the system boundary’ (i.e., emissions avoided through material reuse, recycling or energy recovery beyond end-of-life, compared with virgin material production). Module D emissions lie outside the building LCA system boundary and are therefore reported as supplementary information in typical WLCAs. For this reason, it was not a requirement for module D emissions to be included in the LCA scope for this project. The minimum scope for environmental product declarations (EPDs), set out in EN 15804, includes modules A1-A3, C1-C4, and D1 (i.e., includes module D). However, since this project will produce LCA datasets, not EPDs, this minimum LCA scope need not be rigidly adhered to. Hence, module D has been excluded from the LCA scope, aligning with the cradle-to-grave scope requested by IFC.

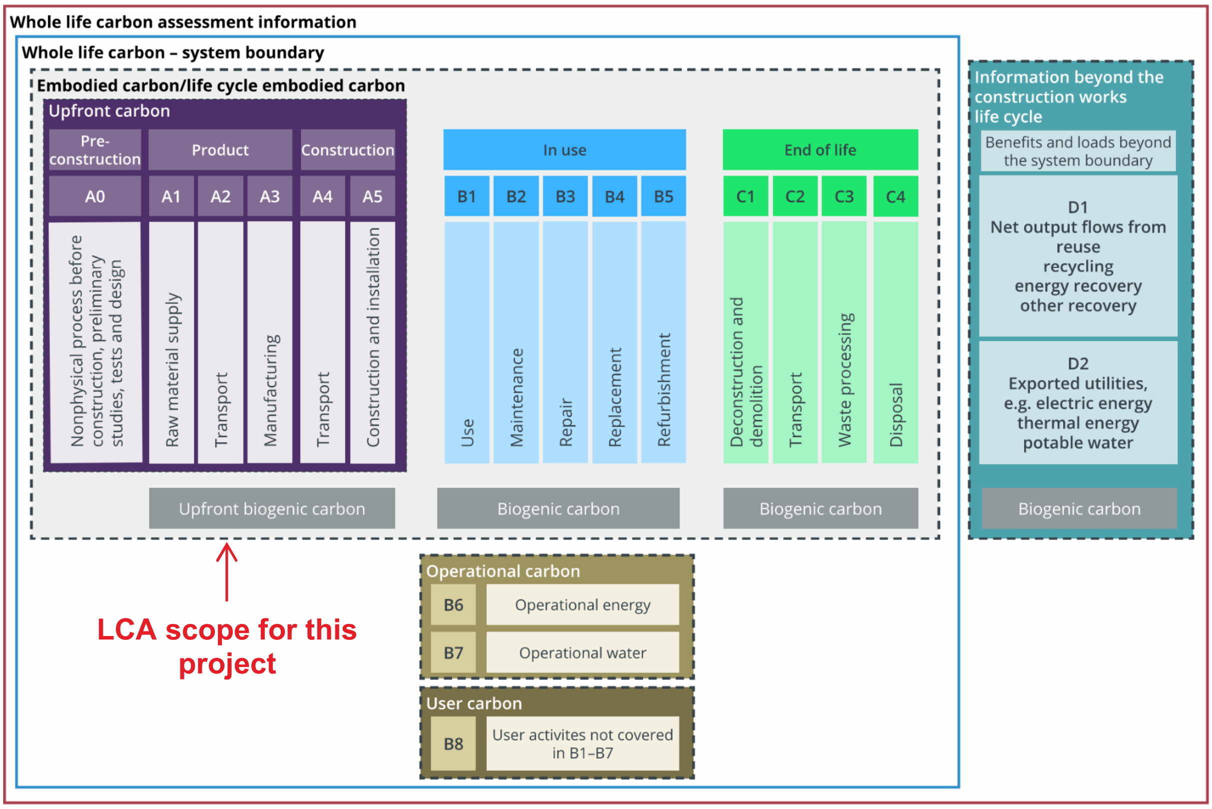

Figure 1: Building and infrastructure life cycle stages and information modules, extracted from RICS PS [2].

2.2 Selection of material-region combinations

For this project, each LCA dataset represents one material-region combination, as explained previously. Prior to conducting the product-level LCAs, a list of material-region combinations was agreed with IFC for analysis. This established the combinations for which data is available, prioritised to address those most suitable and beneficial for inclusion in EDGE.

The process of establishing this list can be divided into five key stages:

1. Long list of materials and regions – At this stage, all possible countries, regions (see section 2.2.1) and materials within the four main material groups (see section 2.2.2) remained open for consideration.
2. IFC's project priorities – IFC's project priorities guided the selection process. See section 2.2.3.
3. Data availability – Availability of data needed to produce the LCA datasets for material-region combinations being considered was checked. See section 2.2.4 for details.
4. Prioritise materials and regions – Material-region combinations were prioritised based on which materials are most used in building construction in each region, and to expand the range of materials available in EDGE to include lower carbon versions of priority materials. See section 2.2.5 to 2.2.8 for details.
5. IFC approval.

It is understood that decisions regarding which building products are included in EDGE, and their relative embodied carbon, can influence construction procurement decisions on EDGE projects globally. This was considered when developing the list of material-region combinations for this project, and particularly the approach to resource-constrained materials (see section 2.3).

2.2.1 Countries and global regions

The EDGE V3 app currently divides the world's countries into seven global regions, namely: Asia, Africa, Middle East and North Africa (MENA), North America, Latin America, Western Europe, Eastern Europe. The objective of this project is to develop LCA datasets for all global regions to facilitate WLCAs being undertaken, regardless of current construction rates in any given region.

To achieve methodological alignment with the ODCi, the regions adopted for this project are the same as those developed and adopted for the ODCi, as set out in Table 7 of the ODCi methodology report and reproduced in Table **1**. These are different to the region definitions used for current EDGE datasets. However, both sets of definitions include all countries, just segmented differently.

Table 1: Regionalisation adopted for the scope definition of the dataset development as per the ODCi methodology.

Regionalisation level 1	Regionalisation level 2	Regionalisation level 3
Global		
Africa	North Africa	North Africa
	Sub-Saharan Africa	Equatorial Africa
		Southern Africa
Middle East	Middle East	United Arab Emirates
		Other Middle East
North America	North America	United States / Canada
Central & South America	Central America	Mexico
		Other Central America
	South America	Brazil
		Other South America
	The Caribbean	The Caribbean
Europe	European Union	EU-27 / Central Europe
		EU-27 / Mediterranean
	Other Europe	Western non-EU
		Eastern non-EU
Oceania	Oceania	Australia / New Zealand
		Other Oceania
Asia	Other Southeast Asia	Southeast Asia
		East Asia
	China	China
	India	India
	Other Asia	Eurasia / Central Asia
		Southern Asia

2.2.2 Materials and material groups

As per the project brief, four ‘material groups’ were considered, namely:

1. **Concrete** – Concrete is the most-used building material on earth by volume and its consumption accounts for about 7-9% of global carbon dioxide emissions [3]. Concrete consists of aggregates (sand and/or gravel) bound together by a binder (commonly referred to as ‘cement’), which reacts with water and hardens, giving concrete its strength. Ordinary Portland cement (OPC), made of 95% clinker (the binder) and 5% gypsum (controls setting), is the most common form of cement used worldwide. Clinker is the most emissions-intensive component of concrete, because it is produced by heating limestone and clay in a kiln to around 1,450˚C (typically using fossil fuels alongside other biomass and waste-derived fuels), and because the breakdown of limestone ($CaCO_3$) into the active ingredient, lime (CaO), releases carbon dioxide [4]. However, alternative, lower carbon cementitious materials are available, with the most prevalent being ground-granulated blast furnace slag (GGBS), fly ash (FA) and ground limestone. Calcined/activated clay is another type of lower carbon binder with the potential to be used at scale globally, but its use is currently confined mostly to countries in Central & South America, Africa, North America and Europe [5].

2. **Steel** – Steel is commonly used in buildings in the form of structural steel sections (many varieties), steel sheets, and as reinforcing bars (rebar), that are embedded within concrete to produce reinforced concrete. Compared to concrete, steel usually has higher embodied carbon per unit mass but is typically used in lower quantities due to its superior strength. Virgin (new) steel is commonly produced via the basic oxygen steelmaking (BOS) process whereby iron ore is heated in a blast furnace (BF) with coke (made from coal) and limestone to around 2,000˚C, producing carbon dioxide, pig iron and slag/GGBS. Pig iron (normally together with some steel scrap) and lime is then heated to around 1,600˚C in a basic oxygen furnace (BOF), producing steel, which is then cast into finished products [6]. Some iron is also produced

by a process called direct reduction ironmaking (DRI) which involves removing the oxygen from iron ore to convert it to iron without having to melt it, with the iron then processed in an electric arc furnace (EAF). This process currently accounts for about 5% of global production. Recycled steel can also be produced using an EAF whereby scrap steel is heated using electricity, which, if decarbonised, can produce lower carbon recycled steel. Even though most scrap steel is recycled, there isn't enough scrap steel available globally to meet demand, and therefore EAFs are used for about 30-35% of global steel production [6, 7]. Virgin steel can also be produced using direct reduction with hydrogen, which, if produced throughout the whole supply chain using net zero processes, can theoretically produce net zero steel. However, this technology is still in the pilot phase of development and currently requires huge amounts of renewable energy [6], so is not included in this study.

3. **Timber** – With increasing efforts to decarbonise building construction, it is widely perceived that timber and other bio-based construction materials have the potential to be lower carbon and more sustainable than conventional materials like concrete and steel [8]. Timber is commonly harvested and dried to produce 'sawn timber' or further processed and bound, using chemical adhesives, into engineered timber products like plywood or glue-laminated timber (glulam) for use in buildings. In addition to the fossil carbon released during timber production, timber also absorbs from the atmosphere and stores biogenic carbon while it grows. However, this biogenic carbon is typically released back into the atmosphere, or transferred to nature, when timber products are landfilled or incinerated at end-of-life, and therefore this temporary biogenic carbon storage is reported separately in WLCAs [2].

4. **Bamboo** – Bamboo is another bio-based material known for its strength and rapid growth rate. Bamboo can be harvested in just 3-5 years, compared to traditional timber, which can take decades to mature. Bamboo sequesters carbon throughout its growth cycle (though as for timber, this biogenic carbon is typically released to the atmosphere at end-of-life) and has a high strength-to-weight ratio. Bamboo structures therefore tend to be more lightweight, which is preferred in earthquake prone regions, and can potentially reduce the need for heavy foundations in construction. Bamboo can be used for structural elements like framing, flooring and wall panels. However, widespread use of bamboo for construction is still limited, partly because bamboo species suitable for structural use only grow in some regions (mainly in Central and South America, Asia and Africa), but also due to a lack of codified knowledge and a small track record of bamboo as a structural material. Despite this, bamboo has the potential to play a larger role in future sustainable construction.

Within each material group (e.g., steel), several different materials (e.g., steel rebar, structural steel open sections) were long-listed with the aim to include those commonly used on building projects, and variations of materials that have lower embodied carbon than their conventional equivalent. Materials included for the project are listed in Table 4.

2.2.3 IFCs project priorities

Following initial long-listing, IFC's priorities for LCA dataset development generally, and for selection of material-region combinations specifically, were established, and are summarised below:

1. **High quality data** – Produce robust product LCA datasets for use in EDGE in Version 4 onwards.

2. **More lower carbon materials** – The datasets selected should provide EDGE users with the option to select both lower carbon material groups (e.g., timber and bamboo) and lower carbon materials within those groups (e.g., calcined clay-based concrete versus OPC-based concrete).

3. **Whole life cycle coverage** – Several concrete, steel and timber LCA datasets, including LCA modules A1-A3, exist within EDGE currently. It was agreed that the datasets developed for this project would supersede those already in EDGE due to the change in LCA scope of the datasets from A1-A3 to A-C (as per section 2.1), and to avoid methodological inconsistencies between new and existing datasets in EDGE.

4. **Geographic coverage** – The EDGE application is intended for use globally. In response to this priority, regions were not prioritised based on factors such as building projections or current uptake rates for building WLCAs. Rather, material-region combinations were selected aiming to maximise inclusion of all countries and global regions where construction materials are produced and used. Note, however, that

for some materials, such as calcined clay-based concrete and bamboo, some countries or regions were excluded because they do not produce or use that material at significant scale currently.

2.2.4 Data sources and availability

Setting up the life cycle inventory (LCI) is the first step for dataset development. LCI is the phase of life-cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle [1]. The development of the LCI relies upon the availability of both background and foreground data.

Background data – Background data is needed to support the development of datasets and is typically sourced from third-party proprietary LCI databases such as ecoinvent or Sphera (formerly GaBi). At the project outset, the intention was to use such databases as the primary source of background data for the project. However, use of such proprietary databases would most likely require ongoing payments or fees by IFC to background data providers. This would hinder development and scaling of EDGE, which is, and is intended to remain, a free app. Hence, this project has utilised data exclusively from publicly available sources, to facilitate the ongoing free use of LCA results by IFC in EDGE. By limiting reliance on third-parties, this change in methodological approach was intended to make the Embodied Carbon and Energy Model, and the estimates generated by it, more future-proof, accessible, transparent and flexible.

Foreground data – Foreground data is the data used to develop the life cycle inventories or models to quantify the materials and processes used for each material-region combination. Foreground data consists of both:

1. Specific data (or 'primary data') – detailed information that is unique to a particular process or component within a product system. According to EN 15804, specific data must be used for at least the core unit processes in an LCI that the manufacturer has control over (i.e., those related to product manufacture module A3 within LCA modules A1-A3, for product-specific LCAs). As the datasets under development are not manufacturer-specific, the primary data should represent the technology mix used in the specified region for the specified material and be as recent as possible.

2. Generic and proxy data – average or representative values used to represent a specific process or material when specific data is not readily available. According to EN 15804, generic and proxy data may be used for processes including upstream and downstream processes (i.e. within modules A, B and/or C) and according to EN 15941:2024, the selection of generic data shall consider their appropriateness and consistency in terms of methodology and regarding the data quality of the inventories, i.e. their representativeness, completeness and precision. Proxy data can be used where data gaps exist if this is clearly stated.

Both foreground and background data were developed via literature review, considering all relevant data sources including, but not limited to research papers, industry association reports, publicly available databases, news articles and manufacturer data. It excluded resources which require ongoing licencing, such as the Sphera, ecoinvent and International Energy Agency (IEA) databases. All data is listed in the 'References' tab of the Embodied Carbon and Energy Model. Each source is assigned a data quality rating, as per Table 2. All data used in the model has a quality rating of Fair or better, with most rated Good or Excellent.

Each dataset generated using the Embodied Carbon and Energy Model is also given a dataset confidence rating, also ranging from Excellent to Poor. See section 3.7.2 for further details. This is distinct from the input data quality rating, described in this section, which is specific to the input data.

Table 2: Input data quality rating.

Input data quality rating	Guidance
Excellent	High level of expertise AND high level of verification (e.g., peer-reviewed journal article, third-party verified EPD, recognised standard).
Good	High level of expertise AND moderate level of verification (e.g., supplier press release, internal document internally reviewed).
Fair	High level of expertise AND low level of verification (e.g., raw data collection from suppliers).
Poor	Moderate/low level of expertise AND low level of verification (e.g., modeller assumption not checked by expert).

For bamboo, Arup collected LCI data from bamboo suppliers via interviews, including LCA modules A-C, as outlined in section 2.4.1. This was practicable given project constraints because the supply-chain for bamboo pole is relatively short, and so the data can be readily collected from producers.

The data sources used for this project are summarised in Table 3.

Table 3: Sources of life cycle inventory (LCI) data for this project.

	A1-C4
Concrete	Foreground data – Literature review Background data – Literature review
Steel	
Timber	
Bamboo	Foreground data – Obtained via interviews with bamboo suppliers. Background data – Literature review

The only materials excluded from the material-region list based primarily on a lack of available data were:

1. Laminated bamboo, which is used for flooring and wall panelling. In contrast to bamboo pole, which is included in the material-region list for the project, laminated bamboo is a manufactured product, with much of the supply-chain based in China. This means that the supply-chain is more complex, making collection of primary data from suppliers more challenging. Production process data for laminated bamboo could not be shared by Arup's supplier contacts who have produced EPDs for laminated bamboo. Laminated bamboo LCA datasets were also not produced by the ODCi, for similar reasons regarding lack of available data from industry associations or in the literature. Notwithstanding this, laminated bamboo could be included in EDGE in future once production data becomes more readily/freely available. Furthermore, laminated bamboo EPDs (and EPDs for all other materials) could be integrated into EDGE to complement the generic LCA datasets developed for this project (see section 2.4.3 for more details).

2. Bamboo pole for countries in the Africa region. Suppliers were contacted to provide data, but data was not forthcoming.

Table 4: Material-region combinations included in this study.

Material group	Materials included in this study	Region(s) included
Concrete	Ready-mix concrete, Portland cement (PC)[2,3]	All global regions.
	Precast concrete, PC[4]	
	Ready-mix concrete, PC + ground limestone (LS)	
	Ready-mix concrete, PC + GGBS[5] (25%)	
	Ready-mix concrete, PC + GGBS (50%)	
	Ready-mix concrete, PC + fly ash (FA) (30%)	Asia, Oceania, Europe, Middle East, North America, Africa[6].
	Ready-mix concrete, PC + calcined clay (CC) + LS (LC3)	Brazil, Colombia, Ghana, Cote d'Ivoire, Angola, Cameroon, France, USA, Saudi Arabia, Canada, Peru, Burkina Faso, India, Argentina, Portugal, Denmark, Czech Republic, Oman[7].
Steel[8]	Steel reinforcement (rebar)	All global regions.
	Steel section[9] (open)	
	Steel section (closed)	
	Steel plate	
	Steel post-tensioning tendons	
	Galvanised steel frame (light gauge)	
	Galvanised steel sheet	
Timber	Sawn timber (kiln dried)	All global regions.
	Sawn timber (air dried/green)	
	Particle board	
	Medium density fibreboard (MDF)	
	Plywood	
	Glue-laminated untreated softwood timber (glulam)	
Bamboo	Bamboo pole (boron treated and air dried)	Costa Rica, Ecuador, Indonesia, Mexico, Nepal, Philippines, Asia, Central & South America[10].

