India Construction Materials Database of Embodied Energy and Global Warming Potential

METHODOLOGY REPORT

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November 2017

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCING THE INDIA CONSTRUCTION MATERIALS DATABASE

The embodied energy and greenhouse gas (GHG) emissions due to construction are a large contributor to annual global emissions. They are estimated at 5% to 10% of the entire energy consumption in developed countries and 10% to 30% in developing countries (IEA, 2016). Although important, information on embodied energy in construction materials in India is scattered in academic papers. This study funded by the Eco-cities program in India is the first of its kind to develop a comprehensive database on the embodied energy and the global warming potential of building materials in India. The study is a first step in providing this information for broad dissemination. This document will serve as a reference and is made available to the public through the EDGE website.

Results from the study will be incorporated into the EDGE green buildings certification platform, an innovation of IFC, which will provide the most tangible value of this data. The EDGE platform includes the EDGE App, a free and user-friendly interface available to the public through the EDGE website that produces instantaneous results for Energy, Water and embodied energy in Materials. An updated version of the EDGE App will incorporate the data from this study for calculation of embodied energy in the Materials category for India, thus providing readily available information easily applied to actual buildings.

A. Why is the database required?

A database of environmental impact data for the most commonly used building products and materials in India will lay the foundation for more comprehensive evaluation of buildings by facilitating the assessment of the construction materials used. Building standards in Europe and the US are now following the lead set by the German Sustainable Building Council (DGNB) and are including the impact of the materials used in construction (building embodied impacts) in the assessment of environmental performance of buildings. In order to provide world-class building assessment for architects and builders in India, a set of market-appropriate data for the embodied impacts of common building materials is therefore required.

B. What are the benefits of a construction materials database?

Both direct and indirect benefits resulting from a building materials database can already be seen in Germany where the market has evolved in response to the release of building material impact data in 2009. When the German data for building materials were initially published 400 different material datasets were included, based on generic data. Immediately after publication, construction materials manufacturers began to undertake detailed assessments and improvements of their own operations to reduce the impact of their processes and to demonstrate the environmental performance of their products compared to the generic data and to that of their competitors. The database has since trebled in size with manufacturer-specific data accounting for over half of the entries.

C. How has the database been developed?

thinkstep has built up a database of the environmental impacts of a comprehensive set of materials used in construction within India. The impact data have been developed using content collected and owned by thinkstep in its GaBi databases, and refined using local knowledge and data in India, including through a stakeholder consultation described in Section III A and Annex E. The database will therefore provide generic data for products as typically used in India (both manufactured locally and imported).

An outline of the methodology is provided in section III and a more detailed description is given in the main body of this report.

II. MATERIALS INCLUDED IN THE INDIA CONSTRUCTION MATERIALS DATABASE

The materials included in the database have been selected to create a comprehensive basis for calculating the impact of specifications used in India, covering structural elements (roof, walls and floors), insulation, windows and flooring. The list has been prepared and refined over the course of the project and has been informed by:

- our analysis of the building elements and materials currently available in IFC's EDGE (Excellence in Design for Greater Efficiencies) software,
- consultation with IFC's EDGE team,
- consultation with key stakeholders,
- our local knowledge of the construction industry in India.

The construction materials that are included in the database are presented in Table 1.

Table 1: List of materials

Material Group for Modelling	Material	Elements using material
A: Concrete and cement-based materials	Aggregate (mixed gravel/crushed stone)	Intermediate Product
A: Concrete and cement-based materials	Aircrete (autoclaved aerated concrete)	Walls, Floors
A: Concrete and cement-based materials	BF slag	Intermediate Product
A: Concrete and cement-based materials	Cement (ordinary Portland cement, OPC)	Intermediate Product
A: Concrete and cement-based materials	Cement based plaster	Walls
A: Concrete and cement-based materials	Cement floor screed (concrete screed)	Flooring
A: Concrete and cement-based materials	Cement mortar	Walls
A: Concrete and cement-based materials	Cement/lime render for external wall finishes	Walls
A: Concrete and cement-based materials	Cement-based terrazzo (in-situ)	Flooring
A: Concrete and cement-based materials	Cement-based terrazzo tile	Flooring
A: Concrete and cement-based materials	Dense concrete block	Wallls
A: Concrete and cement-based materials	FaLG (fly ash/lime/gypsum) block	Walls
A: Concrete and cement-based materials	Ferrocement roof panel	Roofs
A: Concrete and cement-based materials	Ferrocement wall panel	Walls
A: Concrete and cement-based materials	Fiber cement board	Walls, Roofs
A: Concrete and cement-based materials	Glass reinforced concrete	Walls
A: Concrete and cement-based materials	Lightweight concrete block	Walls, Floors
A: Concrete and cement-based materials	Lime (hydrated lime needed for aircrete, FaLG blocks)	Intermediate Product
A: Concrete and cement-based materials	Lime mortar	Walls
A: Concrete and cement-based materials	Medium density concrete block	Walls
A: Concrete and cement-based materials	Microconcrete roof tile	Roofs
A: Concrete and cement-based materials	PFA	Intermediate Product

Material Group for Modelling	Material	Elements using material
A: Concrete and cement-based materials	PFA/fly ash cement (also known as pozzolana)	Intermediate Product
A: Concrete and cement-based materials	Polymeric render for external walls	Walls
A: Concrete and cement-based materials	Portland slag cement	Intermediate Product
A: Concrete and cement-based materials	Precast concrete panels/flooring	Walls, Floors, roofing
A: Concrete and cement-based materials	Ready mix concrete with fly-ash (30% pozzolana)	Walls, Floors, Roofs
A: Concrete and cement-based materials	Ready mix concrete with ordinary Portland cement (OPC)	Walls, Floors, Roofs
A: Concrete and cement-based materials	Ready mix concrete with Portland slag cement (25% GGBS)	Walls, Floors, Roofs
A: Concrete and cement-based materials	Sand	Intermediate Product
A: Concrete and cement-based materials	Shotcrete	Walls, Roofs
B: Gypsum based products	Calcined gypsum (gypsum hemihydrate, plaster of Paris)	Intermediate Product
B: Gypsum based products	Gypsum	Intermediate Product
B: Gypsum based products	Gypsum panel	Walls
B: Gypsum based products	Gypsum plaster	Internal Finishes
B: Gypsum based products	Phosphogypsum	Intermediate Product
B: Gypsum based products	Phosphogypsum panel	Walls
B: Gypsum based products	Plasterboard	Walls
C: Metal and metal products	Aluminum extruded profile	Windows
C: Metal and metal products	Aluminum extruded profile (window frame)	Windows
C: Metal and metal products	Aluminum ingot	Intermediate Product
C: Metal and metal products	Aluminum profiled cladding	Walls, Roofs
C: Metal and metal products	Aluminum sheet	Walls, Roofs
C: Metal and metal products	Aluminum thin composite cladding	Walls
C: Metal and metal products	BOF Steel	Intermediate Product
C: Metal and metal products	Copper sheet	Roofs
C: Metal and metal products	DRI Steel	Intermediate Product
C: Metal and metal products	EAF Steel	Intermediate Product
C: Metal and metal products	Electrogalvanized steel sheet (“corrugated zinc”)	Walls, Roofs
C: Metal and metal products	Galvanized steel stud	Walls
C: Metal and metal products	Steel reinforcement (steel rebar)	Intermediate Product
C: Metal and metal products	Steel section	Walls, Floors, Roofs
C: Metal and metal products	Steel window frame	Windows
D: Glass	Float glass	Windows, Walls
E: Ceramics and clay-based products	Asphalt shingles	Roofs
E: Ceramics and clay-based products	Brick - Bulls trench kiln	Intermediate Product
E: Ceramics and clay-based products	Brick - Clamp kiln	Intermediate Product
E: Ceramics and clay-based products	Brick - High draught/zigzag kiln	Intermediate Product
E: Ceramics and clay-based products	Brick - Hoffman kiln	Intermediate Product
E: Ceramics and clay-based products	Brick (common/facing)	Walls, Floors, Roofs
E: Ceramics and clay-based products	Clay roof tile	Rpofs
E: Ceramics and clay-based products	Glazed ceramic floor tiles	Flooring
E: Ceramics and clay-based products	Honeycomb brick	Walls