[2] Concrete made with Portland cement is the most used worldwide.

[3] Ready-mix strength classes include: C8/10, C16/20, C20/25, C25/30, C28/35, C32/40, C40/50 and C50/60 as per EN 206 notation (used in Europe and UK). Precast strength classes include: C32/40 and C40/50. Datasets are also labelled with equivalent strength class notations used in other regions such as 20 MPa, N20, M25, C25, 4,640 psi, etc., as noted in Table 5.

[4] Higher strength typical for precast applications. These datasets are used to model the concrete component of precast concrete elements, while rebar within the precast concrete is to be modelled separately.

[5] Section 2.3 details the approach to resource-constrained materials.

[6] FA is less prevalently available/used in Central & South America, due to the limited use of coal for electricity generation.

[7] These countries currently produce calcined/activated clay at sufficient scale to justify inclusion in the database [5].

[8] All steel datasets have regional average recycled content.

[9] Open, closed and plated sections have significantly different carbon factors due to differences in production approach.

[10] These countries and regions currently produce and use bamboo at scale. Almost all suppliers interviewed use air rather than kiln drying.

2.2.5 Concrete material-region combinations

All concrete products listed in Table 4 contain binders, or combinations of binders, that are commonly used in the given region. EDGE V3 currently contains ordinary Portland cement (OPC), fly ash (FA) and ground granulated blast furnace slag (GGBS)-based concrete mixes. This project expanded this list to concrete mixes incorporating ground limestone (LS) and calcined/activated clay (CC), which can partially replace clinker in cement, by up to around 15% in the case of LS or 30-55% in the case of calcined clay (with higher replacement rates possible in the future). Limestone and clays are abundant and not fully utilised, in contrast to GGBS and FA, which are expected to decrease in availability over time as the industrial processes generating them (blast furnace ironmaking and coal-fired electricity generation, respectively) are phased down or out as those industries transition to net zero. See section 2.3 on resource-constrained materials for further details.

Limestone calcined clay cement (LC3) is a cement containing 15% ground limestone, 30% calcined clay, 5% gypsum and 50% clinker [9]. Clay calciners (that produce calcined clay) are operational in the countries listed in Table 4, but not elsewhere [5]. Therefore, country-specific, rather than region-specific LCAs were developed. Due to the local nature of cement and concrete procurement, it is unlikely that these mixes would be utilised to any great extent outside of these producing countries, except possibly in nearby neighbouring countries. However, if calcined clay production expands to other countries and regions in the future, it is recommended that datasets for LC3 concrete in these countries and regions be included in EDGE by adopting the same calculation approach used for the datasets developed for this project.

All concrete datasets are modelled at the concrete level rather than the cement level, to align with current EDGE approach, and so that the mixes are representative of typical mix designs. Nevertheless, the Embodied Carbon and Energy Model contains the disaggregated mix constituent embodied carbon data, allowing further cement and concrete formulations to be easily added to the model to generate LCA datasets in the future.

Datasets are provided for concrete strength classes (as per European standard EN 206) C8/10, C16/20, C20/25, C25/30, C28/35, C32/40, C40/50 and C50/60 for ready-mix concrete and C32/40 and C40/50 for precast concrete. For clarity, datasets are labelled with strength class notations used in other regions, as per Table 5.

Table 5: Concrete compressive strength class notations used internationally.

Notation type	Example notation	Example of region(s) typically used	Explanation
Concrete cylinder followed by cube strength, metric	C20/25	Europe (EN 206) and UK (BS 8500)	C20/25 represents concrete with a characteristic cylinder strength of 20 MPa and a characteristic cube strength of 25 MPa at 28 days.
Concrete cylinder strength, metric	20 MPa, N20	Australia	20 MPa and N20 represent concrete with a characteristic cylinder strength of 20 MPa at 28 days.
Concrete cube strength, metric	M25, C25	India, China	C25 and M25 represent concrete with a characteristic cube strength of 25 MPa at 28 days.
Concrete cylinder strength, imperial units	4,640 psi	United States (American Concrete Institute (ACI))	All American Concrete Institute (ACI) standards use 28-day cylinder strength measured in pounds per square inch (psi).

Precast concrete has been included in the product list. However, the datasets do not include rebar, which should be accounted for separately in EDGE. This will allow the rebar rate within precast concrete elements to be adjusted in EDGE when selecting construction assemblies, giving greater flexibility within the app to define the concrete and rebar proportions of precast concrete elements.

Carbon capture and storage (CCS) is an emerging technology which can be used to capture and permanently store up to around 95% of the carbon emissions generated from conventional clinker production [10], though it is noted that the only known operational CCS cement plant, located in Norway, is capturing around 50% of its CO_2 emissions [11]. However, while clinker plants operating with CCS at scale are beginning to come online, with many in development, clinker produced with CCS is not yet widely available. Accordingly, concrete made from clinker produced with CCS has not been included in the product list. However, it should be included in future once it is more widely available and once methods are established to account for the emissions of CCS clinker in concrete LCAs (this is not currently explicitly covered in EN 15804).

Other binders such as natural pozzolans, burnt shale, silica fume and rice husk ash are used as SCMs in concrete in regions where they are available. However, they are considered lower priority for inclusion in the EDGE database at this stage given they are less commonly used than some other binders and are mostly fully utilised globally [9].

2.2.6 Steel material-region combinations

The recycled content of steel is a key driver of steel's embodied carbon. However, this project does not propose to differentiate steel products based on recycled content, because most steel is currently recycled, and so increasing the amount of steel scrap utilised on one project would not be expected to reduce emissions globally. See section 2.3.2 on resource constrained materials for more details. The steel datasets instead contain a typical/average recycled content for the region and product the LCA dataset represents.

A large proportion of the world's scrap feedstock is used to produce reinforcing bars and hot rolled structural steel sections, so these products have the highest recycled content, and correspondingly lower embodied carbon.

EDGE V3 currently contains a dataset for structural steel sections, but this does not differentiate between open sections, closed sections, and plated sections which typically have significantly different carbon factors due to differences in production processes. This project splits the datasets for structural steel sections into three distinct datasets, one for each section type.

Primary steel production using direct reduction with hydrogen has the potential to produce much lower carbon steel but has not yet been implemented at scale [6]. Therefore, this project does not propose to include steel products produced using this process but suggests they could be added in future once available.

Due to the above-mentioned limitations of increasing recycled content in steel, and primary steel production using direct reduction with hydrogen, the selection of steel products for this project instead aims to expand the number of commonly-used steel products in EDGE. The steel products listed in Table 4 are all commonly used in building construction and therefore important for conducting building WLCAs.

A regional approach is proposed for steel because the steel supply chain is global, and material is often transported large distances. Data is available regarding the location of steel production mills in different regions, and this is used to ensure the data is representative of the most likely production location.

2.2.7 Timber material-region combinations

All the timber products listed in Table 4 are commonly used in building construction. Some other timber products (e.g., cross-laminated timber, CLT) were considered, but deprioritised as they are less commonly used. As these supply chains develop and scale there may be benefit in incorporating them into the EDGE database.

2.2.8 Bamboo material-region combinations

Six country-level datasets were developed representing countries where bamboo is commonly produced and used. An additional two datasets were generated, representing the average dataset for Asia and Central & South America. Development of these datasets relied upon input from regional bamboo suppliers, and thus the material-region list has been adapted throughout the project to include countries from which suppliers were willing to share production process data. The original intention was to also collect production data for Bangladesh, Brazil, Colombia, Ghana and Peru; however, production information was not forthcoming.

The drying process – typically either kiln or air drying – is a key determinant of the embodied carbon of bamboo. However, virtually all suppliers interviewed used the air-drying process for production, hence only air-dried bamboo was included in the study. The dataset will therefore not be appropriate for modelling kiln dried bamboo, which would have significantly higher embodied emissions.

Treated and dried bamboo is commonly used in buildings. Untreated and green bamboo was excluded as it is not recommended for use as a final product in buildings due to its poor durability performance.

Region-level datasets were produced for regions where bamboo is commonly produced and used, to cover countries in these regions that are not listed separately. Region-level datasets could also be produced for other regions (e.g., Europe) where bamboo is not commonly used but could be imported. However, this was considered lower priority at this stage.

2.3 Approach to resource-constrained materials

The term ‘resource-constrained materials’ means materials that are fully utilised globally, and for which global supply would not be expected to increase significantly in response to greater demand. Two examples relevant to this study include ground granulated blast furnace slag (GGBS), used as an SCM in concrete, and steel scrap, used to produced recycled steel.

2.3.1 Ground granulated blast furnace slag (GGBS)

GGBS (also referred to as ‘slag’) is a by-product of BF ironmaking, a carbon-intensive industrial process which is expected to be phased down or out as the iron and steelmaking industry shifts towards net zero. Hence, the availability of GGBS is expected to decline in the future. Currently, GGBS availability is approximately 8-12% of clinker production, which equates to a global average cement replacement of around 10%. However, GGBS is a globally constrained resource, meaning it is already fully utilised globally [12]. This means efforts to purchase more GGBS on one project would not be expected to stimulate increased supply globally, rather, it would result in more GGBS being used on one project while less is available for use on other projects, having little positive impact on global emissions [12]. The practice of importing GGBS from abroad at scale to reduce reported emissions on local projects is already observed in countries such as the UK.

In contrast to GGBS, clay (suitable for calcining and use in cement) and limestone are abundant and not fully utilised, as shown in Figure 2. This means greater ‘demand pull’ for these binders would be reasonably expected to stimulate increased supply of those materials, and lead to a reduction in emissions from concrete globally. With EDGE being used to guide lower carbon material procurement decisions on projects globally, it is important that these global dynamics be accounted for and managed in EDGE.

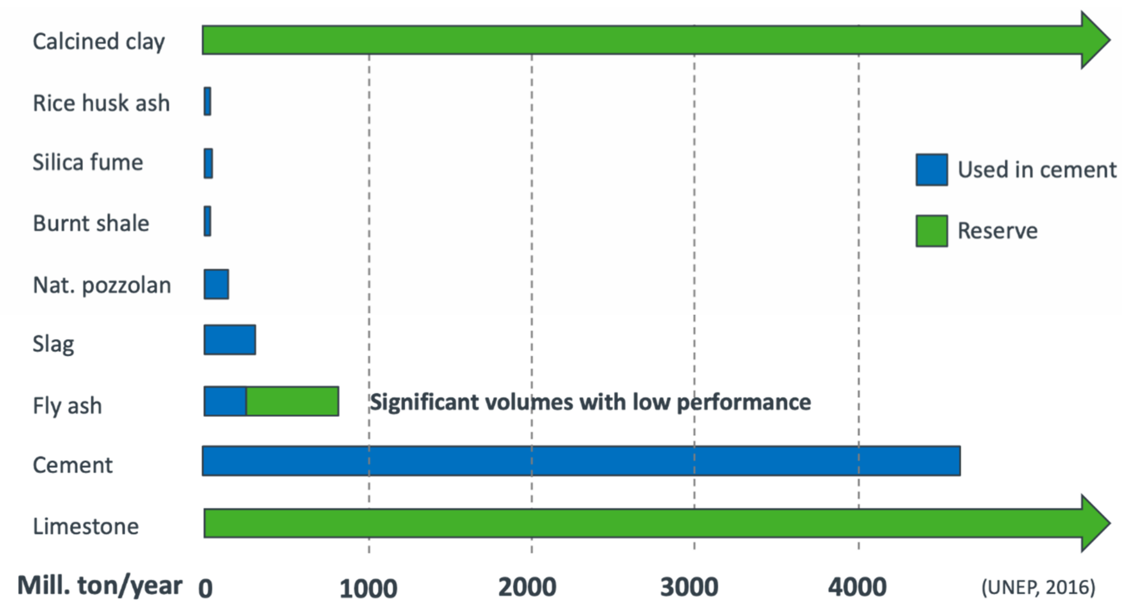

Figure 2: Use and availability of alternative binders for concrete [9].

However, the use of GGBS in concrete does provide a performance benefit in high exposure class environments, i.e., those with greater exposure to chemical attack from sulfates and chlorides, such as for building foundations in contact with aggressive soils. Therefore, efficient use of GGBS globally would include its targeted use in high exposure class applications [12].

The following actions have been taken and are reflected in the product list and guidance produced for the project:

- Concretes with binders such as limestone fines and calcined clays are included to provide lower carbon, non-resource-constrained cement and concrete options for EDGE users.
- Guidance on this issue is included in the training materials for Task 5. The use of higher GGBS (e.g., 50% GGBS) concretes will be recommended only where this provides an important performance benefit,

such as in external or substructure applications with higher exposure. Concrete with 25% GGBS could be used more generally, as the GGBS percentage is closer to the global average of 10%.

This approach is designed to prevent EDGE users from knowingly or unknowingly inflating the sustainability credentials of their projects by selecting a lower carbon concrete mix purely for the purpose of reducing embodied carbon, but without considering global resource constraints. However, the approach will provide enough flexibility to investigate different options considering material efficiency and concrete use cases.

It is currently unclear whether fly ash (FA) is a globally constrained resource or not. It is expected that the material will become less available as coal-burning is phased out to achieve net zero commitments. However, in regions such as the UK, there are significant volumes of fly ash in landfill that could be extracted and processed to produce a standards-compliant SCM for use in concrete [13].

2.3.2 Steel scrap

In 2020, about 85% of steel scrap was recycled at end-of-life [6] with this recycled material accounting for about 30-35% of the total input for new steel production [7, 6]. Due to these high rates of recycling, and a limited stock of existing steel products, steel scrap is also considered a globally constrained resource [14]. Hence, if EDGE users were to specify higher than regional average rates of recycled content for steel elements on projects, this would be unlikely to significantly reduce global emissions.

The following actions have been taken and are reflected in the product list:

- Where available, average steel carbon factors for each region are provided.
- Different carbon factors are provided for different steel products (e.g., rebar, closed sections, open sections and plate) which typically have different recycled content rates.

Steel products with a given recycled content can have different embodied carbon values depending on factors such as production efficiency and the carbon intensity of electricity. Future versions of EDGE could potentially enable the use of steel products that have lower emissions for a given recycled content, provided there is EPD data to demonstrate this. Steel embodied carbon rating systems such as that produced by Responsible Steel [15], which is based on this scrap-variable approach, could be used to guide steel procurement decisions.

2.4 Data sources

This section outlines the main data sources used for the project and any limitations on the use of this data within EDGE.

The Embodied Carbon and Energy Model has been developed using all publicly available data and therefore there are no known restrictions on its ongoing use by IFC in EDGE.

Reference data is listed in the 'References' tab of the Embodied Carbon and Energy Model. All references are assigned a unique reference number, e.g., REF001, that is used throughout this report and in the model.

2.4.1 Primary LCI data collected from bamboo suppliers

Data collected from bamboo suppliers has been used to develop the LCA datasets for bamboo. Data was collected from bamboo suppliers via surveys, with the raw survey data included in REF021-REF026.

There are no known restrictions on use of the data within EDGE, however, it is expected that only the processed LCA datasets for bamboo would be included in EDGE, not the underlying raw data.

2.4.2 Assumptions for upstream and downstream processes

As per EN 15804, generic and proxy data can be used for upstream and downstream processes in an LCI, and to fill data gaps if the assumptions are stated.

Because this project involves the development of generic LCA datasets covering large regions:

1. It is not practicable to produce precise estimates of averages for LCI parameters (e.g., construction site wastage rates) in all cases due to a lack of available detailed and complete data covering all global regions and materials. Nevertheless, detailed data has been used when available to estimate these parameters and assumptions checked with regional experts.
2. Any default values, while representing typical practice, cannot represent all situations of material use in each region. For example, transport distances to site for rebar in Central & South America may vary significantly from project-to-project. Hence, while default values are provided for this project, it is recommended that EDGE users be given the option to edit these values with project-specific information when available, as outlined in more detail on a module-by-module basis in section 2.5.

RICS PS provides default values for assumptions for transport distances to site (Table 17 of RICS PS). However, RICS PS states that the default values are applicable to projects located in the UK and that 'similar default scenarios should be developed for different countries outside the UK'. Therefore, default transport distance assumptions for all material-region combinations have been developed for this project.

Generally, default assumptions for other LCA modules set out in the Embodied Carbon and Energy Model are based on desktop research and are sense-checked by regional and/or materials experts.

2.4.3 Environmental Product Declarations (EPDs)

This project involves the production of generic LCA datasets (representing material use in each region) rather than EPDs. However, EPD data (particularly sector EPDs developed in accordance with EN 15804 for relevant countries and regions) could be integrated into EDGE to complement the LCA datasets developed for this project, provided IFC obtains the appropriate permissions from background data providers to do so.

2.5 LCA methodology by module

This section outlines the methodology used to produce product-level LCA datasets (covering LCA modules A1-A3, A5.3 and C2-C4), for calculating building-level embodied carbon and energy estimates in EDGE (for LCA modules A5.1, A5.2, B2, B3, and C1), and for calculating product-level emissions and energy in EDGE for LCA modules A4 and B4. The modelling approach by LCA module is summarised in Table 6.

Product-level LCA calculations for this project, embedded in the LCA datasets, were undertaken in Excel. The OUTPUTS tab of the Embodied Carbon and Energy Model contains the modelling outputs in a tabular format ready for integration with EDGE, while the DASHBOARD tab contains the results in graphical format. The full unit process models are in the tabs labelled:

- Concrete (A1-A3; C2-C4)
- Steel (A1-A3; C2-C4)
- Timber (A1-A3; C2-C4)
- Bamboo (A1-A3; C2-C4)

Further tabs containing the calculation parameters and approaches for LCA modules A4 and A5 are included in the tabs labelled:

- A4
- A5

Emissions associated with several LCA modules A4, A5.1, A5.2, B2, B3, B4 and C1 are recommended to be calculated in EDGE at the building- or product-level and are therefore not included in the LCA datasets produced for this project. Equations for calculating emissions values for these modules, to be integrated into EDGE, come from RICS PS.

This section provides guidance on the application of RICS PS guidance within EDGE. However, RICS PS should still be referred to directly when developing the application and should be followed if there are any discrepancies between the standard (RICS PS) and the guidance in this report.

Table 6: Summary of modelling approach by LCA module.

LCA module number	LCA module description	Calculate at product or building level?	In LCA datasets?	User editable parameters recommended?	Key guidance
A1-A3	Product stage	Product-level	Yes	No	EN 15804
A4	Transport to site	Product-level	-	Yes – transport distances for materials to site [km]	RICS PS section 5.1.3
A5.1	Pre-construction demolition	Building-level	-	Yes – existing building GIA [m^2] (if applicable)	RICS PS section 5.1.4
A5.2	Construction activities	Building-level	-	Yes – new building GIA [m^2]	RICS PS section 5.1.4
A5.3	Waste and waste management	Product-level	Yes	No	RICS PS section 5.1.4
B1	Use	Product-level	No – negligible (see section 2.5.7)	No	RICS PS section 5.2.1
B2	Maintenance	Building-level	-	Yes – new building GIA [m^2]	RICS PS section 5.2.2
B3	Repair	Building-level	-	Yes – new building GIA [m^2]	RICS PS section 5.2.3
B4	Replacement	Product-level	-	Yes – element service life [years]	RICS PS section 5.2.4
B5	Refurbishment	Product-level	-	Yes – refurbishment year (if applicable)	RICS PS section 5.2.5
C1	Deconstruction	Building-level	-	Yes – new building GIA [m^2]; deconstruction scenario.	RICS PS section 5.6.1
C2	Transport to waste processing	Product-level	Yes	No	RICS PS section 5.6.2
C3	Waste processing	Product-level	Yes	Yes, for timber and bamboo products only [end of life process].	RICS PS section 5.6.3
C4	Waste disposal	Product-level	Yes	Yes, for timber and bamboo products only [end of life process].	RICS PS section 5.6.4

2.5.1 Module A0 (pre-construction stage)

According to RICS PS section 5.1.1, LCA module A0 captures emissions related to non-physical processes before construction, such as preliminary studies, impact assessments, risk assessments, stakeholder engagement, design and technical studies, product/material tests, site surveys and acquisition of land and design.

RICS PS states that 'they can be included in the WLCA scope, depending on the purpose of the assessment', and are usually most applicable to large, complex projects such as infrastructure projects or masterplans, where significant travel or physical model development may be required during the design stage.

For typical WLCAs undertaken in EDGE, it is recommended that LCA module A0 emissions be ignored (taken as zero) as they are expected to be insignificant in most cases compared with emissions in other LCA modules. Furthermore, it is expected that most EDGE users would not have information readily available for an accurate assessment of LCA module A0 emissions.

2.5.2 Modules A1-A3 (product stage)

The Excel-based Embodied Carbon and Energy Model, which should be viewed alongside this report, contains all working relevant to LCA modules A1-A3 for all materials.

Electricity factors

The Electricity factors tab is used to calculate embodied emissions and embodied energy associated with electricity used for material production. In all cases, the full scope 1, 2 and 3 emissions associated with fuels and electricity are counted in the LCA, as per RICS PS guidance.

The carbon intensity of electricity consumption in each country is based on REF008, with additional allowances made for well-to-tank (WTT) fuel emissions and electricity transmission and distribution (T&D). An allowance for WTT emissions of 21% of generation emissions is added based on applying the ratio for the UK grid from REF005. Allowances for T&D losses are made using data from REF362, which differentiates T&D losses for low, medium and high voltage use. Hence, different electricity emissions factors are provided for low, medium and high voltage grid connections. REF362 contains data for some but not all countries, with the 'World' values used for countries where there is no data. The International Energy Agency (IEA) publishes carbon factors for electricity by country, including WTT and T&D allowances, which are typically updated annually. However, these have not been used in the Embodied Carbon and Energy Model as the data is proprietary and its use would entail licence fees [16].

The embodied energy of electricity is estimated using the approach set out in REF337, adopting the 'technical conversion efficiencies' approach. The electricity generation mix for each country is taken from REF305.

Weighted embodied carbon and energy factors for electricity are estimated for Portland cement clinker, steel and timber production, accounting for the location and output of material production within the region, using data from REF002, REF086 and REF287.

Transport emissions

The Transport emissions tab sets out the transport modes, default fuels, empty running factors and energy consumption factors for transport modes that can be selected from during modelling. It also includes the WTT and tank-to-wheel (TTW) emissions factors associated with transport fuels, such as diesel and gasoline. Key sources include UK Government GHG reporting factors (REF146), EcoTransIT (REF147) and Global Logistics Emissions Council (REF144). These figures are primarily used to calculate emissions for LCA modules A2 (raw material transport), A4 (transport to construction site), and C2 (transport to waste treatment).

Material LCA calculation structure

The calculation structure, common for all materials, is shown in Table 7. The calculation logic flows down the table, with sections used to distinguish LCA modules (A1, A2, A3, etc.) and production process steps (e.g., raw material extraction – limestone, clinkering, etc.). Material-region combinations included in the study are set out in columns labelled V1, V2 … Vn, with V meaning 'value'. For concrete, numbers V1.1, V1.2 etc. are also used to model strength class variations of concrete mixes. Each calculation process step is accompanied by narrative and references, as well as a date of last update and the initials of the person who last updated that line of the model. Model input parameters are highlighted light yellow to distinguish them from calculated values (shown in white), which are derived from input parameters. All input parameters are accompanied by narrative and usually one or more references (e.g., REF004) indicating where the value has come from. Input parameters also include an impact rating – either high, medium or low – to indicate the level of sensitivity of the model output to the input. While not rigidly defined, indicatively:

- High impact inputs – impact >10% of the final embodied carbon/energy figure.
- Medium impact inputs – impact 1-10% of the final carbon/energy figure.
- Low impact inputs – impact <1% of the final carbon/energy figure.

Technological, geographic and temporal relevance columns are also used to indicate the relevance of data input parameters to the material-region combination being modelled. They are based on the judgement of the modeller and are not rigidly or quantitatively defined.

Table 7: Calculation table structure in the Embodied Carbon and Energy Model.

Item description	Unit	V1	V2	Vn	Description of assumption / methodology	Reference(s)	Impact rating	Technological relevance	Geographic relevance	Temporal relevance	Date last updated	Updated by
Quantity of aggregates	*$kg/m^3{}_{concrete}$*	*800*	*1000*	*1100*	*Based on mix designs*	*REF004*	*Low*	*High*	*High*	*High*	*21-Apr-26*	*MM*
Embodied emissions (A1-A3) - TOTAL	*$kgCO_2e/m^3{}_{concrete}$*	*361*	*209*	*261*	*Summing above values*	-					*1-Mar-26*	*MM*
Major section break												
Minor section break												
Heading												

Key:

Input/calculated values:

Input
Calculated value

Relevance:

High
Medium
Low

Impact rating:

High (indicatively impacting final answer by >10%)
Medium (indicatively impacting final answer by 1-10%)
Low (indicatively impacting final answer by <1%)

Concrete (A1-A3; C2-C4)

This tab sets out the embodied carbon and energy calculations for concrete material-region combinations listed in Table 4. Figure 3 summarises the concrete production (A1-A3) processes explicitly modelled in the Embodied Carbon and Energy Model.

For minor, less impactful sub-processes within the overall production process (e.g., production of concrete admixtures), embodied carbon and energy estimates are made, but not modelled in detail as this would add unnecessary complexity to the model without necessarily making the results more accurate.

Concrete-related emissions can be estimated using either the 'net' or 'gross' emissions accounting approach. The model is set-up to automatically output either net or gross values, with the selected approach inputted in the DASHBOARD tab. The net approach excludes all emissions from waste fuels used in the cement kiln, whereas the gross approach includes fossil-fuel-related emissions from waste fuels but excludes biogenic carbon emissions from fuels. The net approach is more common in mainland Europe and is the default approach in EN 15804. However, the gross approach is more common in the UK as it provides a more complete picture of emissions from cement and concrete production [17]. Net values are presented in this report.

Steel (A1-A3; C2-C4)

This tab sets out the embodied carbon and energy calculations for steel material-region combinations set out in Table 4. Figure 4 summarises the steel production (A1-A3) processes included in the Embodied Carbon and Energy Model.

As noted on Figure 4, the economic allocation approach is used to assign emissions to primary products and co-products generated during coke making, ironmaking – blast furnace, steelmaking – basic oxygen furnace (BOF), and steelmaking – electric arc furnace (EAF).

Due to lack of availability of product-specific data on regional consumption of steel end products, the steel datasets more accurately represent in-region production of steel products. EDGE users should therefore select steel datasets based on the production region of steel (if known), rather than the consumption region. However, since inter-regional trade of finished steel products (estimated at around 176Mt/year in 2024 based on World Steel data [18]) represents less than 10% of total crude steel production (estimated at around 1,885Mt/year in 2024 [18]), the regional production values are expected to be appropriate as baseline estimates in EDGE V4.

Timber (A1-A3; C2-C4)

This tab sets out the embodied carbon and energy calculations for timber material-region combinations set out in Table 4. Figure 5 summarises the timber production (A1-A3) processes included in the Embodied Carbon and Energy Model.

Inter-regional trade of timber products is accounted for in the model. Most of the process modelling shown in Figure 5 is for in-region *production* of the timber product, e.g., using regional electricity emissions factors. However, the final embodied carbon and energy figures for the datasets are meant to represent in-region *consumption* of timber products. Therefore, the final figures are a weighted average of the in-region production emissions factors for the regions from which these timber products are imported. For example, 72% of kiln dried sawn timber consumed in Africa comes from European production, with most of the remaining share coming from African production. Hence the emissions factor for kiln dried sawn timber in Africa is a weighted average of 72% European production values, 24% African production values, and 4% other region values.

Due to data availability, LCA module A3 production processes for particle board, MDF, plywood and glulam are aggregated. For air dried and sawn dried timber, they are disaggregated into log yard processes, sawing, drying and planing.

Bamboo (A1-A3; C2-C4)

This tab sets out the embodied carbon and energy calculations for bamboo material-region combinations set out in Table 4. Figure 6 summarises the bamboo pole production (A1-A3) processes included in the Embodied Carbon and Energy Model.

Due to the labour-intensive nature of bamboo pole production, calculations include worker-hour emissions, as per the method set out in REF181. These are excluded for other materials as they are insignificant.

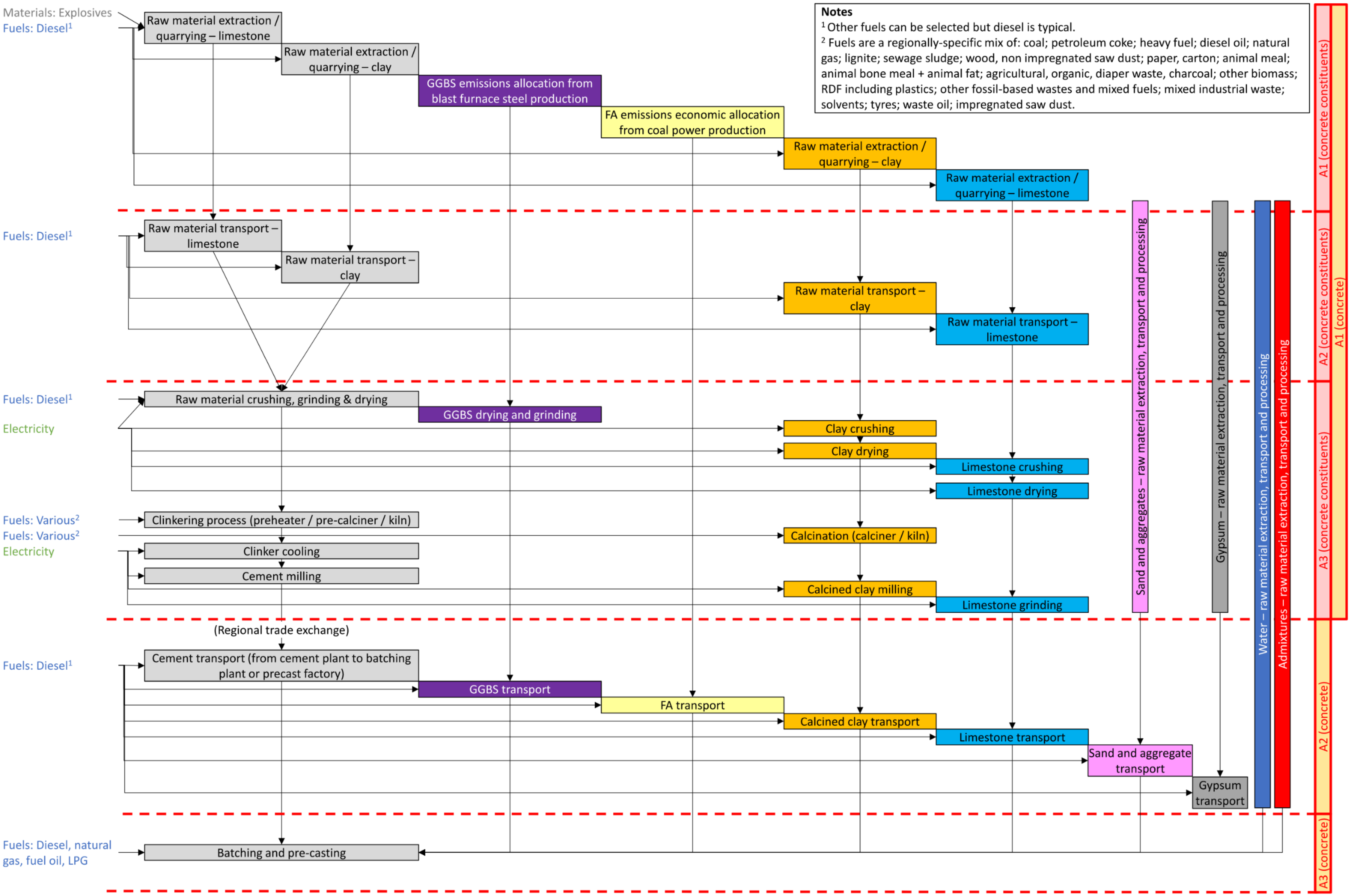

Figure 3: Concrete production (A1-A3) process in the Embodied Carbon and Energy Model.

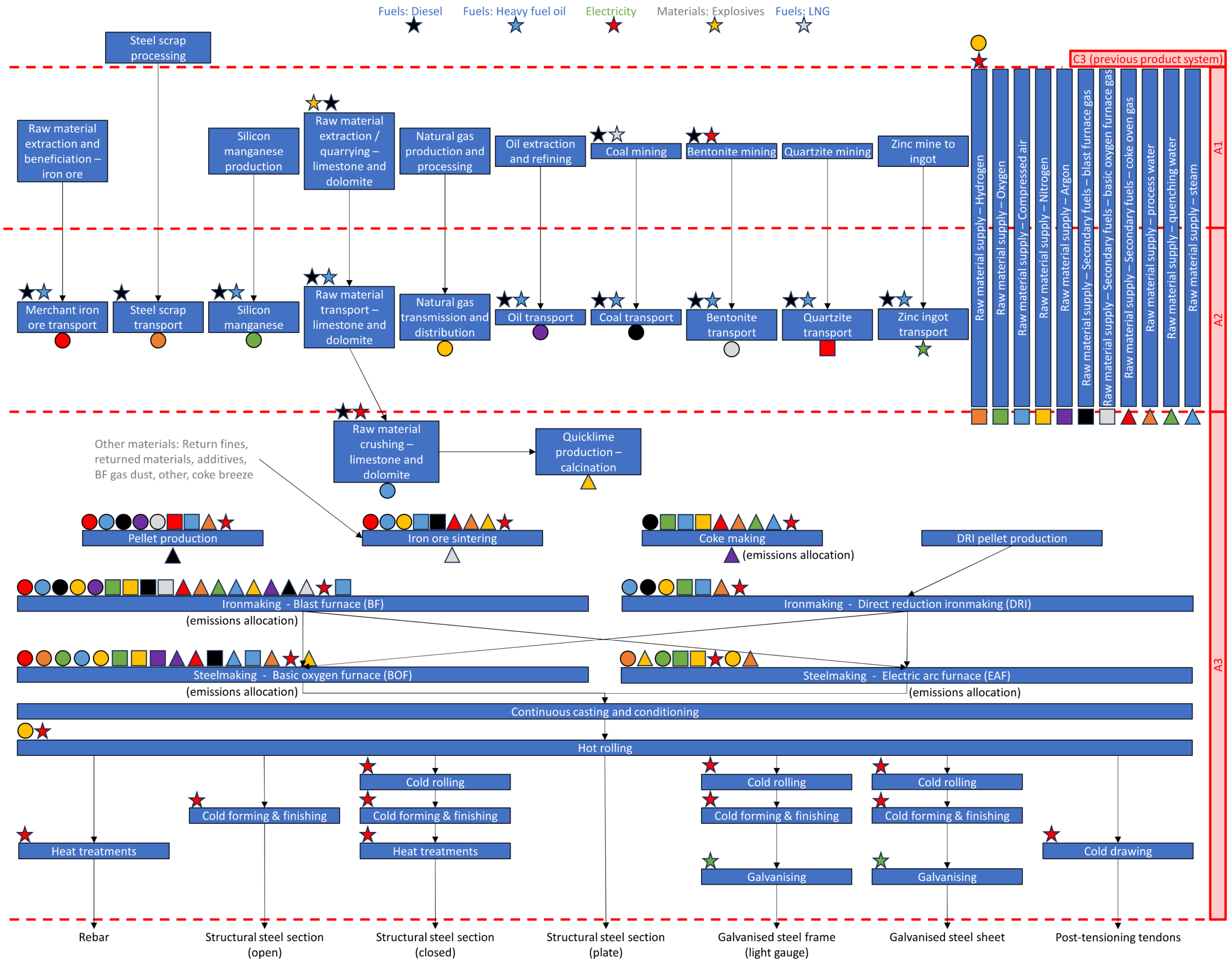

Figure 4: Steel production (A1-A3) process in the Embodied Carbon and Energy Model.