Material Group for Modelling	Material	Elements using material
E: Ceramics and clay-based products	Polished stone cladding	Walls
E: Ceramics and clay-based products	Stone floor tile	Flooring
E: Ceramics and clay-based products	Vitrified ceramic floor tiles	Flooring
F: Plastics and polymer-based products	Adhesive for parquet	Flooring
F: Plastics and polymer-based products	Carpet (nylon)	Flooring
F: Plastics and polymer-based products	Carpet tile (nylon)	Flooring
F: Plastics and polymer-based products	Flooring adhesive for vinyl/carpet/linoleum	Flooring
F: Plastics and polymer-based products	Polyurethane rigid insulation foam (HCFC blown)	Walls, Floors, Roofs
F: Plastics and polymer-based products	Polyurethane rigid insulation foam (pentane blown)	Walls, Floors, Roofs
F: Plastics and polymer-based products	Rubber flooring	Flooring
F: Plastics and polymer-based products	Tile adhesive for ceramic/concrete tiles	Flooring
F: Plastics and polymer-based products	Underlay/fixing for laminate flooring	Flooring
F: Plastics and polymer-based products	u-PVC window frame	Windows
F: Plastics and polymer-based products	Vinyl (PVC) flooring	Flooring
G: Timber and wood-based products	Air-dried sawn timber	Walls, Floors Roofs
G: Timber and wood-based products	Bamboo flooring	Flooring
G: Timber and wood-based products	Cork flooring tile	Flooring
G: Timber and wood-based products	Kiln-dried timber	Walls, Floors, Roofs
G: Timber and wood-based products	Linoleum flooring tile	Flooring
G: Timber and wood-based products	Particle board/chipboard	Walls, Floors
G: Timber and wood-based products	Plywood	Walls. Floors. Roofs
G: Timber and wood-based products	Timber window frame	Windows
G: Timber and wood-based products	Wood block flooring	Flooring
G: Timber and wood-based products	Wood laminate/multi-layer parquet flooring	Flooring
H: Insulation	Cellulose insulation	Walls, Roofs
H: Insulation	Cork insulation	Walls, Roofs, Floors
H: Insulation	Expanded polystyrene insulation (EPS)	Walls, Roofs, Floors
H: Insulation	Glass wool	Walls, Rppfs
H: Insulation	Stone wool	Walls, Roofs
H: Insulation	Woodwool board insulation	Walls, Floors, Roofs
I: Soil, mud and earth-based products	Mud plaster	Walls
I: Soil, mud and earth-based products	OPC stabilized soil block	Walls
I: Soil, mud and earth-based products	PFA stabilized soil block	Walls
I: Soil, mud and earth-based products	Portland slag cement stabilized soil blocks	Walls
I: Soil, mud and earth-based products	Rammed earth	Walls
J: Other natural products	Jute flooring	Flooring
J: Other natural products	Straw bale	Walls

Special case materials

There is very little production or use of cellulose insulation in India. However, this material is projected to have environmental benefits due to its being predominantly composed of recovered post-consumer waste paper. As such, cellulose insulation has been included in the list of materials evaluated to support potential adoption.

III. APPROACH

A modeling approach was formulated based on previous experience with European databases for embodied energy in materials. Key assumptions relevant to India were identified to customize the approach for India. A list of priority materials for India was created. This was then vetted with India-based industry stakeholders with expertise in estimating the embodied energy of the priority materials as described below and in Annex E.

A. Stakeholder engagement

A targeted consultation was conducted with key stakeholders in the Indian construction sector. The aim of the consultation was to collect feedback on the modeling approach and main assumptions used in the development of the materials in the India Construction Materials Database to ensure that the final models were suitably representative. The consultation was focused on establishing:

- Technology coverage: Whether the database included all the materials relevant for the Indian construction industry.
- Geographical representativeness: Whether the domestic/import mix was representative.
- Technological representativeness: In particular, whether assumptions around constituent materials, material quantities, energy and fuel usage, water consumption and losses during production were representative. This also included whether the appropriate references were being used.

Priority Materials

The consultation covered 36 “priority materials” - the materials most commonly used in the Indian construction industry as well as some key alternatives to commonly used materials in major sectors. Priority materials were sorted into material categories as listed in Table 2 below. In addition, materials to be included in the final database, but not designated as “priority materials” were listed to allow stakeholders to comment on whether the materials included were representative of the materials used in construction in India for the sector in question.

Table 2: Priority materials in the India Construction Materials Database

Material Category	Materials
Aluminum	Aluminum ingot Aluminum extruded profile Aluminum profiled cladding Aluminum sheet Aluminum thin composite cladding
Brick	Brick (common/facing)
Cement	Ordinary Portland cement (OPC) Portland slag cement PFA (pulverized fuel ash)/fly ash cement (also known as pozzolana)

Material Category	Materials
Concrete	Ready mix concrete with ordinary Portland cement (OPC) Ready mix concrete with Portland slag cement (25% GGBS) Ready mix concrete with fly-ash (30% pozzolana) Lightweight block Medium density block Precast concrete panels/flooring
Glass	Float glass
Gypsum & Gypsum products	Gypsum (natural gypsum stone) Calcined gypsum Phosphogypsum Plasterboard FaLG (fly ash/lime/gypsum) block
Insulation	Expanded polystyrene insulation Stone wool Glass wool Polyurethane rigid insulation foam (pentane blown) Polyurethane rigid insulation foam (HCFC blown)
Plastics	Carpet (nylon) tile Vinyl (PVC) flooring u-PVC window frame
Steel	BOF steel slab DRI EAF steel slab EAF steel slab (scrap-based) Steel reinforcement bar (rebar) Steel section
Timber	Air dried sawn timber Kiln dried timber

Selection of Stakeholders

For the selection of stakeholders, a market share analysis was undertaken to identify the top 3-4 producers as well as some representative bodies/trade associations for the identified priority materials. 30 organizations were selected based on the following criteria:

- Coverage of Indian market: More than 70%
- Existence of representative body who could respond on behalf of the industry/materials

Based on the above criteria, relevant contacts in these organizations were identified through phone calls, emails, references etc. Details of the stakeholders approached are included for each priority material group in Annex E.

Consultation process

A clear, simplified questionnaire for each priority material type was prepared to be circulated to the identified contacts in these organizations. The questions and received responses are detailed in Annex E. A one-to-one conversation explaining the expectations and requirements was undertaken with all the organizations. The questionnaire was also explained verbally, with some in-person meetings and discussions. From each of the 14 returned questionnaires, feedback was collected and reviewed to consider whether the database needed any amendment. At least one questionnaire was received for each priority material. Other stakeholders approached either declined to provide feedback or in some cases did not feel confident commenting on the assumptions made.

Overall, there were relatively few areas where stakeholders suggested changes be made, with positive comments received about the technological coverage and geographical representativeness. For glass, data were provided to alter the batch material mix to better reflect Indian manufacturers. For cement, one stakeholder suggested to include a Portland slag cement with a 70% ground granulated slag content. This is at the maximum allowed by the Bureau of Indian Standards (IS 455, 1989) and given the limited availability of slag and potential challenges that can occur in using cement with very high GGBS content, this has not been included in the final database.

The approach for developing each data for each material for India has involved collection of primary data and, where appropriate, adaptation of existing LCA models to reflect the range of production technologies available in India.

B. Environmental indicators reported

Indicators for use in EDGE Software

The EDGE Embodied Energy Indicator is based on primary energy. This is measured using the net calorific value (lower heating value), which is determined by subtracting the heat of vaporization of the water vapor from the gross calorific value (higher heating value) of the fuel. It is provided in MJ/kg. Resources with energy content can be used as an energy source (fuel energy) or as a feedstock or material input. Feedstock energy is defined by ISO 14040:2006 as "heat of combustion of a raw material input that is not used as an energy source to a product system". The EDGE Emerging Economies embodied energy indicator includes the feedstock energy of fossil fuels in its primary energy calculations but does not include feedstock energy of renewable resources that are not intended to be used as an energy source, for example the timber in wooden products. Feedstock energy is an inherent physical property of a material so, in accordance with EN 15804, when modeling processes that generate co-products the feedstock energy has always been allocated reflecting the physical flows.

In addition to the EDGE Embodied Energy Indicator, the global warming potential (GWP) is reported for each material used in EDGE. GWP is assessed for all materials using the 5th Assessment Report impact values (IPCC, 2014). In this study GWP results are reported including biogenic carbon[1] stored within the product. Consequently, for some biomass-based products GWP may be negative indicating that these products absorb more carbon dioxide during the growth phase than is emitted during production. Users of these data should note that some or all of this biogenic carbon will

[1] During photosynthesis biomass takes up carbon dioxide from the atmosphere. The absorbed carbon becomes incorporated into cells for the growth or renewal of the plant's tissues. This carbon is referred to as biogenic carbon, and the process of absorption is referred to as carbon sequestration. Biogenic carbon may be released back as carbon dioxide when the biomass is combusted or may break down into a mixture of carbon dioxide and methane when the biomass decomposes (the proportions of each gas depend on the extent to which the decomposition occurs aerobically, forming carbon dioxide, or anaerobically, forming methane).

be released at end-of-life, depending on the end-of-life treatment of the product. For transparency, the amount of carbon sequestered in these biomass-based products and their renewable feedstock energy is reported in Table 3.

As with feedstock energy, carbon sequestration is an inherent physical property of a material. As such, when modeling processes that generate co-products the carbon content has been allocated reflecting the physical flows, thereby accounting for the actual amounts of carbon contained in each co-product. Carbon sequestered in leaf litter or other biomass that is left in the forest or field is assumed to be carbon neutral. Changes in soil carbon or carbon emissions associated with land use change have not been considered.

Table 3: Sequestered carbon for products containing biomass

Dataset Materials containing biomass	Sequestered carbon (kg CO2/kg)	Renewable feedstock energy (MJ/kg)
Air-dried sawn timber	1.59	16.53
Bamboo flooring	1.72	16.00
Cellulose insulation	1.47	16.77
Cork flooring tile	1.69	18.34
Cork insulation	2.11	21.40
Fiber cement board	0.06	0.56
Gypsum Panel	2.5E-03	0.03
Jute flooring	1.34	15.05
Kiln-dried timber	1.59	16.53
Linoleum	1.42	12.41
Mud plaster	0.08	0.65
Particleboard/chipboard	1.50	15.52
Phosphogypsum panel	2.5E-03	0.03
Plasterboard	0.06	0.032
Plywood	1.33	13.30
Rammed Earth	0.12	1.20
Straw bale	1.59	13.00
Timber window frame	1.56	16.20
Wood block flooring	1.59	16.53
Wood laminate/multi-layer parquet flooring	1.51	15.62
Woodwool board insulation	0.53	5.50

Additional indicators for use in top level stakeholder reporting

Four further indicators, ozone depletion, acidification, eutrophication and photochemical ozone creation (Low level smog) are provided for products for use in top level reporting by IFC. These indicators are based on characterization factors provided in CML–IA version 4.1, as used in EN 15804. The source documentation for each indicator is provided in Table 4 below. These indicators cannot be provided to users through the EDGE software at a material or project level, but IFC will be able to aggregate project data to report on overall savings for these indicators.

Table 4: Additional Indicators

Indicator	Reference
Ozone Depletion Potential (steady state)	(World Meteorological Organisation (WMO), 1992) (World Meteorological Organisation (WMO), 1995) (World Meteorological Organisation (WMO), 1999) (World Meteorological Organisation (WMO), 2003) (Solomon, 1992)
Acidification Potential (average Europe total)	(Huijbregts, 1999) (Heijungs, 1992) (Hauschild, 1998)
Eutrophication Potential	(Huijbregts, 1999) (Heijungs, 1992) (Hauschild, 1998)
Photochemical Ozone Creation Potential	(Jenkin, 1999) (Derwent, 1998) (Andersson-Sköld, 1992) (Carter W. , 1994) (Carter W. , 1997) (Carter W. , 1998) (Carter W. P., 1995)

C. Software and database

The life cycle inventories have been modeled using the GaBi ts software system and database for life cycle engineering. The model for each material has been developed in accordance with ISO 14040 and ISO 14044, the two international standards which define the process of life cycle assessment. Each model also conforms to the modelling requirements set out in EN 15804:2012, which provides the core rules for developing Environmental Product Declarations for construction products.

D. System boundaries

The system boundary for each material represents the "cradle to gate", i.e., manufacturing and transport in the supply chain. As defined in EN 15804:2012, the system boundary represents Modules A1 to A3 which include:

- the extraction and processing of raw materials,
- the use of energy in transport and manufacturing, and
- any processing of secondary material and energy used once the secondary material has been recovered from waste.

Transport from production location to the building site is not included within the system boundary, however for products that are normally imported to India (for example cork flooring or linoleum) the impacts of transport to India have been modeled. For products where installation requires significant ancillary material (for example flooring or tiling adhesive) or on site processing (e.g., mixing of ready-mix concrete), then these installation processes have been included. Material losses occurring during the installation stage are excluded.

E. Declared unit and reference flow

All data are presented in terms of a declared unit or reference flow of one kilogram of material. For materials specified by volume (e.g. concrete, timber), by area, (e.g. flooring) or by length (e.g. window frames), the 1 kg declared unit can be related back to a specification unit using the density value for that material provided in this report.

As noted in section III C, some products include consideration of ancillary materials such as adhesives. For these products, the declared unit refers to 1 kg of the product as it leaves the manufacturing site, not as installed (so the ancillary materials are in addition to the 1 kg product).

F. Data selection

An extensive review of data sources has been undertaken to ensure that models have been developed with the best available data. Wherever possible data on Indian production processes have been used to ensure technological and geographical representativeness. Where this has not been possible due to a lack of India-specific data sources, data for European production processes have been used with input materials and fuels adjusted to reflect Indian production. In these cases, the likely technological differences between Indian and European production have been assessed and, where possible, discussed with stakeholders to ensure that data for these materials remain representative.

All key data sources used in development of the material models have been referenced with information on the input of materials or fuels provided in the text for publicly available data sources or sources without data confidentiality constraints. In some cases, data confidentiality means that unit process data and individual inputs/outputs of materials or energy sources cannot be listed. This is particularly the case for industry data provided through the GaBi database.

G. Representativeness of data

Time reference

The life cycle inventories are developed using the most recent primary data available from reliable and representative sources. Where adaption of other regional data is required to develop the LCI data, the most recent available secondary data are used.