Notes

[1] Fuels are a regionally-specific mix of: Hard coal, oil, diesel, natural gas, liquified petroleum gas (LPG) and woodchips.

[2] Fuels are a regionally-specific mix of: Diesel, natural gas, liquified petroleum gas (LPG) and woodchips.

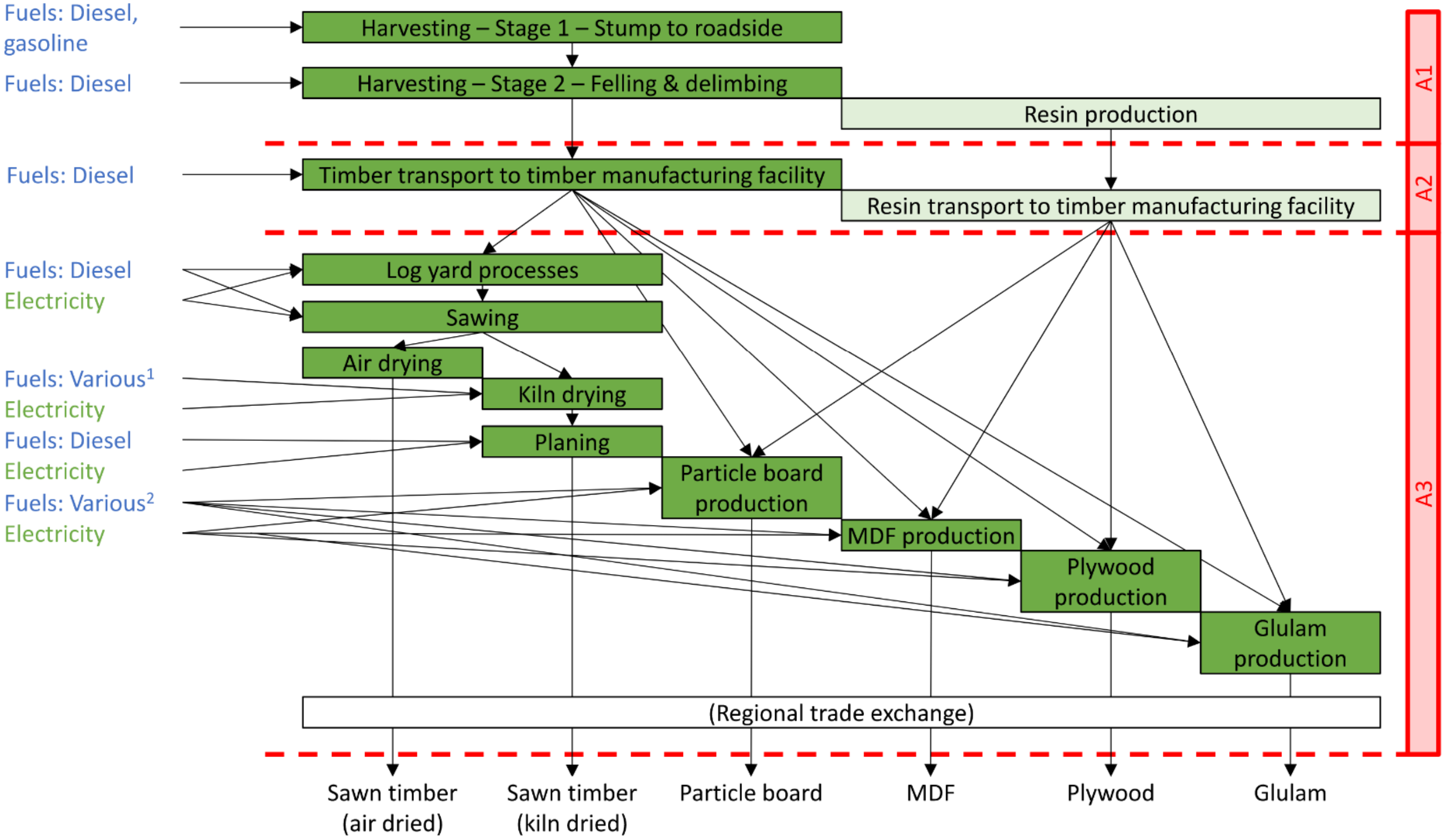

Figure 5: Timber production (A1-A3) process in the Embodied Carbon and Energy Model.

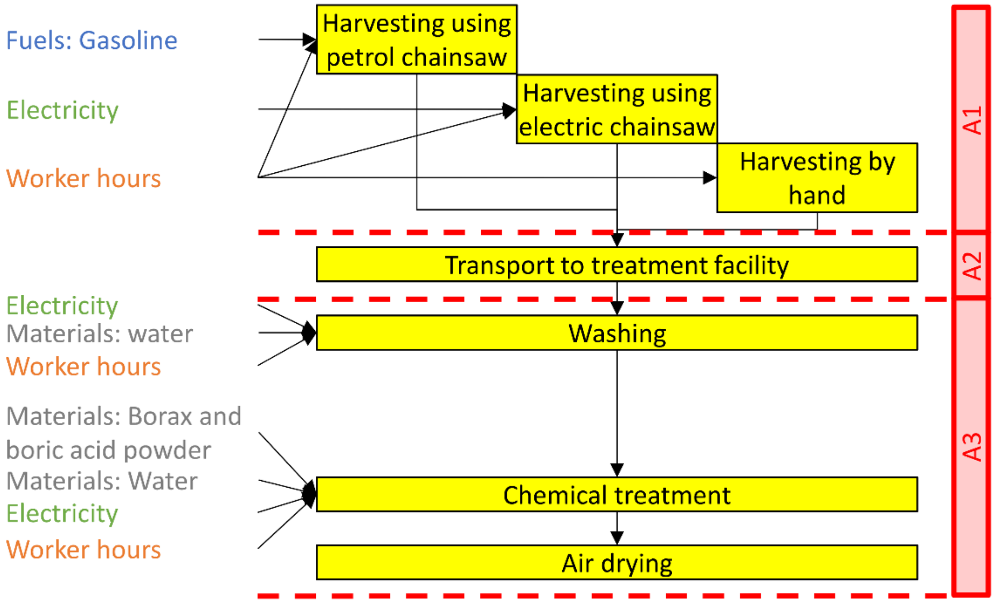

Figure 6: Bamboo pole production (A1-A3) process in the Embodied Carbon and Energy Model.

2.5.3 Module A4 (transport to site)

It is recommended that transport-to-site emissions be calculated in EDGE using Equation 1, taken from RICS PS section 5.1.3. Where transport to site occurs in stages involving more than one transport mode (e.g., road transport and shipping), the emissions from each transport mode should be summed to calculate the total emissions for LCA module A4. The first table in the A4 tab of the Embodied Carbon and Energy Model demonstrates the calculation approach.

$$A4 = a \times b \times (c1 + (e \times c2))$$

Where:

a = Material or product mass [kg or t]. This will be calculated in EDGE based on the user-selected construction assembly and material quantities defined for each assembly (either default or user input). Construction assemblies have been developed for Task 6.

b = Transport distance [km]. Recommended default transport distances are provided for use in EDGE and are listed in the A4 tab of the Embodied Carbon and Energy Model, with the understanding that EDGE will provide users the ability to define the transport distance if they know where the construction product will be sourced from.

c1 = Carbon conversion factor outward journey [$kgCO_2e/t.km$]. These factors (both c1 and c2, below) have been sourced from EcoTransIT [19], the Global Logistics Emissions Council (GLEC) Framework for Logistics Emissions Accounting and Reporting [20] [21] and UK Government Greenhouse Gas Conversion Factors for company reporting [22]. Default energy consumption factors for use in EDGE are also provided in the A4 tab of the Embodied Carbon and Energy Model. These can be combined with the emissions factors for fuels and electricity to calculate the emissions intensities (c1 and c2) for that transport mode.

e = Empty running factor [%]. Recommended default values are given in the Embodied Carbon and Energy Model and are based on RICS PS section 5.1.3 guidance, GLEC or EcoTransIT as appropriate for each transport mode.

c2 = Carbon conversion factor return journey [$kgCO_2e/t.km$].

Equation 1: A4 transport to site emissions calculation.

Table 8: Default empty running factors for use in EDGE.

Transport mode description	Example mode(s)	Empty running factor
Road freight where return load is possible	Heavy goods vehicle	43% (or national equivalents if available in EcoTransIT and GLEC reports)
Road freight where return load is not possible	Concrete mixer trucks	100%
Rail transport		0%
Sea transport		0%

Default transport distances

Default LCA module A4 transport distances have been developed for each material-region combination and set out in the A4 tab of the Embodied Carbon and Energy Model. These were established by considering UN Comtrade data on the inter-regional trade of construction materials, RICS PS guidance, Timber Development UK (TDUK) data, steel plant and port locations relative to major urban centres, and practical restrictions, such as the maximum ranges of ready-mix concrete trucks. This is set out in REF143, REF368, REF369 and REF370. Recommended default transport distance values are shown in Table 9.

However, material transport distances for individual projects may differ significantly from these default values, as project-to-project variability in A4 distances is expected to be high, particularly for steel and timber products. Therefore, it is highly recommended that EDGE users should have the ability to input actual/known transport distances for key construction materials in EDGE, to generate accurate embodied carbon estimates.

Table 9: Default transport distances by material with justification.

Material	Default road transport mode and distance	Default sea transport mode and distance
Ready-mixed concrete	25km by concrete mixer truck based on practical constraints of delivering ready-mixed concrete, and RICS PS section 5.1.3 guidance.	N/A, assumed locally produced (consistent with RICS PS guidance).
Precast concrete	120km by rigid HGV based on RICS PS guidance, assuming nationally manufactured.	N/A, assumed nationally produced (consistent with RICS PS guidance).
Steel products	300km via HGV based on a study of distances from major cities in each region to steel plants and major ports (REF369). Distances account for both manufacturer-to-port and port-to-site transport.	Bulk carrier. Distance varies by region, based on import/export data for each product from UN COMTRADE.
Timber products	400km to 800km depending on the product, based on European industry data from Timber Development UK (REF370). Distances account for both manufacturer-to-port and port-to-site transport.	Bulk carrier (except for plywood, which is container ship) based on REF370. Distance varies by region, based on import/export data for each product from UN COMTRADE.
Bamboo	120km by rigid HGV based on RICS PS guidance, assuming nationally manufactured.	N/A, assumed nationally produced.

2.5.4 Module A5.1 (pre-construction demolition)

RICS PS section 5.1.4 states that:

> "For all schemes, any carbon impacts resulting from the deconstruction/demolition, transporting and disposal of waste as part of the main works must be accounted for in A5.1, which should be reported separately…If actual figures are not available, a standard assumption for the UK of 35 $kgCO_2e/m^2$ should be adopted (rate from monitored demolition case studies in central London), applied to the GIA of the existing areas being demolished that fall within the boundary line. Assessments in other countries may use these default figures, but should use a national equivalent if available; the assessment should then make clear what source has been used. The $kgCO_2e/m^2$ value suggested should be superseded with site-specific data when available."

It is expected that most EDGE users will not have detailed data to calculate LCA module A5.1 emissions, and therefore the default value of 35 $kgCO_2e/m^2$ GIA can be used to estimate these emissions in EDGE, as per Equation 2, if the project involves pre-construction demolition. These emissions should then be reported separately from other emissions in module A5 that are related to construction of the new building (see section 2.5.5).

Equivalent calculations, for countries outside the UK, have not been identified, but could be added to EDGE if available in the future.

$$A5.1 = 35 \times GIA(existing\ building)$$

Where:

A5.1 = Emissions for LCA module 5.1 [$kgCO_2e$].

GIA (existing building) = The gross internal area (GIA) [m^2] of the existing building on site to be demolished, measured in square metres. This should be a user-input in EDGE if applicable.

Equation 2: A5.1 pre-construction demolition emissions calculation.

If required, the embodied energy associated with pre-construction demolition should be taken as 500 MJ/m^2 GIA.

Emissions values which are calculated at the building-level, including LCA modules A5.1, A5.2, B2, B3 and C1 should preferably be presented in EDGE as 'unclassified', rather than being assigned to a particular building element (e.g., substructure). However, if it is necessary to assign these values to building elements, this should be done proportionally based on the relative A1-A4 values for these elements.

2.5.5 Module A5.2 (Construction activities)

Construction activity impacts include impacts from any construction activities and installation processes on-site, including temporary works, energy consumption for site accommodation and use of plant, machinery and equipment. RICS PS section 5.1.4 states that:

> "Baseline building-specific impacts related to construction activities in the UK are anticipated to be 40 $kgCO_2e/m^2$ GIA. Assessments in other countries may use this default figure but should use a national equivalent if available; the assessment should then make clear what source has been used. The $kgCO_2e/m^2$ value suggested should be superseded with site-specific data when available."

As for LCA module 5.1, it is expected that most EDGE users will not have detailed data to calculate LCA module A5.2 emissions, and therefore the default value of 40 $kgCO_2e/m^2$ GIA can be used to estimate these emissions in EDGE, as per Equation 3.

Alternatively, regional values, developed for this project and presented in the A5 tab of the Embodied Carbon and Energy Model, can be used. Regional values are based on an estimated breakdown of emissions attributed to electricity, diesel, liquefied petroleum gas (LPG), concrete, plywood, sawn wood and water supply and treatment. This breakdown yields an estimate of 40 $kgCO_2e/m^2$ GIA for UK buildings when combined with UK-specific emissions factors for energy and materials. Estimates for other regions are then developed using regional emissions factors for electricity and materials.

$$A5.2 = 40 \times GIA(new\ building)$$

Where:

A5.2 = Emissions for LCA module 5.2 [$kgCO_2e$].

GIA (new building) = The gross internal area (GIA) [m^2] of the new building being constructed, measured in square metres. This should be a user-input in EDGE. Note that to calculate construction site emissions associated with refurbishments, only the additional GIA of the refurbishment should be included, and the resulting module construction site emissions should be reported under LCA module B5 (see section 2.5.10 for details).

Equation 3: A5.2 construction activities emissions calculation.

Regional estimates of the estimated embodied energy associated with construction sites activities (LCA module A5.2) are included in the A5 tab of the Embodied Carbon and Energy Model.

2.5.6 Module A5.3 (Waste and waste management)

According to RICS PS section 5.1.4, LCA Module A5.3 captures emissions from the production and transport of products that will be wasted, and any impacts associated with waste treatment. These emissions are calculated using Equation 4 and are embedded within the LCA datasets.

In the Embodied Carbon and Energy Model, emissions estimates for LCA module A5.3 are generated using the same end-of-life processes as those modelled for LCA modules C2-C4. For timber and bamboo products, these emissions estimates exclude biogenic carbon since EDGE V4 will only be used to calculate upfront carbon.

$$A5.3 = a \times b$$

Where:

a = Waste rate [%]. Recommended default values for the waste rate, for each material-region combination, are included in the A5 tab of the Embodied Carbon and Energy Model. These were developed based on desktop research and expert interviews and are mostly aligned with RICS PS Table 18.

b = Site waste treatment embodied carbon factor. As per Table 19 of RICS PS, this value is a function of emissions from other LCA modules, included in the LCA datasets for each material-region combination. It also depends on the disposal scenario, either ‘Disposal to landfill/incineration’ (b = [A1-A3] + [A4] + [C2] + [C4]), ‘Reuse or recycling on-site’ (b = [A1-A3] + [A4] + [C3]), or ‘re-use or recycling offsite’ (b = [A1-A3] + [A4] + [C2] + [C3]). Default disposal scenarios adopted for each material-region combination are included in the Embodied Carbon and Energy Model, with the resulting LCA module A5.3 figures presented in the OUTPUTS tab.

Equation 4: A5.3 waste and waste management emissions calculation.

2.5.7 Module B1 (use)

As per section 5.2.1 of RICS PS, the in-use module (B1) captures the non-energy-related impacts during the life of a built asset arising from its components. It is divided into two components:

1. B1.1 In-use: material emissions and removals – Release from materials of gases with GWP, e.g. blowing agents from insulation; reabsorption of CO_2 into products containing lime and cement through carbonation, and removals from vegetation.
2. B1.2 In-use: fugitive emissions (refrigerants) – Accidental release of refrigerants with GWP from mechanical, electrical and public health (MEP) equipment such as cooling systems and heat pumps.

Regarding B1.1, no significant emissions with global warming impact are expected to be released from bamboo, timber, or steel. Some natural re-carbonation would occur for concrete elements. However, these impacts are expected to be very small and are difficult to predict. Any carbonation that does occur in LCA module B1 normally just reduces the amount of carbonation that occurs in module C3 from exposure of crushed concrete after waste processing. Therefore, LCA module B1 emissions have been taken as zero for all materials considered for this project, and any emissions from natural re-carbonation of concrete are included in LCA modules C3 and C4.

For this project, B1.2 emissions are not applicable, as MEP systems and associated embodied energy and carbon are outside the scope of this project.

2.5.8 Modules B2-B3 (maintenance and repair)

Maintenance and repair impacts are addressed in sections 5.2.2 and 5.2.3 of RICS PS, respectively.

Given that EDGE is typically used for high-level and/or early-stage WLCAs, where users may not have detailed information about materials and energy used to repair and maintain the building, a simplified approach to calculating emissions for modules B2 and B3 is recommended, based on RICS PS. RICS PS section 5.2.2 states that:

> "…for module B2 impacts in the UK, a total figure of 10 $kgCO_2e/m^2$ gross internal area (GIA) may be used to cover all building element categories, or 1% of modules A1–A5, whichever is greater… Assessments in other countries may use this default figure but should use a national equivalent if available; the assessment should then make clear what source has been used."

Therefore, maintenance impacts should be calculated at the building level in EDGE as a function of LCA modules A1-A5, as per Equation 5.

$$B2 = \text{MAX}\,(10, 0.01 \times [A1 - A5])$$

Where:

B2 = LCA module B2 emissions [$kgCO_2e/m^2$ GIA].

[A1–A5] = emissions calculated for LCA modules A1 to A5 [$kgCO_2e/m^2$ GIA].

Equation 5: B2 maintenance impacts emissions calculation.

For LCA module B3, RICS PS section 5.2.3 states that:

> "…in the UK repair impacts should be assumed as equivalent to 25% of B2 maintenance impacts for the relevant items and 10% of A1–A3 impacts for MEP – in accordance with the CIBSE TM65 methodology. Assessments in other countries may use these default figures but should use national equivalents if available; the assessment should then make clear what source has been used."

Therefore, Equation 6 should be used to calculate LCA module B3 impacts for non-MEP items in the scope for this project.

$$B3 = 0.25 \times B2$$

Where:

B2 = LCA module B2 emissions.

B3 = LCA module B3 emissions.

Equation 6: B3 repair impacts emissions calculation.

Equivalent calculations, for countries outside the UK, have not been identified, but could be added to EDGE if available in the future.

Embodied energy calculations for LCA module B2 should be undertaken using 1% of LCA module A1-A5 embodied energy, as per Equation 5, since the value of 10$kgCO_2e/m^2$ GIA given in RICS PS applies to embodied carbon, not embodied energy.

2.5.9 Module B4 (replacement)

As per RICS PS section 5.2.4:

> "Module B4 must take into account any carbon impacts associated with the anticipated replacement of built asset components, including any impacts from the replacement process, over the RSP. All impacts from the production, transportation to site and installation of the replacement items must be included, as well as any losses during these processes, as well as any impacts associated with the removal and end-of-life treatment of replaced items. For both buildings and infrastructure, the repair and replacement impacts must be considered using the same data for materials and products as was used in modules A1–A5 for installation and modules C and D for their end of life."

Therefore, for materials included in this project, LCA module B4 emissions can be calculated in EDGE using Equation 7.

RICS PS states that "only a whole number of replacements (no partial replacements) is allowed; in the case of a partial number of replacements resulting from the estimated service life of the component and the RSP of the building, the number is rounded up." Therefore, as per Equation 7, the term (RSP/expected lifespan – 1) should be rounded up to the nearest whole number. For example, if RSP is 60 and expected lifespan is 25, 60/25-1 = 1.4, but EDGE should account for 2 replacements, not 1.4 replacements.

$$B4 = ROUNDUP\left(\frac{RSP}{Expected\ lifespan} - 1\right) \times [A1 - A5; C1 - C4]$$

Where:

B4 = LCA module B4 emissions.

Expected lifespan = Expected lifespan of the product in years. Default expected lifespans for building component can be taken from RICS PS Table 20. For the materials considered for this project, the expected lifespan will be equal to the building RSP (normally 60 years) in most cases, except if the material (e.g., timber, bamboo or light gauge steel framing) is used for studwork, in which case the default lifespan will be shorter (30 years), as per RICS PS.

RSP = Reference study period, which should be taken as 60 years in most cases for buildings as per section 4.2 of RICS PS. When accounting for emissions related to LCA module B5 (refurbishments), the RSP in this equation should be replaced with (RSP – T), where T is the year in which the refurbishment is planned to occur, to only count the material replacement emissions for the period between when the refurbishment occurred, and the RSP (normally 60 years).

[A1-A5; C1-C4] = Emissions calculated for LCA modules A1-A5 and C1-C4 for the product. LCA module D is excluded from the scope of assessment (as per section 2.1 of this report) and therefore excluded from the equation. LCA modules C1, A5.1, and A5.2 are calculated at the building level as a function of the existing or new building GIA. For simplicity and given their relatively minor contribution to overall embodied emissions, these can be excluded from the calculations for LCA module B4.

Equation 7: B4 replacement impacts emissions calculation.

2.5.10 Module B5 (refurbishment)

According to RICS PS section 5.2.5, LCA module B5 captures:

> "…planned alteration or improvement to the physical characteristics and/or performance of the building, for it to perform a future function that was identified as likely at the time of the assessment. This would typically involve a predetermined change that will occur during the service life of the project."

For most building WLCAs undertaken in EDGE, it is expected that LCA module B5 will be zero, as is typically the case for detailed building WLCAs where refurbishments are not anticipated at the time of construction of the base building. Assessing the embodied carbon emissions of the base building only is also sensible for benchmarking, rather than including what may or may not be built in the future. This could be assessed later for the new part of the building. Furthermore, given the added complexity of accounting for LCA module B5 emissions, both for EDGE users and regarding EDGE application development, it may be justifiable to take LCA module B5 as zero in all cases for upcoming versions of EDGE.

Nevertheless, EDGE could include the option for users to specify future planned alternations in their WLCAs, in which case LCA module B5 emissions would be calculated using Equation 8.

$$B5 = [A1 - A5]_{refurbishment} + [C1 - C4]_{dismantled\ elements}$$

Where:

B5 = LCA module B5 emissions.

$[A1\text{-}A5]_{\text{refurbishment}}$ = LCA module A1-A5 emissions associated with the planned refurbishment.

$[C1\text{-}C4]_{\text{dismantled elements}}$ = LCA module C1-C4 emissions associated with elements dismantled during the refurbishment process.

Equation 8: B5 refurbishment impacts emissions calculation.

Additionally, RICS PS states that:

> "…Adjustments must also be made to all modules B, C and D in the WLCA from the point of change, in order to accommodate the impact of the altered asset."

Impacts in LCA module B should be calculated for the refurbishment in the same way as for the base building, but accounting for the shorter modelled lifespan of the refurbishment, (RSP – T), where T is the year in which the refurbishment occurred after practical completion of the base building. This is so that:

- LCA module B2 and B3 emissions related to the refurbishment are factored down by (RSP – T)/RSP to account for the maintenance and repair occurring for the refurbishment only after it has been constructed. The module B2 and B3 emissions for the base building would still be calculated based on the full RSP.
- LCA module B4 emissions only include the material replacement emissions for the period between when the refurbishment occurred (T years after completion of the base building), and the RSP, as noted for Equation 7. For example, if the refurbishment included some timber elements with a 30-year service life, but the refurbishment is planned to occur 30 years after the base building is constructed (T = 30), there would be zero rounds of replacement of those elements between when the refurbishment was carried out, and the 60-year RSP.

LCA module C1 emissions for the refurbishment should be calculated as per Equation 3 and Equation 9, but based on the additional GIA of the refurbishment only (which would need to be a user input in EDGE).

LCA module C2, C3 and C4 emissions for the refurbishment should be calculated in the same way as for materials that are part of the base building, i.e., as per sections 2.5.12, 2.5.13 and 0.

2.5.11 Module C1 (deconstruction and demolition)

As per RICS PS section 5.6.2, LCA module C1 should cover all site-based activities required to decommission, dismantle, deconstruct and/or demolish the built asset being assessed.

As for LCA modules B2 and B3, a simplified approach to calculating LCA module C1 emissions is recommended given typical EDGE users may not have detailed information about the end-of-life scenario that applies or the related energy consumption for site accommodation and plant use.

RICS PS states that:

> "Where no other information is available, the C1 impacts for a given asset should be treated as a proportion of the A5.2 impacts from construction activities. Where no specific measures have been taken to improve end-of-life recovery, the recommended BAU proportions are as indicated in Table 25. Where the design team has demonstrated that design for disassembly and recovery has been incorporated, the assessor should make a reasonable adjustment to these figures to reflect an increased rate of recovery."

Therefore, Equation 9 should be used to calculate LCA module C1 emissions at the building level in EDGE.

$$C1 = P \times [A5.2]$$

Where:

C1 = LCA module C1 emissions [$kgCO_2e$ or $kgCO_2e/m^2$ GIA].

P = Percentage [%], which should be taken as 25% for 'Business as usual' scenarios, 30% for 'Good practice' scenarios and 50% for 'Best practice' scenarios, as per Table 25 of RICS PS. This end-of-life scenario description can be an optional user input in EDGE. Note, however, that based on this formula, 'Best practice' corresponds to greater recovery of building elements for reuse (and therefore improved circularity) but higher embodied carbon emissions, due to the additional resources typically required for material recovery.

[A5.2] = LCA module A5.2 emissions, calculated as per section 2.5.4. Note that when counting demolition emissions associated with refurbishments, the calculation for LCA modules A5.2 and C1 should be based on the additional GIA of the refurbishment only.

Equation 9: C1 demolition impacts emissions calculation.

2.5.12 Module C2 (transport to waste processing)

LCA module C2 captures emissions from the transport of materials from deconstruction and demolition to the appropriate final location, including any interim stations. Guidance on LCA module C2 calculations is included in RICS PS section 5.6.3.

LCA module C2 emissions are embedded in the product-level LCA datasets and are calculated in the same way as for LCA module A4 (see Equation 1) but adopting transport distances for the end-of-life stage rather than the construction stage.

Transport distances and end-of-life waste treatment scenarios assumed for LCA module C2 calculations are included in the concrete, steel, timber and bamboo tabs of the Embodied Carbon and Energy Model.

2.5.13 Module C3 (waste processing)

LCA module C3 captures emissions from preparing waste materials for reuse, waste treatment or recovery, prior to the material reaching its end-of-waste state. Guidance on LCA module C3 calculations is included in RICS PS section 5.6.4.

LCA module C3 emissions are embedded in the product-level LCA datasets. End-of-life waste treatment scenarios assumed for LCA module C3 calculations are included in the concrete, steel, timber and bamboo tabs of the Embodied Carbon and Energy Model.

End of life treatment processes for biomaterials (timber and bamboo) were estimated based on an analysis of the World Bank's What a Waste 2.0 dataset (REF109). End of life processes in REF109 are classified as per Table 10. A limitation of the REF109 dataset is that it does not map the waste material (e.g., timber) to the end-of-life process. REF109 shows that around 31% of UK waste is incinerated; however, it is known from UK data (REF136) that incineration rates for timber are close to 100% for timber products such as MDF, particleboard and plywood, while a combination of incineration and recycling into other products is prevalent for products such as solid hardwood, solid softwood and glulam. To correct for this, incineration rates for timber were taken as 100% if the country-level incineration rate exceeded 20%, with the assumed incineration rate for timber scaling linearly up to 100% for regional incineration rates below 20%. The remaining percentage shares for timber end of life processes were then divided between landfill (high methane risk) and landfill (low methane risk) based on the classifications in Table 10, and the country-level figures in REF109. Reuse and recycling rates were assumed to be zero in all cases, due to a lack of data, and because the biogenic carbon emissions associated with reuse and recycling are nearly identical to those for incineration (i.e., 100% release of biogenic carbon to atmosphere in the case of incineration, or 100% biogenic carbon transfer to the next product system in the case of recycling and reuse).

Table 10: Mapping of end-of-life processes in the World Bank's What a Waste 2.0 dataset to those used in the Embodied Carbon and Energy Model.

Embodied Carbon and Energy Model end-of-life process	What a Waste 2.0 dataset processes
Landfill (high methane leakage risk)	Landfill unspecified, controlled landfill, open dump, other, unaccounted for.
Landfill (low methane leakage risk)	Landfill with landfill gas system, anaerobic digestion, composting, waterway marine.
Recycling	Recycling
Incineration	Incineration
Reuse	N/A – assumed zero.

The C3 and C4 datasets in the Embodied Carbon and Energy Model should be used together, to reflect the overall mix of recycling, reuse, landfill and incineration at end of life in each region.

2.5.14 Module C4 (waste disposal)

According to RICS PS section 5.6.5, LCA module C4 captures emissions from any processing required prior to disposal, and from the degradation of landfilled materials, or incineration without energy recovery or in a plant not classified as a recovery operation. This is only applicable for items not being recovered for reuse, recycling or other recovery.

LCA module C4 emissions are embedded in the product-level LCA datasets. End-of-life waste treatment scenarios assumed for LCA module C4 calculations are included in the concrete, steel, timber and bamboo tabs of the Embodied Carbon and Energy Model.

3. Findings

The DASHBOARD tab of the Embodied Carbon and Energy Model contains the main modelling results. Key findings are summarised herein for each material.

3.1 Concrete (A1-A3)

Figure 7 and Figure 8 present the regional embodied emissions and embodied energy (respectively) estimates for Portland cement clinker, which is the key emissions-intensive component in cement and concrete. The following key findings are evident from the analysis:

1. More than half the emissions from clinker production are process emissions from the breakdown of limestone ($CaCO_3$) into lime (CaO) and carbon dioxide during clinkering (grey bars). These do not vary significantly by region as they are inherent to the chemical process and not significantly influenced by production process or fuel type.
2. Most of clinker production's remaining emissions are from kiln fuel use (red bars). The use of alternative and biomass fuels such as refuse-derived fuel (RDF) is common in Europe, accounting for around 50% of total fuel use. This explains the lower fuel-related emissions factors for Europe, despite the region having a relatively older and less efficient kiln fleet, indicated by the red bars for kiln fuel-related energy in Figure 8. In contrast, Asian cement plants use around 93% fossil-based fuels, leading to higher fuel-related emissions despite the region having a relatively newer and more efficient kiln fleet according to the available data. Note that the above is based on the "net" accounting approach (discussed in section 2.5.2), whereby the emissions from waste fuels used in the cement kiln are excluded from the emissions value for the cement and concrete products. When adopting the "gross" emissions accounting approach, fuel-related emissions are more similar from region to region.
3. The remaining processes normally account for <10% of clinker-related emissions, with clinker milling (dark green bars) and clinker transport (from cement plant to batching plant) (light blue bars) estimated as having the highest emissions aside from kiln processes. Oceania and North America are more import-dependant than other regions – with imports as a share of total consumption estimated at around 42% and 18%, respectively – leading to higher estimated clinker transport emissions than for other regions.

Figure 9 presents the regional embodied emissions estimates for concrete, with only C32/40 mixes shown, for clarity. The following key findings are evident:

1. Embodied emissions of concrete are strongly related to the SCM replacement rate, with higher SCM replacement almost invariably leading to reduced emissions at the concrete level. Hence, 50% GGBS and LC3 (30% calcined clay and 15% ground limestone) mixes have the lowest emissions of concretes included in this study.
2. Cementitious materials i.e., clinker, gypsum, GGBS, ground limestone, fly ash and calcined clays account for more than three quarters of concrete's emissions for all concretes in this study. This figure is normally around 89% for Portland cement clinker-based ready-mix concretes. Hence, reducing the binder content through efficient design is an important way to reduce concrete-related embodied carbon.
3. The pre-casting / heat curing process is energy and emissions intensive, accounting for around 15-18% of emissions for precast concretes in this study. Precast concretes typically also contain higher cement contents, and lower SCM replacement rates, due to higher early strength requirements (among other requirements). Thus, they are often higher in embodied carbon than their ready-mixed equivalents. However, use of precast does present possible carbon and energy-related benefits such as enabling modular construction and reducing on-site work and material wastage.

The following findings are evident from Figure 10, which presents the embodied emissions of different cementitious materials by region:

1. All alternative SCMs are significantly lower emissions than Portland cement clinker, which typically emits around 0.7-0.95 $kgCO_2e/kg$ (A1-A3). SCMs are typically below 0.35 $kgCO_2e/kg$ (A1-A3).

2. GGBS (purple bars in Figure 10) is normally higher carbon when used in the Africa region, as it needs to be imported from further afield. Calcined clays (orange bars in Figure 10) are produced in many African countries, such as Ghana, Angola, Cameroon, Burkina Faso and Cote d'Ivoire, offering a viable alternative to GGBS for producing lower carbon concrete in Africa, as well other regions in which it is available.

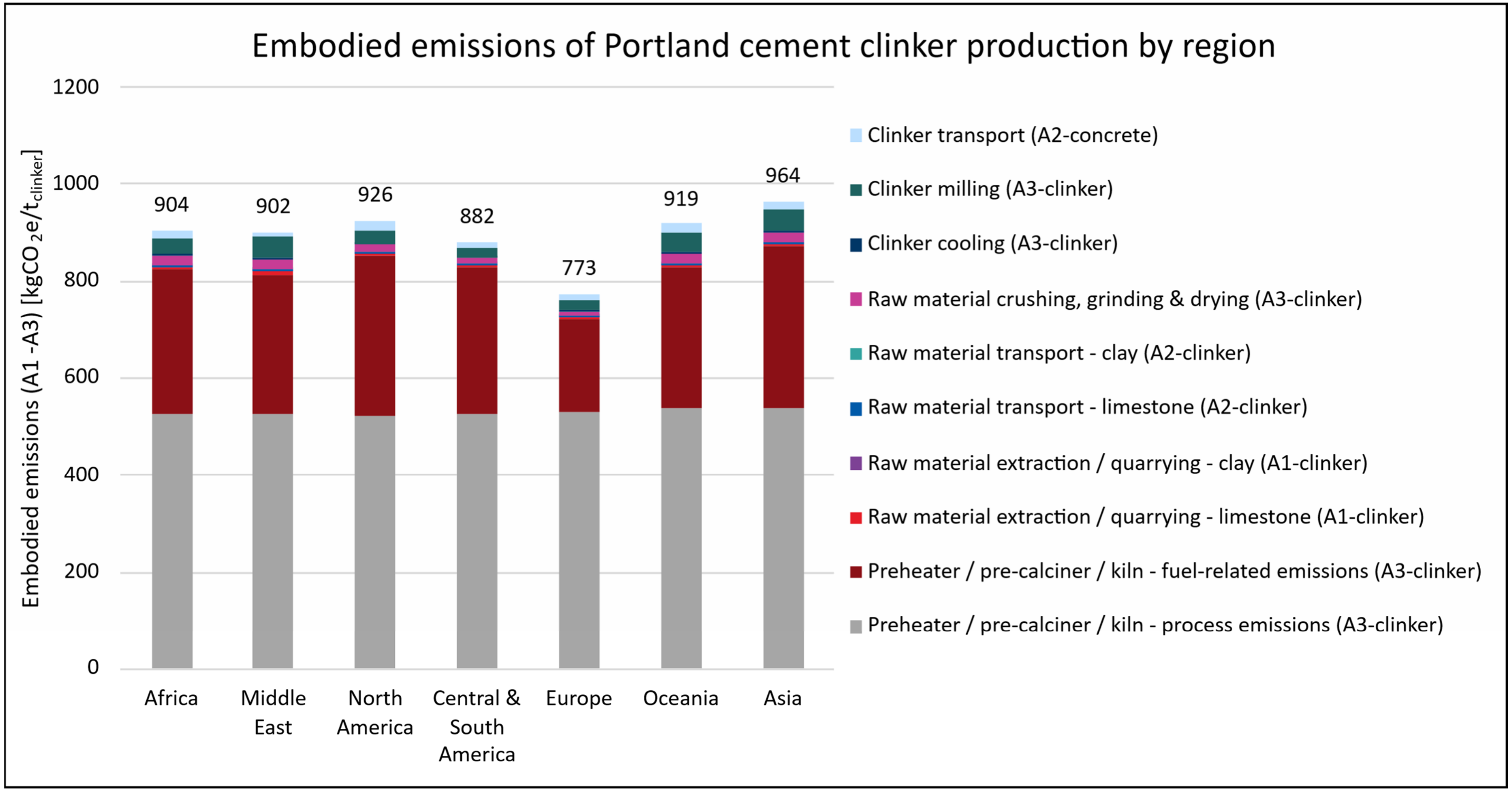

Figure 7: Embodied emissions of Portland cement clinker by region (net emissions[11]).