Technology reference

Wherever possible, the approach represents the mix of technologies relevant to India. This is particularly relevant for some materials, such as bricks, where the type of technology used has a significant influence on the impact of the product.

Geographical reference

The life cycle inventory models are developed to be representative of consumption of the product in India. In some cases, where the product consumed in India is typically from an imported source, the production geography of the dataset will represent the import source country or source mix.

IV. OVERVIEW OF THE MODELING PROCESS

The India Construction Materials Database has been developed based on primary data from Indian producers where such information was available. In cases where primary data were not available, European or other regional processes have been adapted to represent production in India through review and changes to:

- energy consumed in production (energy consumption, electricity grid, fuel mix, etc.),
- production routes and technologies for each material (e.g., continuous vs. batch kilning of brick, blast furnace, and basic oxygen furnace vs. electric arc furnace in the production of steel), and
- input materials used (e.g., recycled content, use of by-products, etc.).

The data are as representative as possible given available primary and secondary data.

H. Electricity and fuels

India’s Central Electricity Authority publishes grid emissions data for power generation in the country (Bhawan, 2014), but these are reported based on production capacity, whereas for the purpose of the database modelling it is required to use emission factors per unit of consumption. As such, Indian electricity in the database is modeled using the GaBi 2016 dataset for electricity, based on production of electricity in India for the year 2012, as detailed in the LCI documentation (thinkstep, 2016). The electricity dataset uses International Energy Agency (IEA) data on fuels used for production, efficiencies, imports, fuel quality and transmission losses etc., as provided, for example, in (IEA, 2015).

The IEA data for India are based on a number of Indian sources. Among the Indian institutions that submit energy data to the IEA are the Ministry of Power, the Central Electricity Authority, the Ministry of Coal, the Ministry of New and Renewable Energy, the Ministry of Petroleum and Natural Gas and the Petroleum Planning and Analysis Cell, and the Ministry of Statistics and Programme Implementation.

IEA data are used within GaBi because they are recognized as the most consistent and well-used source for electricity data globally. There is a time delay in the age of data used because of the time required for national bodies to publish energy statistics, for IEA to source data and to check and publish it, and then for thinkstep to process this data to generate LCA datasets for both electricity and all energy using processes.

GaBi datasets used to model fuels and electricity in the database use IEA data that includes emissions factors for fuels provided in India’s Initial National Communication under the UNFCCC (Ministry of Environment & Forests, 2004) for coal and from the IPCC 2006 Guidelines (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 1.4) for imported coal gas/oil/diesel/naphtha.

The grid mix for the electricity dataset is illustrated in Figure 1. The electricity mix is dominated by hard coal, with substantial fractions generated from lignite, hydro and natural gas sources, and smaller contributions from nuclear, wind, fuel oil and biomass. The category "Other" depicted in Figure 1 is composed of photovoltaics (0.19%), coal gases (0.13%), waste to energy (0.11%), and biogas (0.08%).

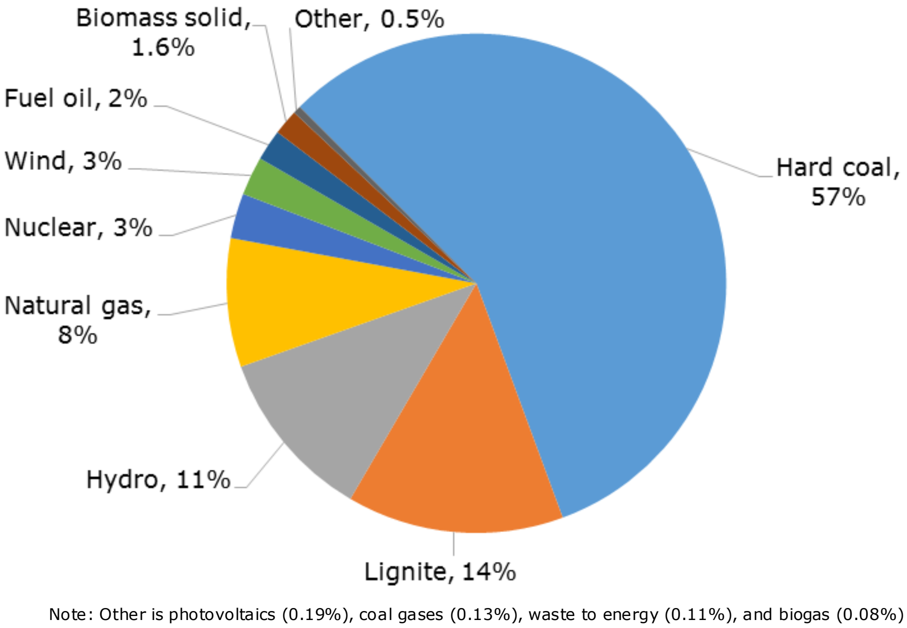


Figure 1: Electricity mix for India

I. Waste treatment

Treatment of waste and co-products generated during production

Following EN 15804, where process waste and scrap arise in the construction material production models, treatment impacts are included within the models until final disposal. If the waste is recycled it is treated as closed loop recycling where there is a balancing input of recycled material. For other recycled outputs, the impacts of waste processing are included until the waste has been recycled, then economic allocation may be applied (see following section), treating the resulting secondary materials as co-products. All co-products are accounted for using economic allocation.

Inputs of co-products and secondary material

Allocation of impacts for processes that produce one or more co-products has been applied in line with the requirements of EN 15804. This means that allocation has been based on physical properties (e.g. mass) if the difference in revenue between co-products is low (co-products contribute more than 25% of the revenue). Co-products that account for less than 1% of the total revenue may be neglected. In all other cases (i.e. where co-products account for less than 25% of the revenue, but more than 1%) economic allocation has been applied (although, as noted in section III A, feedstock energy and sequestered carbon are always allocated based on physical flows). Secondary materials from post-consumer processes are assumed to have no impact when they leave the previous system boundary, but will incur impacts for any subsequent secondary processing thereafter. Secondary materials from production processes (preconsumer) are classed as co-products and will have impacts allocated in line with the methodology described above. Co-products that do not generate revenue are therefore burden free.

Energy recovered from waste and secondary fuels

Any energy recovered during waste treatment of production wastes is credited using the mix of energy and fuels representative of India. Where waste from other systems is used as a fuel, as a conservative approach, the impacts are included within the system boundary.

V. DETAILED MODELING APPROACH FOR EACH MATERIAL

A. Concrete and cement-based materials

The cement-based products provided in the India Construction Materials Database are lightweight concrete block, medium weight concrete block (hollow), dense concrete block, autoclaved aerated concrete block (aircrete), fly ash/lime/gypsum (FaLG) block, cement based plaster, ferrocement panels, precast reinforced concrete panels/flooring, cement screed, ordinary Portland cement (OPC), ready-mix concrete, pulverized fly ash (PFA) ready-mix concrete, ground granulated blast furnace slag (GGBS) ready-mix concrete, micro-concrete roof tiles, fiber cement boards, mortar, cement render, polymeric render, glass reinforced concrete, shotcrete, and pozzolana concrete. The intermediate products modeled to account for the composition of these concrete products include fly ash, GGBS, quicklime, aggregate, and sand.

Manufacturing impacts for the concrete products in India generally account for a very small proportion of cradle-to-gate or life-cycle impacts. Overall impacts are dominated by the production of the raw materials. In particular, the amount of cement contained in the product mixture and the use of alternative cementitious products such as PFA and GGBS have a large influence on the overall impact. Therefore the environmental profile of the ordinary Portland cement has a lot of influence on the indicator results for these products.

To follow the progression of the manufacturing steps, the report first describes the models for each of the basic component materials and intermediate products (e.g. fly ash, GGBS, and Portland cement). Sections covering the final products (ready-mix concrete, fiber cement boards, etc.) follow.

A1: Concrete precursors

Cement (ordinary Portland cement, OPC)

The main processes in cement production are raw material extraction and production of clinker. The current dataset describes the entire cement process including processing of raw materials and the transport to the cement plant.

The extraction of the main limestone raw material from the quarry normally takes place in the immediate area of the cement works. The raw materials are extracted, homogenized, kilned and ground. The result is ground clinker, a necessary ingredient in all types of cement.

The percentage of input raw materials for the production of ordinary Portland cement is cement clinker (95%), gypsum (5%) and a small amount of ethylene glycol (0.006%). The main energy source for the production of clinker in India is hard coal, and Indian grid electricity has been used as representative of the cement industry electricity which now uses coal/lignite and petroleum coke-based captive power plants as the preferred option (WBCSD Cement Sustainability Initiative, 2013).

Note: the *IN: Cement (Ordinary Portland Cement, OPC)* dataset in GaBi was published by thinkstep in February 2016 and is used directly in the India database. Documentation is available online (thinkstep, 2016).

Portland slag cement

The Indian Standard for Portland slag cement specification (IS 455, 1989) was adopted by the Bureau of Indian Standards after the draft finalized by the cement and concrete sectional committee had been approved by the civil engineering division council. This standard forms the basis for the GaBi model for Portland slag cement.

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and ground granulated slag from blast furnace steel production in suitable proportions and grinding the mixture to thoroughly and intimately mix the constituents. It may also be manufactured by separately grinding Portland cement clinker, gypsum and granulated slag and then mixing them intimately.

Granulated blast furnace slag is produced during the reduction of iron ore to iron in a blast furnace. Molten slag is tapped from a blast furnace, rapidly quenched with water ("granulated"), dried and ground to a fine powder. The rapid quenching "freezes" the molten slag in a glassy state, which gives the product its cementitious properties. Molten slag can also be air cooled which gives a slag which can be used as an aggregate, but which does not have cementitious properties.

Current production of granulated slag in India is estimated to be 10 million metric tons per year, all of which is used in cement. There is scope for plants that currently air cool blast furnace slag (producing about 12 million metric tons) to install granulators to increase the production of granulated slag (WBCSD Cement Sustainability Initiative, 2013) though the amount of granulated slag would still be small in comparison to the production of ordinary Portland cement, estimated at 330 million metric tons (Indian Bureau of Mines, 2015). The impact of granulated slag is calculated using economic allocation according to EN 15804 for the outputs of the blast furnace.

The percentage of input raw materials for the production of Portland slag cement is cement clinker (70%), granulated blast furnace slag (25%), gypsum (5%) and a small amount of ethylene glycol (0.006%).

The model is representative of production in India with 0.036 MJ electricity used for grinding from the Indian grid. The granulated slag used is from blast furnace production within India (Visvesaraya, 1998).

Pulverized fuel ash (PFA)/fly ash cement (also known as pozzolana)

Coal/lignite based thermal power generation has been the backbone of power capacity addition in India. Indian coal is of low grade with ash content of the order of 30-45% in comparison to imported coals which have a much low ash content of around 10-15%. (CEA, 2014-15). Over 60 million metric tons of fly ash are produced each year in India of which around 50% is currently used (Haque, 2013) – this compares to total OPC production of 330 million metric tons each year.

To reduce the requirement of land for disposal of fly ash in ash ponds and to address the problem of pollution caused by fly ash, the Ministry of Environment, Forests and Climate Change (MoEF&CC) has issued a number of notifications on fly ash utilization (CEA, 2016) (Bhavan, 2004).

The percentage of input raw materials for the production of Portland slag cement is cement clinker (65%), pulverized fly ash/pozzolana (30%) and gypsum (5%).

The GaBi dataset uses economic allocation according to EN 15804 for the various outputs from the production of electricity from hard coal. The impacts allocated to the fly ash are less than 0.3% of the impacts for all co-products because of the low value of fly ash relative to the electricity produced by the power station.

Aggregate (mixed gravel/crushed stone)

In 2010, the total consumption of all aggregates in India was reported as 2.2 billion metric tons (ABI, 2013) and records from India's Department of Commerce Export Import Data Bank show that imported aggregates totaled less than 1 million metric tons in 2014-2015 (DGCIS, 2016), meaning that imports constitute less than 1% of India's consumption of aggregates. Aggregate is therefore modeled as being produced in India.

Natural aggregate is extracted from the earth, often in concert with stone quarrying activities. The extracted mineral aggregate is washed, separated via vibration from non-mineral particles, and sorted in vibration sieves or in an upstream classifier. Fuel, electricity and water consumption for sand and aggregate processing (extraction, conveyors, vibration screens) are based on a CPCB industry report providing typical data for a small mains connected crusher (CPCB, 2009).

Sand and gravel are co-products from aggregate processing. Impacts have been calculated based on mass allocation so both have the same impact per kg.

Sand

Records for imports from India's Department of Commerce Export Import Data Bank show that imports account for less than 1% of sand consumption, with the great majority of sand used in India coming from domestic production (DGCIS, 2016). Sand is therefore modeled as produced in India. A CPCB industry report indicates that sand from marine or riverbed sources is in limited supply, with co-generation with aggregate being the dominant source of sand within India (CPCB, 2009).

As described above in the section on aggregate, sand production is modeled as a co-product from aggregate processing with impacts calculated based on mass allocation.

Quicklime (calcium oxide)

When limestone (calcium carbonate) is heated carbon dioxide is liberated and quicklime is formed - this process is called calcination. Quicklime is used in cement, aircrete blocks and in basic oxygen steelmaking amongst other processes.

As modeled, to make 1 kg quicklime requires limestone (1.76 kg), coal (0.57 MJ), natural gas (0.73 MJ), lignite (2.64 MJ), coke (0.02 MJ) and electricity (0.104 kWh). India-specific raw materials and energy are modeled.

Hydrated lime (calcium hydroxide)

Hydrated lime is manufactured commercially by treating quicklime with water. It is used in production of FaLG blocks, which is a manual process where using quicklime would be too dangerous.

As modeled, to make 1 kg hydrated lime requires quicklime (0.76 kg), water (0.38 kg) and electricity (0.0017 kWh). India-specific raw materials and energy are modeled.

A2: Ready mix concrete

Ready mix concrete with ordinary Portland cement (OPC)

India is the second largest producer of cement in the world and cement demand is expected to reach 550-600 million metric tons/year by 2025. The housing sector is the main factor driving cement use, accounting for about 67% of the total consumption in India. Ready mix concrete is recognized as having an essential role in the continuing development of Indian infrastructure.

For M40 concrete the following composition has been used OPC (11%), gravel (47%), sand (37%) and water (5.7%), based on IS 10262:2009 (Bureau of Indian Standards, 2009).

It is assumed that raw materials are extracted in India and concrete production uses 1.5 kWh/m^3 Indian grid electricity and 0.0168 GJ/m^3 diesel (ACC Limited, 2016).

Ready mix concrete with fly-ash (pozzolana) replacing 30% OPC cement

The pozzolanic properties of fly ash from Indian coal fired electricity generation make it a suitable substitute for some of the ordinary Portland cement (OPC) in concrete. The permitted replacement ratio of fly ash in OPC is 15-35% (IS 1489 Part-1), but is usually no more than 30%. Hence for the Indian database ready mix concrete with 30% of the OPC replaced with fly ash has been modeled.