[11] See section 2.5.2 for a description of the "net" versus "gross" emissions accounting approaches. Net values are presented in this report.

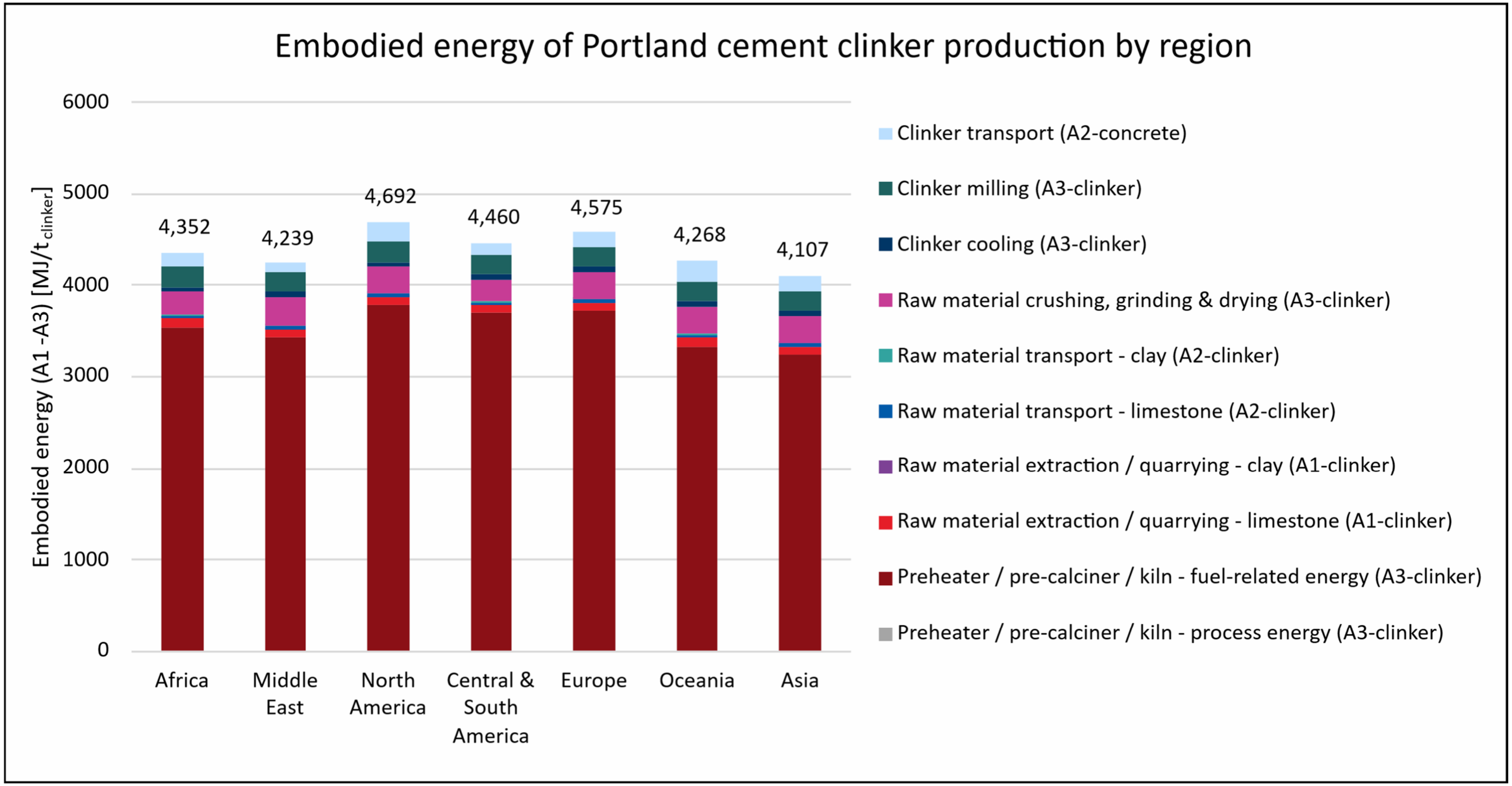

Figure 8: Embodied energy of Portland cement clinker by region.

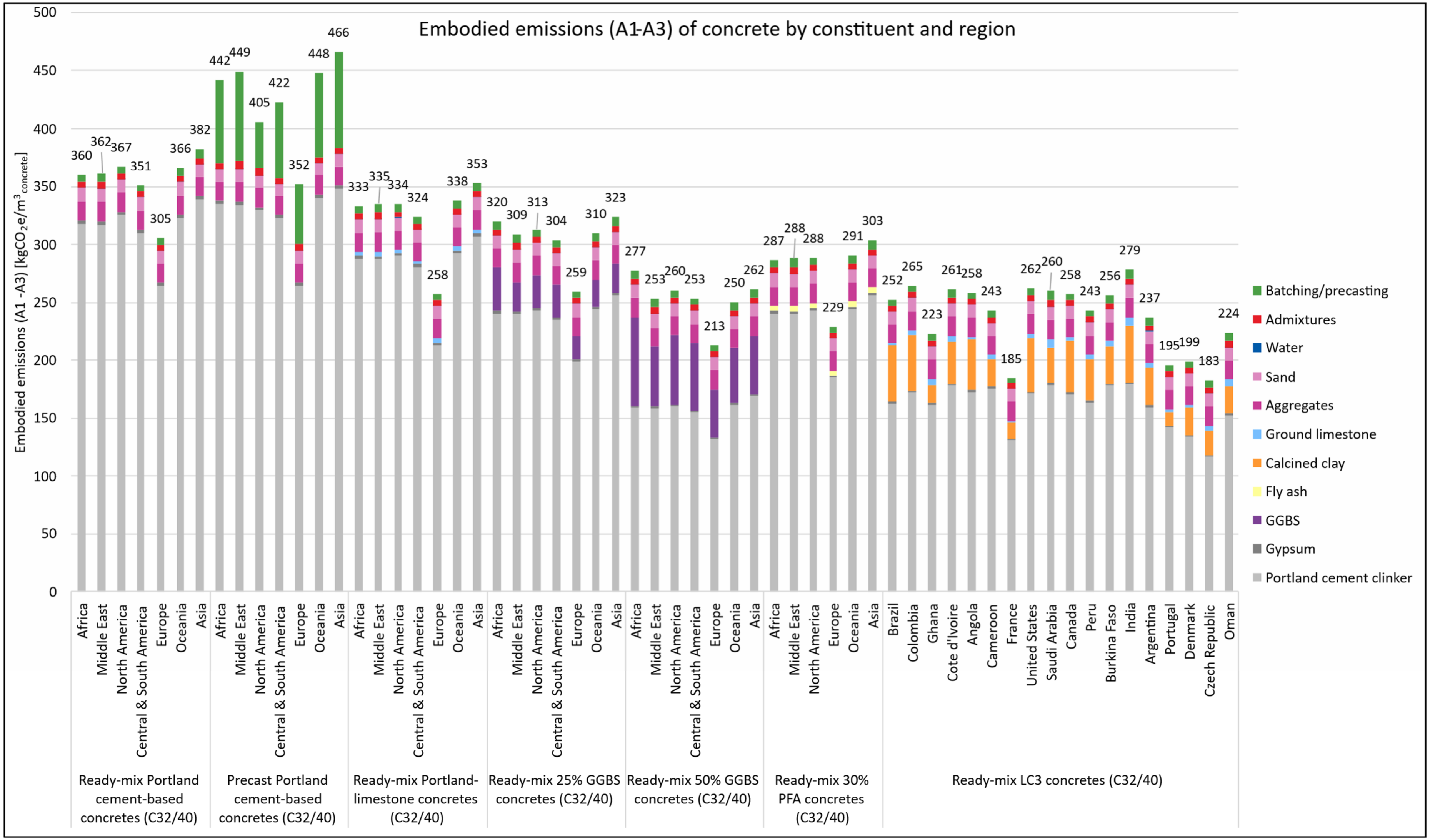

Figure 9: Embodied carbon of C32/40 concrete mixes by region and cement type (net emissions). Other concrete strength classes are included in the model but omitted from the graph for clarity.

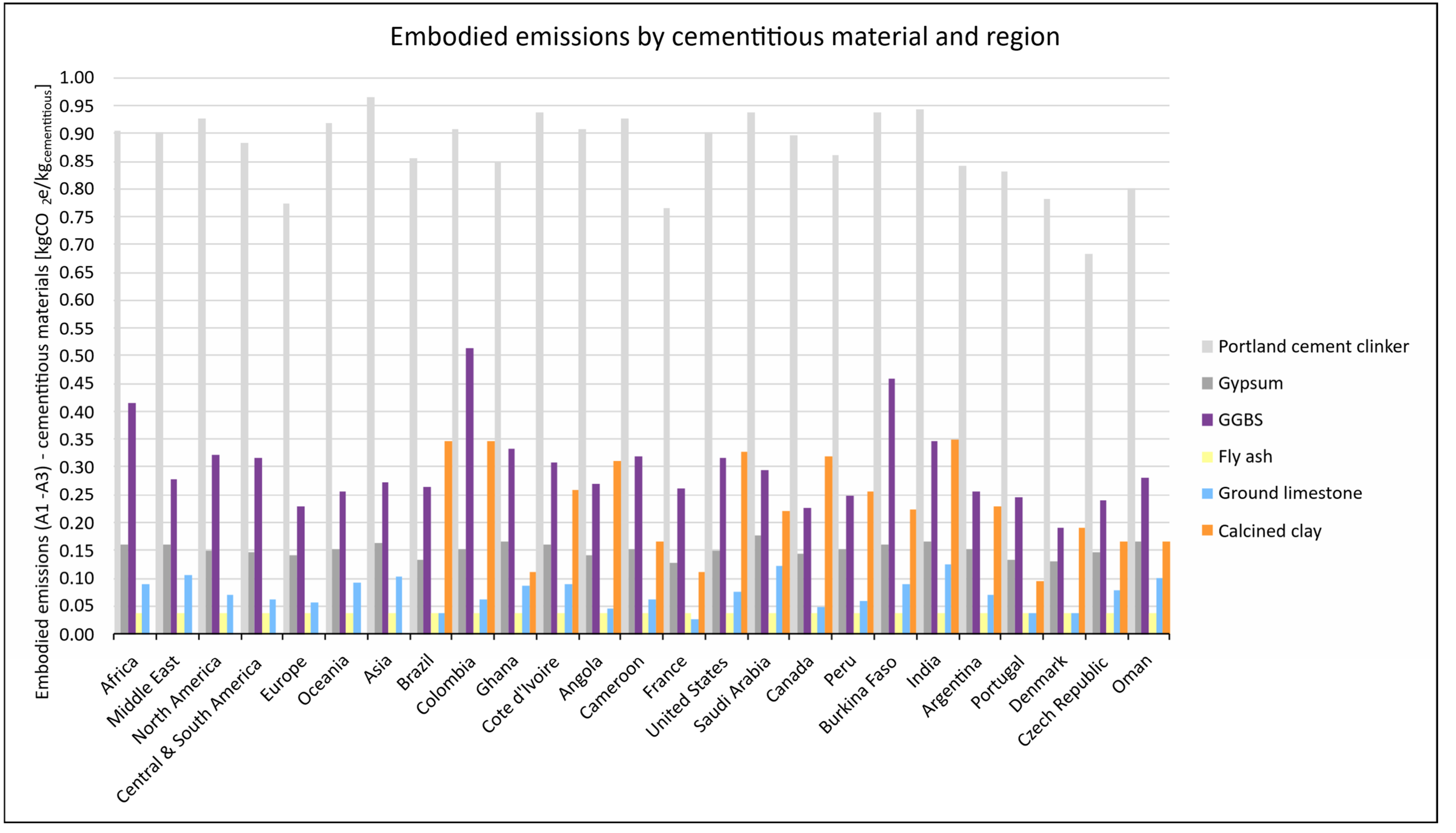

Figure 10: Embodied emissions by cementitious material and region (net emissions).

3.2 Steel (A1-A3)

Figure 11 presents the estimated embodied emissions (A1-A3) of steel products including rebar, structural steel sections (open, closed, and plate), post-tensioning tendons, galvanised steel frame (light gauge) and galvanised steel sheet. The following findings are evident from the analysis:

1. Embodied carbon of steel products is primarily driven by the ratio of basic oxygen furnace (BOF) and electric arc furnace (EAF) steelmaking, and, relatedly, the ratios of virgin iron and steel scrap used during production. Furthermore, the emissions intensity of electricity generation is a major factor given the high amounts of electricity used, particularly in EAFs.

2. Differences in the emissions intensity of different steel products is primarily driven by the factors mentioned previously. However, LCA modules A3 steel processing steps (shown by the purple bars in Figure 11) are also an important differentiator. For example, structural steel plate is continuously hot rolled without the need for further downstream processes. This leads to lower A3 emissions compared with galvanised steel sheet, which requires further cold rolling, cold forming and finishing, and galvanising.

3. Regional variation in emissions intensity is again driven primarily by differences in scrap content, BOF/EAF split and emissions intensity of electricity. Asia generally uses higher embodied carbon steel than other regions due to lower scrap share, lower EAF share, and higher carbon electricity.

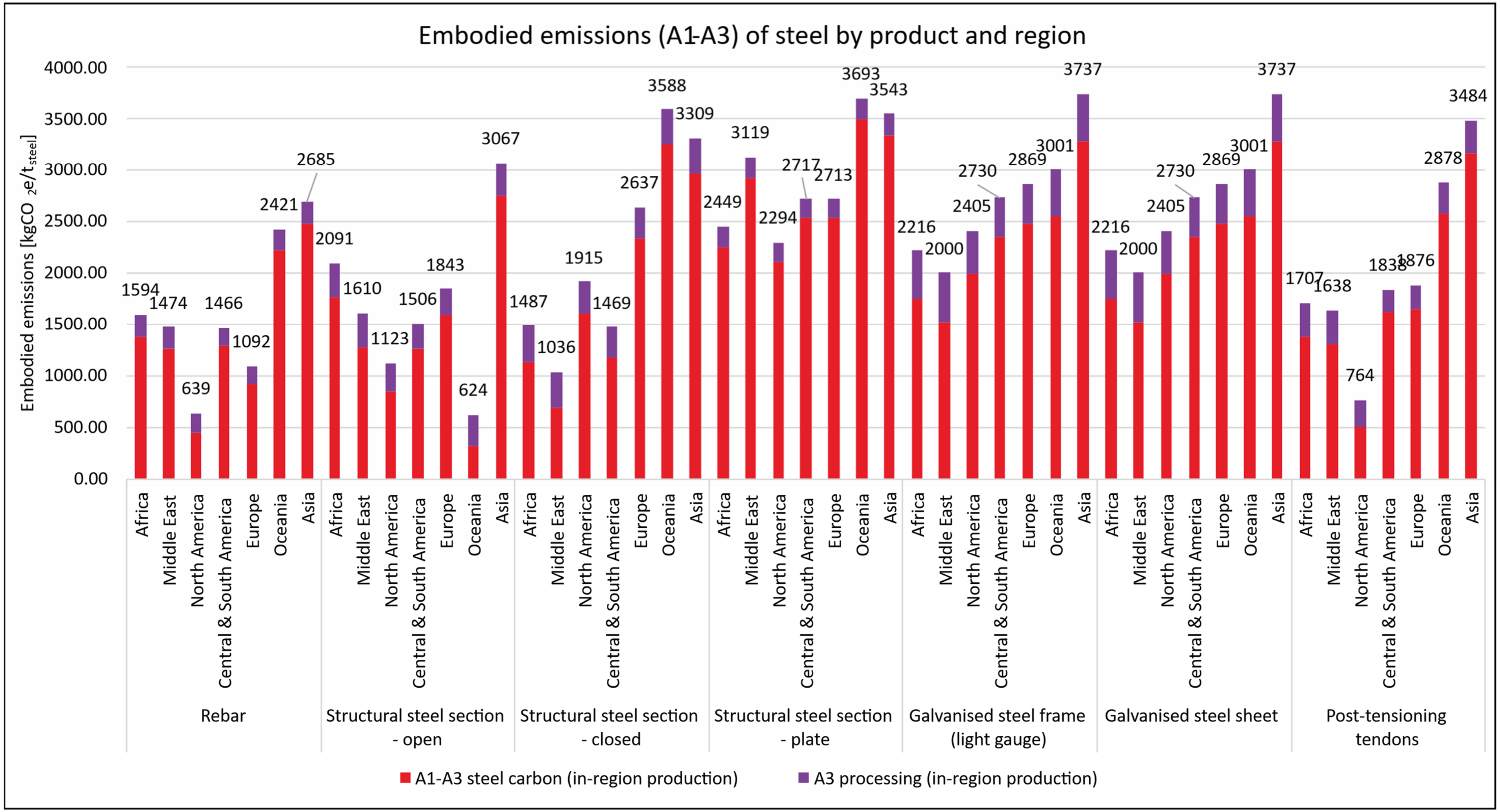

Figure 11: Steel embodied emissions by product and region (production-based).