The modeled composition of 30% fly-ash ready mix concrete is OPC (7.5%), fly ash (3.2%), gravel (47%), sand (37%) and water (5.7%) based on IS 10262:2009 (Bureau of Indian Standards, 2009).

It is assumed that raw materials are extracted in India and production uses the same energy as OPC ready mix concrete.

Ready mix concrete with Portland slag cement (25% GGBS)

In ready mix concrete made from Portland slag cement some of the ordinary Portland cement is replaced with ground granulated blast furnace slag. The permitted replacement ratio of slag in ordinary Portland cement (OPC) for concrete is 25–70 % (IS 455).

For M40 concrete, the following mix of ingredients has been assumed OPC (8.1%), granulate slag (2.7%), gravel (47%), sand (37%) and water (5.7%) based on IS 10262:2009 (Bureau of Indian Standards, 2009). It is assumed that raw materials are extracted in India and production uses the same energy as OPC ready mix concrete.

Glass reinforced concrete

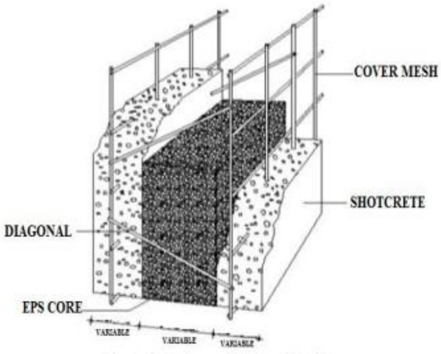
Glass reinforced concrete or glass fiber reinforced concrete (GFRC) is a type of fiber-reinforced concrete. It can be molded to shape and is mainly used in exterior building façade panels and as architectural precast concrete. GFRC is produced using fine sand, ordinary Portland cement, polymer (usually an acrylic polymer), water, other admixtures and alkali-resistant glass fibers. Glass fiber reinforced cementitious composites have been developed for the production of thin sheet components, with a paste or mortar matrix and around 5% fiber content. The density of the glass reinforced concrete is assumed to be 2550 kg/m^3. The constituent materials used for making a glass reinforced concrete block are shown in Table 5 below (Pshtiwan N. Shakor, 2011).

Table 5: Raw materials for glass reinforced concrete blocks

Material Name	Mass (%)
Water resisting admixtures	0.22
Glass fibers	0.02
Silica	1.56
Fly ash	3.91
Water	6.06

Shotcrete

Shotcrete is concrete that is sprayed onto a surface and reinforced with conventional steel rods, steel mesh, and/or fibers. Shotcrete is sprayed onto the surface and, due to the force with which it leaves the nozzle, is compacted on impact. It can be projected onto any orientation or shape of surface, including walls and ceilings.



The figure (Rao, 2014) shows the structure of a typical block of shotcrete on two sides with two wire mesh surfaces, diagonal links and an EPS core. This structure has been used as the reference for the material composition applied in the model which is as follows: Wire mesh (3.64 kg/m^2), shotcrete (230 kg/m^2) and EPS insulation (EPS) (2.5 kg/m^2) (Rao, 2014). Table 6 below (Beaupré, 2003) shows the shotcrete composition used in the model. The density of shotcrete is generally between 2230 to 2390 kg/m^3. In this study a density of 2288 kg/m^3 has been modelled.

Table 6: Raw materials for shotcrete

Material Name	Quantity	Unit
Cement	400	kg/m^3
Silica	40	kg/m^3
Fine aggregate	1110	kg/m^3
Coarse aggregate	460	kg/m^3
Water	268	liters/m^3
Water-reducing admixture	1.5	liters/m^3
Superplasticizer	5	liters/m^3
Air-entraining admixture	2.5	liters/m^3

Cement floor screed (concrete screed)

Cement floor screed is modelled using ordinary Portland cement and washed sand, using a ratio of 1 part cement to 4 parts sand by volume (20% cement, 80% sand by mass of dry ingredients). Ordinary Portland cement and sand inputs are as described in this report. These dry constituents are mixed with water (12% of the total mixture by mass) at the construction site using electricity from a diesel generator.

A3: Precast concrete

The precast concrete building industry is growing rapidly in India and the long term market prospects for precast products appears to be strong. In India, precast technology has been most commonly used in large construction projects such as bridges, flyovers, tunnels and metro rails, but it can now also be increasingly found in smaller projects such as construction of hotels, hospitals, residential buildings, showrooms, schools, etc. Some specific products within the broad categories of precast concrete production include dense, lightweight and aerated concrete blocks, precast concrete flooring and precast cladding.

Precast concrete blocks are categorized as lightweight, medium and dense, based on their different densities. Lightweight aggregates are used to make lightweight and medium density concrete blocks. The cement used for all blocks is ordinary Portland cement. Further description of the various concrete blocks is given below.

Lightweight concrete block

Globally, lightweight aggregates such as pumice and expanded clay are commonly used in production of lightweight concrete block. In India, all pumice is imported; there is no domestic production (India Department of Commerce, 2016). Thus, the model for lightweight concrete block uses expanded clay as the lightweight aggregate material. A lightweight concrete block has a density lower than 1100 kg/m^3, a value of 1087 kg/m^3 was used in the model. The raw materials used are cement (28%), expanded clay (26%), sand (32%) and water (14%) (thinkstep, 2016). Electricity (0.0092 MJ/kg) is modeled based on data for Indian production (MSME Development Institute, 2016). The technologies used for the production as well as production of raw materials and energy are representative of India.

Medium density concrete block

The medium density block can be a hollow or solid block with a density lower than 1450 kg/m^3. The raw materials used are cement (22%), expanded clay (16%), sand (51%) and water (11%) (thinkstep, 2016). Electricity (0.0092 MJ/kg) is modeled based on data for Indian production (MSME Development Institute, 2016). The materials and energy, along with the production process technology, are representative of India. The density of medium density concrete block is modeled as being 1400 kg/m^3.

Dense concrete block

Dense concrete blocks have a density in the range 1800 - 2200 kg/m^3 and are normally solid, or have a small void. A ready-mix concrete is prepared and pumped into molds to get the desired shapes and sizes. The design mix used for making dense concrete block is ordinary Portland cement (15%), gravel (58%) and sand (19%) (thinkstep, 2016). To represent the Indian production scenario, Indian specific datasets are used for electricity (0.0092 MJ/kg) and material inputs in the concrete block models.

Aircrete (autoclaved aerated concrete)

Aircrete is a versatile lightweight construction material and usually used as blocks. India has more than 25 manufacturers of aircrete with a cumulative capacity of 4 million cubic meters and has witnessed 10 fold growth in past few years (AACPA, 2016). Aircrete blocks are a steam cured mix of sand or pulverized fuel ash (PFA), cement, lime, anhydrite (gypsum) and an aeration agent. The typical density of aircrete blocks is 500 kg/m^3 and the raw material and energy composition is shown in Table 7below (CDM, 2016).

Table 7: Raw material and energy inputs for aircrete blocks

Material Name	Quantity	Unit
Fly ash (PFA)	272	kg/m^3
Lime	71	kg/m^3
Cement	95	kg/m^3
Anhydride	12	kg/m^3
Aluminium powder	0.46	kg/m^3
Water in the mix	370	kg/m^3
Electricity	11	kWh/m^3
Fuel Oil	8	Litre/m^3

Fiber cement board

Fiber cement boards are made of fiber reinforced cement, a composite building material. Fiber cement boards have many applications in construction including use as exterior siding, substrate for tiled walls or underlay for flooring. A typical material composition of fiber cement is Portland cement (37%), silica sand (56%), pulp/cellulose fiber (3.5%), coating pigment (0.5%) and water (4.5%) (UAC Berhad, Malaysia, 2013). Energy consumption is in the form of electricity (0.035 kWh/kg of fiber cement board) and thermal energy from heavy fuel oil (0.02 MJ/kg of fiber cement board) (thinkstep, 2016). India-specific upstream models and datasets are used to represent the Indian production scenario in the model. The density of fiber cement board is modeled as being 1700 kg/m^3.

Ferrocement wall panel

Ferrocement is a type of thin wall reinforced concrete, commonly constructed of hydraulic cement mortar, reinforced with closely spaced layer(s) of continuous and relatively small size steel wire mesh and steel reinforcing bars. In India, ferrocement is used often because the constructions made from it are better resistant against earthquakes (Naveen &

Suresh, 2015). Ferrocement panels have been modelled based on an ingredient ratio of 0.75:1:2 for water, ordinary Portland cement (53%) and sand formed into 1 m^2 25 mm thick panels with 100mm upstand, using 16 reinforcing steel bars (3 mm diameter) and 1.4 m^2 wire (100 g/m^2) (Rural Housing Knowledge Network, 2013). The overall product mix is sand (52%), ordinary Portland cement (26%) water (20%) and steel (1.8%). The fabrication is assumed to be hand mixed and molded with the galvanized sheet molds being used 200 times before replacement. The Indian production is represented using India specific upstream models and datasets. The area density of ferrocement wall panels is modeled as being 86 kg/m^3.

Ferrocement roof panel

Ferrocement panels are a high-strength alternative to asbestos fiber cement sheets and are lighter than reinforced cement concrete (RCC) roofing systems. These characteristics mean that ferrocement roof panels are suitable for use in the majority of roofing elements. The underlying model is the same as for the ferrocement wall panel described above. India-specific upstream models and datasets are used to represent the Indian production scenario in the model.

Precast concrete panels/flooring

The growing development and expansion of Indian towns and cities has created the need for faster construction and lower costs in the construction industry. The cost effectiveness and uniform quality of the precast technology has increased its use in India. Year round construction is possible with precast panels that are quickly erected on site, providing the opportunity to rapidly enclose a building and speed up construction. Precast concrete panels can be fabricated under controlled factory conditions to exacting tolerances.

The modeled production technology for precast concrete panels is similar to that of the European process. It involves pumping of ready mix concrete (95.2%) over a wire mesh (4.8%), which is then allowed to cure to form a solid concrete panel (thinkstep, 2016). The material and fuels in the European model are replaced by Indian specific datasets to represent the Indian production scenario. The density of concrete used in the model is 2200 kg/m^3 (equivalent to that used in the dense concrete block). Installation of these panels is not included in the model.

Microconcrete roof tile

Microconcrete roof tiles are used as cladding for sloping roofs as a substitute for country tiles, asbestos and other corrugated materials. Microconcrete roof tiles are sold as a pre-fabricated corrugated tile available in standard dimensions such as 240 mm x 488 mm x 8 mm with a mass of 2.5 kg/tile. According to the Department of Science and Technology, Government of India the main raw materials used per tile are cement (0.68 kg), coarse sand (0.68 kg), fine sand (1.36 kg) and water with a water-cement ratio of 0.5 (i.e. 0.34 kg water input per tile). (DoST, 2016). The power consumption per tile is 1.78 kWh.

Cement-based terrazzo tile

Terrazzo tiles were the most commonly used flooring tiles until the early nineties. The tiles are composed of marble chips which are mixed with colored or white cement, which are subsequently mechanically ground, hydraulically pressed before being finished, cured and polished. Terrazzo tiles are typically used as a finish for floors, stairs or walls. Terrazzo is used in both interior and exterior applications. (MSME - Development Institute, 2013)

In general, terrazzo tile are found in two forms: single-layered tiles formed of a single uniform mixture and dual-layered tiles formed of a hard-wearing facing layer and a concrete layer which is not exposed to wear. The dual-layered tile is more commonly used in the Indian market.

To produce dual-layered tiles, the mixtures for the two layers are prepared and stored in compartments provided adjacent to the hydraulic presses. For modelling the terrazzo tile a typical thickness of 25mm and weight of around 50 kg/m2 was considered. The typical raw material requirement for Indian production is shown in Table 8 (FICCI, 2007).

Table 8: Raw material and energy inputs for cement-based terrazzo tile

Material Name	Quantity[2]	Unit
Portland (gray) cement	0.265	kg/kg
White cement	0.031	kg/kg
Sand	0.359	kg/kg
Stone/marble chips	0.226	kg/kg
Mineral colors	0.0158	kg/kg
Water (net water)	0.207	kg/kg
Electricity	0.075	kWh/kg

Cement-based terrazzo (in-situ)

In-situ terrazzo may be used in residential or commercial buildings where a hard wearing surface that can be easily cleaned is required. Owing to these characteristics, terrazzo flooring is most commonly used in high-traffic areas, such as corridors or communal/shared areas such as entrances or lobbies. In-situ terrazzo is able to achieve a seamless,

[2] In the model a 10% increase in overall input is assumed to account for wastages occurring during production.

uniform finish, as opposed to fixed-size tiles. However, in-situ terrazzo is generally more expensive to install and repair/replacement can be more difficult than with tiles.

In-situ terrazzo is formed of three layers – a lime concrete cushioning layer which sits on top of the floor structure, a concrete underlayer and a terrazzo topping. According to the Indian code of practice for laying in-situ terrazzo flooring (Bureau of Indian Standards, 1999), the cushioning layer should be a minimum of 75mm deep, the underlayer and terrazzo topping combined should be at least 30mm. The minimum thickness of the terrazzo layer is assumed to be 12mm, making the underlayer at least 18mm. Based on these dimensions, the in-situ terrazzo floor system is assumed to be a minimum of 105mm deep, with an estimated mass of 252 kg/m^2. The terrazzo layer consists of six parts marble aggregate to three parts cement, one part marble powder, one part water and a small proportion of stone color, assumed to be 0.15 parts (1/20 of the cement content).

Based on a lime concrete cushioning layer, a concrete underlayer and the terrazzo layer described above, the material mix for the concrete-based in-situ terrazzo floor is as shown in Table 9 below:

Table 9: Raw material and energy inputs for cement-based terrazzo (in-situ)

Material Name	Quantity[3]	Unit
Portland cement	0.165	kg/kg
Marble aggregates/powder	0.0826	kg/kg
Stone aggregate	0.101	kg/kg
Lime	0.105	kg/kg
Sand	0.574	kg/kg
Mineral colors	0.00177	kg/kg
Water (net water)	0.0709	kg/kg
Electricity	0.00284	MJ/kg
Diesel	0.00665	MJ/kg

A4: Mortar and plaster

Mortar and plaster are produced by mixing cementitious materials, lime, water and fine aggregate materials (usually sand) to produce a thick mixture which hardens as it dries.

Mortar is primarily used to fix bricks or blocks into place during construction, while plaster is used to cover and protect the walls or ceilings of buildings. A number of different mortar and plaster types

[3] In the model a 10% increase in overall input is assumed to account for wastages occurring during production.

are described below covering a range of ingredient mixes suitable for a variety of applications.

The models described below reflect production in India with raw materials, fuels and electricity all assumed to be produced domestically.