3.3 Timber (A1-A3)

Figure 12 presents the estimated embodied emissions (A1-A3 excluding biogenic) of timber products including sawn timber (kiln dried and air dried) particle board, medium density fibreboard (MDF), plywood and glue-laminated timber (glulam). The following findings are evident from the analysis:

1. Highly processed manufactured timber products such as particle board, MDF and plywood have significantly higher embodied carbon than less-processed products such as air-dried sawn timber, kiln dried sawn timber and glulam.
2. The use of resins – i.e., chemical adhesives – is a major contributor to the embodied emissions of timber products, responsible for up to around half of the product-stage (A1-A3) total for products such as plywood. This is shown by the purple bars in Figure 12.
3. Differences in fuel types (e.g., hard coal versus wood chips) for timber manufacturing, as well as differences in embodied emissions of electricity, are important drivers of regional differences in the embodied emissions of timber product production.
4. Regional trade in timber products generally reduces regional variation in the embodied emissions of timber product consumption – shown by the black dots in Figure 12 – as higher-emissions products are imported to regions with lower-emissions production, and lower emissions products imported to regions with higher-emissions production.

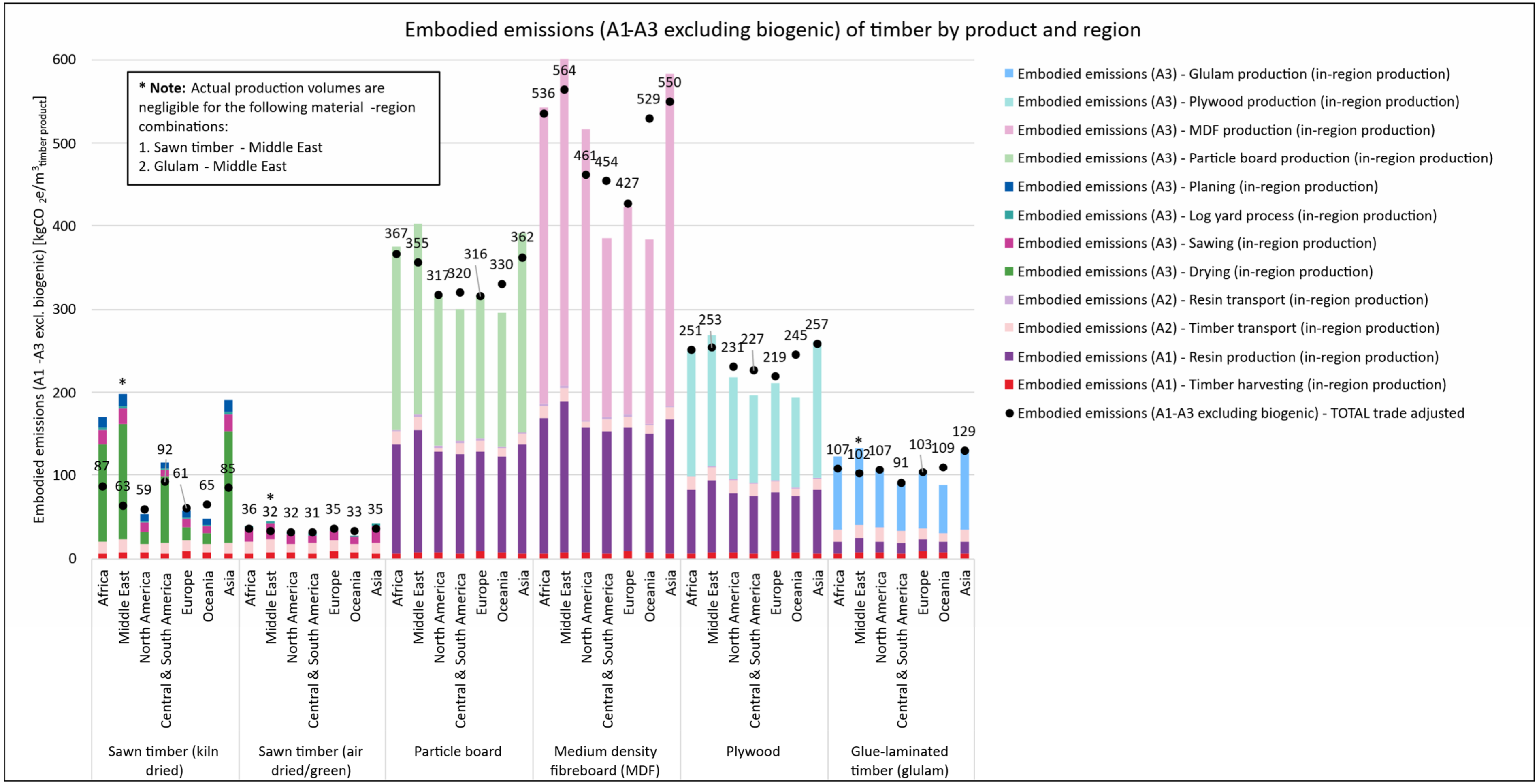

Figure 12: Timber embodied emissions by product and region.

3.4 Bamboo (A1-A3)

Bamboo pole LCA results are presented in Figure 13 (A1-A3 excluding biogenic) and Figure 14 (life cycle biogenic carbon). The following findings are evident from the analysis.

1. Most of the embodied emissions for bamboo pole relate to the chemical treatment stage (purple bars in Figure 13). These emissions are sensitive to the quantities of boric acid and borax powder used per kilogram of final bamboo product, for which data is quite variable from supplier-to-supplier. Due to this variability, a global average value has been adopted in the model, as there is not enough primary data to confidently model systematic regional variations in boric acid/borax use. A similar approach was taken for modelling transport distances (global average estimated as 18km) from plantation to site and harvesting times. However, regional electricity and worker hour energy use factors were used in all cases, hence the datasets are regionalised.
2. Washing, transport and harvesting (turquoise, blue and red bars in Figure 13) are all significant contributors to embodied emissions for bamboo pole. Virtually all the harvesting-related emissions are from worker hour energy use as opposed to equipment (e.g., chainsaw) use.
3. Based on collected data, virtually all bamboo suppliers use air (rather than kiln) drying and do not use fertilisers for bamboo production. This is reflected in the embodied carbon figures. The air-drying process produces no or negligible emissions.
4. Life cycle biogenic carbon emissions are estimated at between 600 and 1,700 $kgCO_2e/t_{dry\ bamboo}$ for these regions. This is based on the waste end-of-life process regional figures, estimated using the World Bank's What a Waste dataset (REF109) – see section 2.5.13 for further details. For Philippines, Indonesia and Nepal, landfilling (with high methane leakage risk) is the main end-of-life process for biomaterials. Mexico, Costa Rica and Ecuador have higher rates of landfilling with low methane leakage risk. The Asia region also largely utilises incineration. Landfilling with high methane leakage risk releases significant methane emissions at end of life, as seen in Figure 14. However, these regional averages may not be relevant to every project. Hence, due to the sensitivity of life cycle biogenic emissions to end-of-life processes, it is recommended that future EDGE versions, accounting for life cycle biogenic carbon emissions, allow users to input the end-of-life process applicable to their project. Life cycle biogenic carbon emissions could then be calculated using Embodied Carbon and Energy Model values.

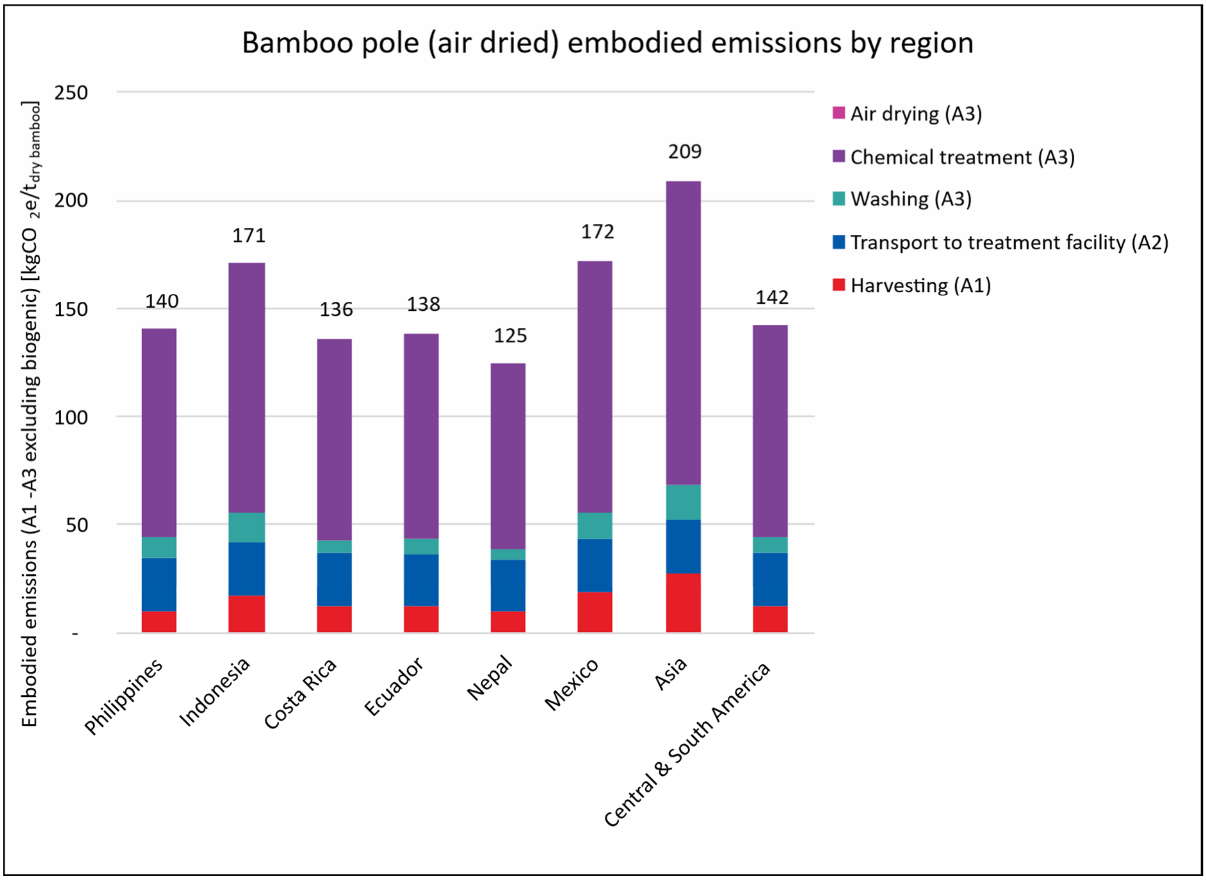

Figure 13: Bamboo pole (air dried) embodied emissions by region.

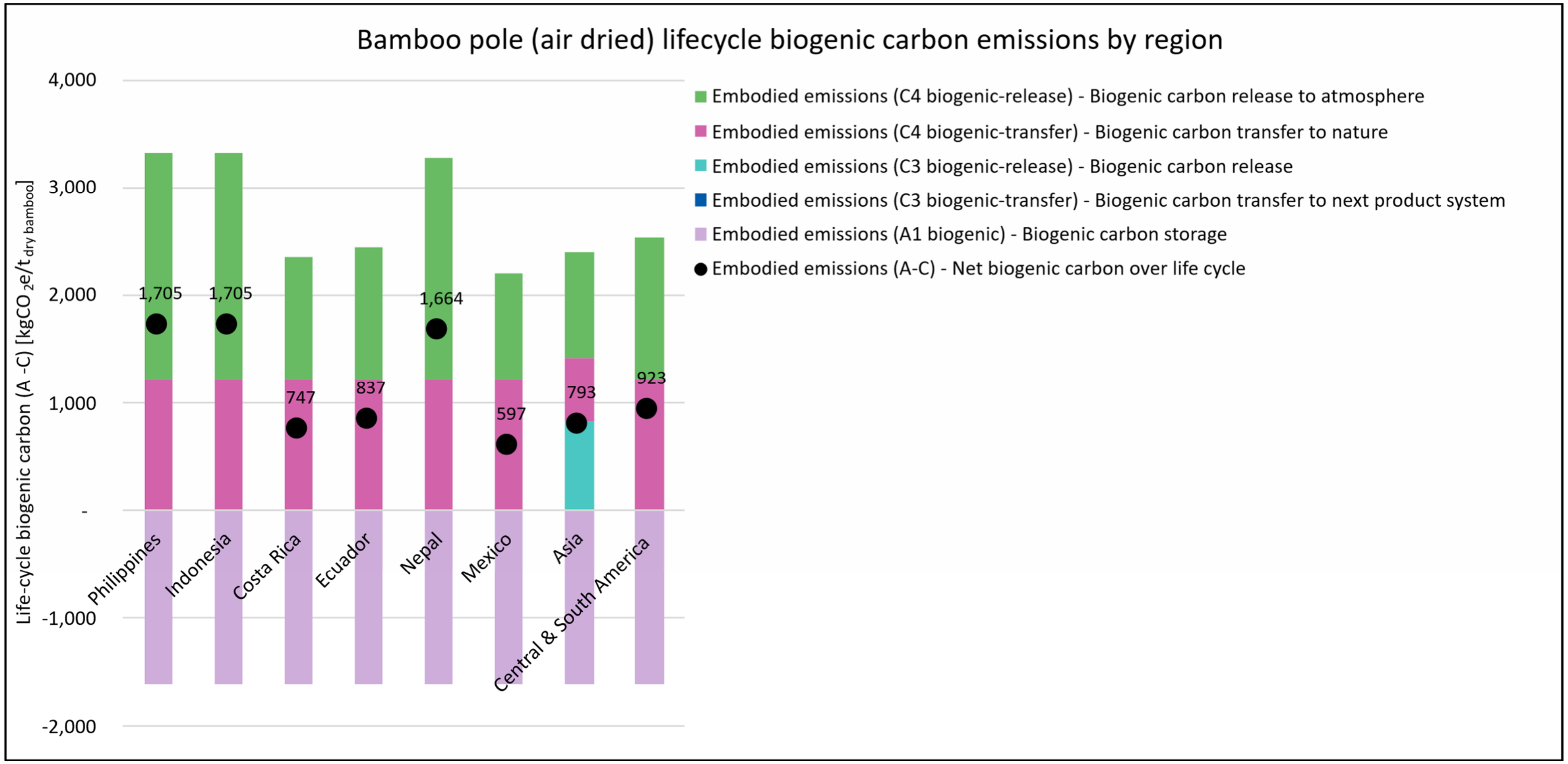

Figure 14: Bamboo pole (air dried) life cycle biogenic carbon emissions by region.

3.5 Transport to site (A4)

Energy consumption factors for a selection of transport modes included in the Embodied Carbon and Energy Model are shown in Figure 15.

Values in blue in Figure 15 are the common default transport modes assumed for ready-mix concrete transport (concrete mixer truck), road transport of other materials (HGV (all diesel) – All rigids – Average laden), and sea transport (Container ship – Average). However, other transport modes are selected as appropriate for different material transport stages in the model. The following well-established findings are evident:

1. Road transport is far more energy and emissions intensive per tonne-kilometre than rail and shipping.
2. Larger and more heavily-laden transport modes are generally less energy and carbon intensive than smaller and less heavily laden modes.

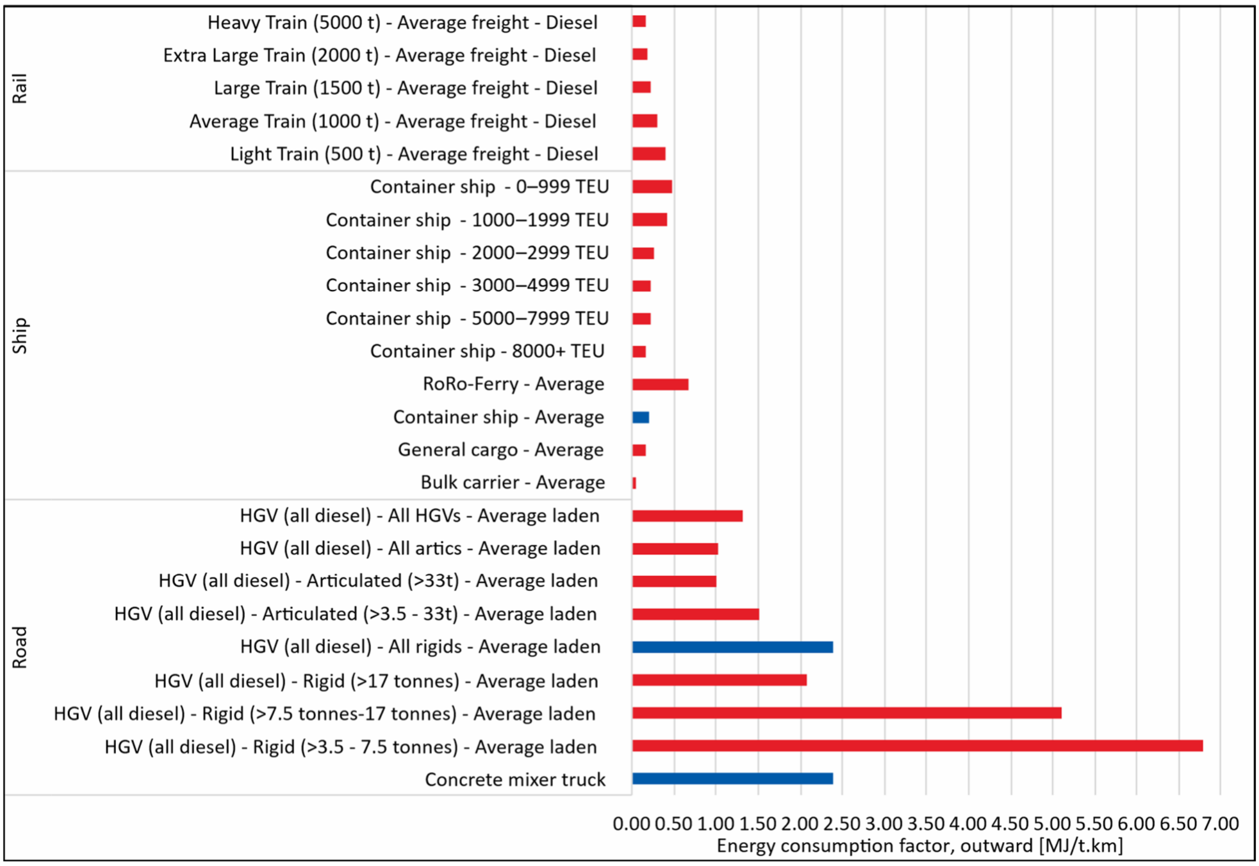

Figure 15: Energy consumption factors for a selection of transport modes included in the Embodied Carbon and Energy Model.

For each transport mode, an appropriate fuel must be selected to model the emissions intensity of the transport leg. Fuel emission intensities are presented in Figure 16. These are broken down into:

- Well-to-tank (WTT) emissions – red bars in Figure 16 – associated with the extraction, transport and processing of fuels up until the point they are input into vehicles.
- Tank-to-wheel (TTW) emissions – purple bars in Figure 16 – directly from combustion of the fuel in the vehicle.

Taken together, these emissions are the well-to-wheel (WTW = WTT + TTW), or full life cycle, emissions from the fuel.

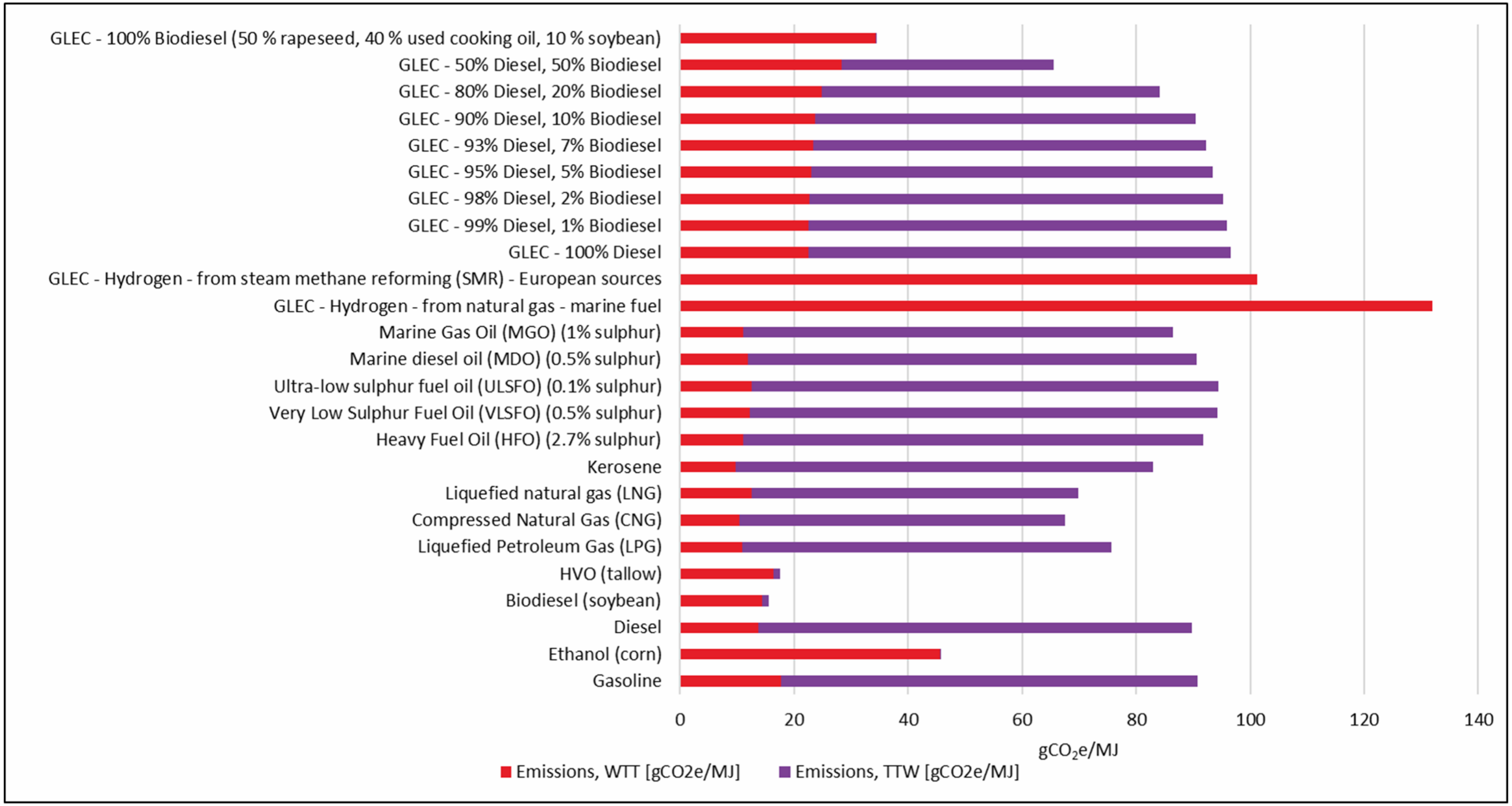

Figure 16: Well-to-tank (WTT) and tank-to-wheel (TTW) emissions associated with fuels that can be selected from in the Embodied Carbon and Energy Model.

3.6 Construction site emissions (A5.2)

Regionalised construction site emissions (LCA module A5.2) estimates are presented in Figure 17.

These estimates illustrate how emissions from site fuel use (mainly diesel, shown in purple) and site electricity are expected to be the highest contributors to site emissions. Electricity-related emissions (red bars) vary by region due to differences in the emissions intensity of electricity generation.

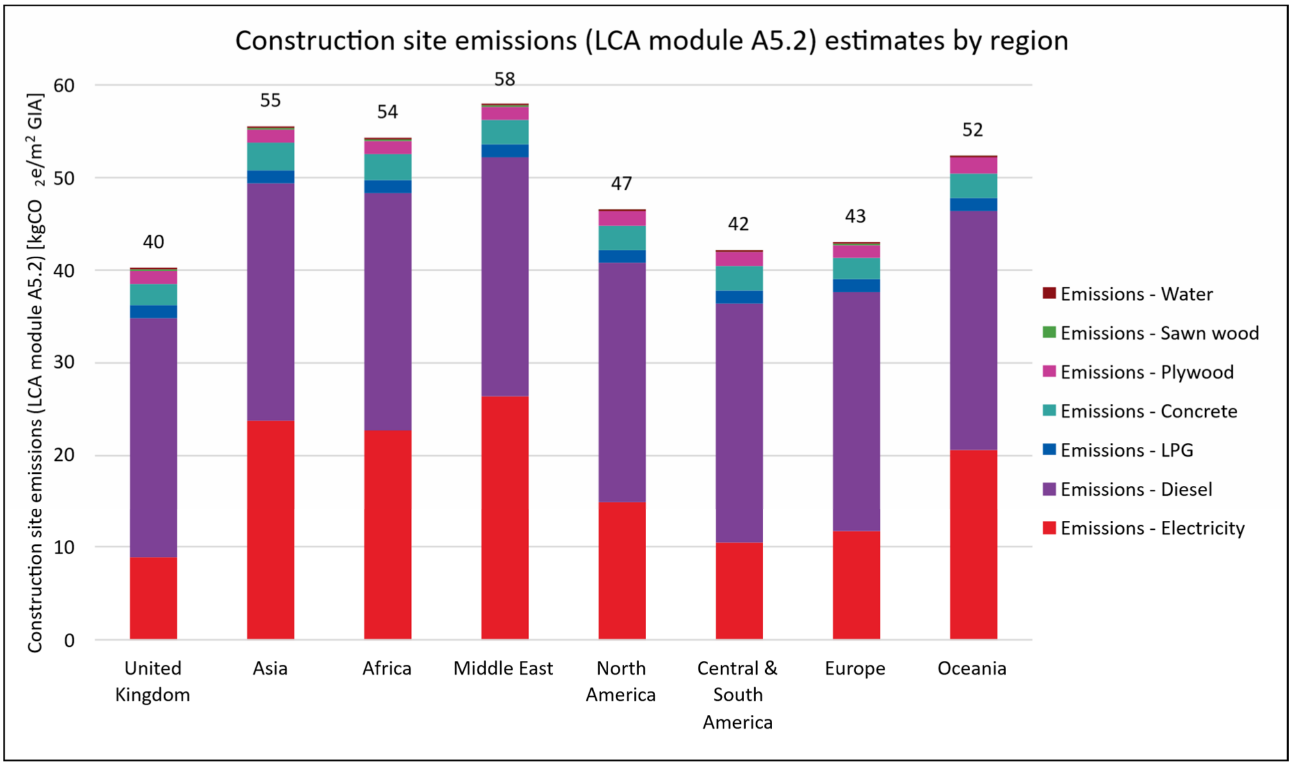

Figure 17: Construction site emissions (LCA module A5.2) estimates by region.

3.7 Data quality, dataset confidence, and modelling limitations

3.7.1 Data quality

The data used and listed in the References tab of the Embodied Carbon and Energy Model, is generally of Excellent or Good quality. Where data is of Fair quality, this is usually because it is internally developed for the project by Arup material experts, or it is raw data collected from material suppliers. No data of Poor quality was used in the model.

3.7.2 Dataset confidence

All datasets developed for this project are assigned a confidence rating based on:

1. The inherent variability in the material production process and embodied carbon. Higher variability leads to lower confidence that the model accurately represents the embodied carbon and energy of material production.
2. The availability of regionally specific data to develop the model. Lower data availability leads to lower confidence, as above.

As shown in Table 11, most of the datasets have a confidence rating of Excellent due to relatively low variability in production process data and relatively high availability of regionally-specific data. However:

- Concrete datasets for the Middle East and Africa receive a rating of Good due to lower availability of data on kiln fuel efficiencies and fuel use. These regions should therefore be prioritised for further primary data collection.
- Similarly, timber datasets for Africa, Middle East, Asia, Central and South America receive a rating of Good due to lower availability of production-related data.
- Bamboo datasets receive a confidence rating of fair due to significant variability in the production process data. This variability reflects the inherent nature of bamboo production, which is understood to be less homogeneous and smaller in scale than for concrete, steel and timber.

Table 11: Dataset confidence rating summary.

Material group	Material-region combination(s)	Variability in production process data	Availability of regionally-specific data	Dataset confidence rating
Concrete	All mix types, all regions except Africa and Middle East	Low	High	Excellent
	All mix types, regions of Africa and Middle East	Low	Low	Good
Steel	All products, all regions	Low	High	Excellent
Timber	All products, all regions of Europe, North America, Oceania	Low	High	Excellent
	All products, all regions of Africa, Middle East, Asia, Central & South America	Low	Low	Good
Bamboo	Bamboo pole, all regions	High	High	Fair

3.7.3 Modelling limitations

- **Regionalisation** – All datasets developed for this project are regionalised. However, as the embodied carbon and energy models for each material-region combination contain multiple input parameters, not all parameters are regionalised. When developing the model, two main factors were considered when deciding which parameters to regionalise:
  - Data availability – If data is not available, the parameter cannot be regionalised.
  - Impact – Higher-impact parameters, indicated in the 'Impact rating' column of the model (see Table 7), were prioritised for regionalisation.
- **Geographic representativeness** – Most datasets developed for this project represent a wide geographic area (a region), within which much variation in material production exists. To address this, further country-level datasets should be developed in the future, to complement the region-level datasets, using the same methodology as developed for this project.

4. Conclusions and Recommendations

This report outlines the methodology adopted for the MAGC Research Project to determine material-region combinations and develop the cradle-to-grave product-level LCA datasets – covering LCA modules A1-A3, A5.3 and C2-C4 – for these in accordance with EN 15804. The report also provides guidance on how embodied carbon and energy can be calculated in EDGE, at the building-level for LCA modules A5.1, A5.2, B2, B3, and C1, and at the product-level for LCA modules A4 and B4, in accordance with RICS PS.

It is recommended that:

- The LCA datasets for this study, estimating embodied carbon and energy per unit material, be made available in EDGE V4 for calculating the upfront carbon and energy of buildings. Construction assembly data for structural building elements, developed for Task 6, can be used to estimate the material types and quantities. Taken together, these can facilitate product- and building-level embodied carbon and energy calculations in EDGE.
- For LCA modules not embedded in the LCA datasets, including A5.1, A5.2, B2, B3 and C1, the EDGE application should calculate the building-level emissions via the methods described in section 2.5, using the default LCA data provided in the Embodied Carbon and Energy Model and this report. Simplified approaches to calculating emissions in these modules have been made available where possible to make the EDGE app more accessible and user-friendly. This also considers that embodied carbon assessments would typically be undertaken at early design stages when limited information is available about the building.
- For LCA module A4, also not embedded in the LCA datasets, the EDGE application would preferably calculate the product-level emissions via the method described in section 2.5.3, using the default LCA data provided in in the A4 tab of the Embodied Carbon and Energy Model. EDGE users preferably could at least edit the default material transport distances if project specific data is available, as well as the transport mode and fuel type.
- The use of resource constrained materials such as GGBS and steel scrap should be managed within EDGE to prevent exacerbation of existing resource constraint issues. This should include providing clear user guidance on the use of resource-constrained materials on projects and in EDGE models (developed for Task 5).
- Future versions of EDGE would ideally estimate embodied – rather than just upfront – carbon, to more completely account for material-related emissions over the whole life cycle. This is especially pertinent for biomaterials like timber and bamboo, whose life cycle biogenic carbon emissions can be significant. EDGE users should ideally be given the ability to select whether biomaterials used on their project are sustainably sourced (impacting biogenic storage at the product stage) and their end-of-life process (impacting biogenic carbon release at end of life). This could also encourage sustainable biomaterial sourcing and responsible end-of-life processes on EDGE projects.
- The Embodied Carbon and Energy Model can be used as a framework for further product/producer- and region-specific data collection. Each additional dataset can be added as an additional column in the model. Input parameters, indicated by the yellow cells, can be collected, and new embodied carbon and energy estimates automatically generated. Not all input parameters may be available, in which case the default/generic values given in the existing model can be used.

Potential future modelling developments could include (in order of priority):

1. **Updates to LCA datasets:** LCA datasets should ideally be updated periodically (e.g., every five years, which is the default validity period for EPDs according to EN 15804) to remain up-to-date.
2. **Other lower carbon materials:** It was beyond the scope of this project to consider material groups other than concrete, steel, timber and bamboo. However, it is recommended that future LCA dataset development for other materials (e.g., brick, glass, aluminium) adopt a similar methodology to that presented in this report and in the Embodied Carbon and Energy Model. Within the material groups

considered for this project, the following materials are recommended to be prioritised for addition to EDGE in future, once they are more widely used and LCI data about them is more readily available:

a. Country-specific LCA datasets for the materials included in this study, to complement the region-level datasets.

b. Concrete with cement containing clinker produced with CCS (once more widely available, and once LCA methodologies for accounting for emissions from CCS in EPDs/LCA datasets are established, since this is not currently part of EN 15804).

c. Calcined clay-based concrete mixes, and bamboo, for other countries and regions (if/when production is established and data becomes available for other regions).

d. Steel produced using direct reduced iron (DRI) route with lower carbon hydrogen, and/or other lower carbon virgin production methods, if/when more widely available.

e. Laminated bamboo products used for e.g., flooring and wall panelling (subject to data availability).

3. **Environmental product declarations:** This project produces generic LCA datasets, covering key structural materials in all global regions, rather than EPDs, which are usually specific to an individual product, supplier and/or country. EPDs are generally more available for developed countries and regions than for developing countries and regions. However, EPDs could be made available in EDGE, complementing the generic datasets developed for this project, provided IFC gains the appropriate permissions from third-party background data providers to do so. This way, the generic datasets would provide global coverage of key materials, while EPDs would provide more variety and product specificity for use on individual EDGE projects.

4. **Building-level default embodied carbon values**: RICS PS provides default embodied carbon values or functions for several building-level LCA modules (e.g., A5.1, A5.2, B2, B3, C1) that can be used when conducting WLCAs for buildings located outside the UK. These values and functions should be included in the EDGE embodied carbon calculations for completeness and alignment with RICS PS. However, RICS PS suggests that country- or region-specific equivalent values should be adopted if available, and that project-specific information should be used to estimate emissions in these modules if available. This project has provided regional estimates for LCA module A5.2 (construction site emissions). Regional estimates for other modules could be developed as part of a separate project. However, in most cases it may not be practicable for EDGE users to reduce embodied carbon in their building by changing project aspects affecting these modules, as it would require detailed information not always readily available at early design stages (except perhaps for LCA modules A5.1 and A5.2, where building developers and contractors can make decisions about site electrification and fuel use, for example). Therefore, this is recommended to be lower priority.

5. **LCA scope:** LCA module D could be added to LCA datasets in future iterations of EDGE to quantify benefits and loads beyond the system boundary. However, given the uncertainty regarding existing module D emissions factors and calculation methodology, this is recommended to be lower priority.

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