Cement mortar

Cement mortar is a mixture of cement, sand and water. Cement mortar is more widely used than lime mortar as a construction material. Cement mortar sets and hardens quickly, allowing for rapid construction. However, due to the strength of the bond between bricks/blocks and cement mortar, masonry bonded using cement mortar cannot be reused at the end of life and therefore can only be crushed for use as hardcore or recycled aggregate. The proportion of cement to sand in mortar varies from 1:2 to 1:6 depending on the strength requirements of the application in question (Malik, Code of Practice for Preparation and use of Masonry Mortars, 1981). In the model the following composition is used: cement (13%), sand (81%), water (6%) (i.e., a 1:6 ratio of cement to sand). It is further assumed that 5% wastage occurs.

Lime Mortar

Lime mortar is a mixture of lime (slaked lime or hydraulic lime), sand and water. Slaked lime ($Ca(OH)_2$ is used in lime mortar to be used for masonry work, while hydraulic lime is added to mortar to be used in foundation work or other potentially damp conditions. Generally, the lime to sand ratio is around 1:2. (Malik, Code of Practice for Preparation and use of Masonry Mortars, 1981). Using lime mortar allows masonry to be easily reclaimed and reused at the end of life, rather than downcycled as aggregate or fill.

In the model the following composition is used: lime (31%), sand (63%), water (6%) (i.e. a 1:2 ratio of cement to sand). It is further assumed that 5% wastage occurs. The model reflects production in India with raw materials and electricity used for mixing also assumed to be sourced from India.

Cement based plaster

Cement based plaster is a versatile and weather-resistant surfacing material used for the protective and/or decorative coating of internal walls and ceilings. The primary material used in the production of cement based plaster are ordinary Portland cement (16%), sand (75%) and water (11%). (Standard, 2000). Electricity from a diesel generator is used for mixing the plaster.

Mud plaster

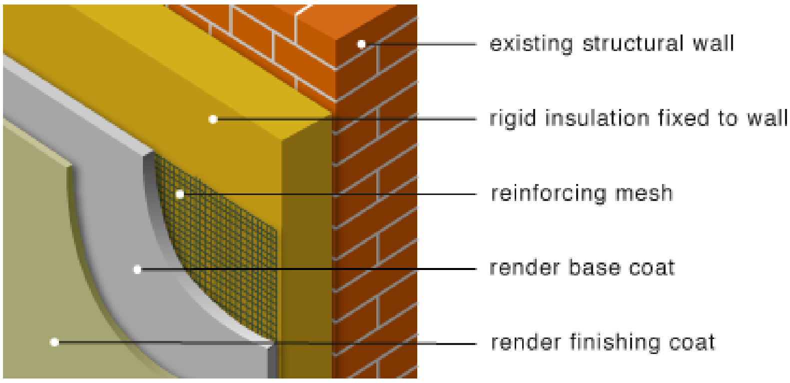
Mud plaster is composed of 27% clay, 67% sand, 5% rice straw and 1% lime by mass (Practical Action, 2009). It has been assumed that clay and sand used to produce mud plaster are extracted by machine (as described in the sections on sand and clay), while the production of rice straw is as described in the section on straw bale (section J). The composition is mixed mechanically on site using a diesel generator. During mixing, water is added to compensate for evaporation. The density of mud plaster is modeled as being 1000 kg/m^3.

Cement/lime render for external wall finishes

Cement/lime render is a homogeneous mixture produced by mixing cementitious materials, water and inert materials, such as sand, to the required consistency for use in protecting and providing a decorative finish to the external face of masonry walls. The proportion of cementitious material to sand varies from 1:2 to 1:6 depending upon the strength required for the application in question (Malik, Code of Practice for Preparation and use of Masonry Mortars).

In the model the following composition is used: cement (11%), lime (11%), sand (67%), water (10%). It is further assumed that 5% wastage occurs.

Polymeric render for external walls



Traditional render is formed of a simple mix of sand, cement and water. Modern renders contain a range of additives including polymers, silicones, acrylics, alternative aggregate materials, reinforcement and crack fibers.

Polymer insulation renders are suitable for a variety of external wall applications. These can be applied either directly to the substrate or alternatively applied as a finish to an existing wall.

The benefits of polymer render systems include enhanced weatherproofing properties, vapor permeability (reducing condensation, high impact strength, color consistency and a wide variety of color options.

In the model the following composition is used: epoxy (4.3%), cement (21%), sand (63%), water (12%). 0.37 kWh of electricity is required for mixing (L.K. Aggarwal, 2007). It is further assumed that 5% wastage occurs. The area density of polyurethane foam is modeled as being 3 kg/m^2.

B. Gypsum based products

B1: Gypsum precursors

Gypsum

Gypsum ($CaSO_4.2H_2O$) is a hydrated calcium sulfate used widely in industry. In 2012-13 India produced 3.54 million metric tons of gypsum. In India, gypsum is mined by opencast manual mining except in a few semi-mechanized mines in Rajasthan. Of the total gypsum produced in India, fertilizer/pottery grade gypsum accounts for about 82%, cement/paint grade 12% and 5% is lower grade. In semi-mechanized mines, gypsum is excavated by backhoe excavator and directly loaded into trucks/dumpers. The trucks and dumpers loaded with gypsum are either dispatched directly to customers or are transported to railway sidings for further loading into railway wagons for wider distribution. In some mines of Rajasthan, the excavated gypsum is ground before dispatching to user or party. The deposits are found at shallow depths and scattered over large areas.

Most of the gypsum used in the construction industry currently in India is natural gypsum (Gypsum, 2015) and this is used as the basis for modeling most gypsum-based products in the database. The production technology is representative of Indian production process. The fuels and electricity used are from Indian sources (thinkstep, 2016).

Phosphogypsum

Phosphoric acid plants are an important source of a synthetic gypsum known as "phosphogypsum" which is gypsum produced as a by-product from the purification process. Whilst 2.9 million metric tons of phosphogypsum is used each year in the cement and fertilizer industries, it is estimated that 6.3 million metric tons are produced, so there are extensive stockpiles of phosphogypsum available for use in construction products. However, there can be problems with residual acidity, and impurities such as fluorine compounds and trace elements including radioactivity (Indian Bureau of Mines, 2013). Marine gypsum, which is recovered from salt product in coastal regions, is another source of synthetic gypsum, entirely used in the cement industry.

Across all industries, India consumes 60% natural gypsum, 34% phosphogypsum and 6% marine gypsum. To model phosphogypsum, economic allocation has been used to account for 5.44 kg of phosphogypsum produced per kg of phosphate. The cost of phosphate is USD 805/ton (equivalent to 53,977 INR/ton as of July 2016) (Phosagro, 2014). The cost of phosphogypsum is assumed as 1000 INR/ ton as the cost in the market is 350-1200 INR/ton of phosphogypsum, which means the phosphogypsum product stream has approximately 10% of the value of phosphate product stream and so is allocated about 10% of the environmental impacts from phosphate production. India-specific upstream models and datasets have been used to represent the Indian production scenario. It should be noted that, using these values, the impact of phosphogypsum is significantly greater than that of natural gypsum.

Calcined gypsum (gypsum hemihydrate, plaster of Paris)

Calcined gypsum, also known as gypsum hemihydrate and plaster of Paris, is used in a number of gypsum based

When gypsum rock (gypsum dehydrate, $CaSO_4.2H_2O$) is heated at temperatures above 130^oC some water is driven off to produce the gypsum hemihydrate ($CaSO_4.½H_2O$) form (Omahen, 2002). Various methods for calcining gypsum are used in India including rotary drum, pan type, kettle and fluidized bed calciners (Acharya, 2013) There are around 300 producers of gypsum plaster in India with an estimated installed capacity of 180,000 metric tons per annum (Ministry of MSME, Govt. of India, 2002).

The modeled process is considered to be generally representative of production in India and assumes that 26 kWh electricity and 1050 MJ fuel oil along are required to calcine 1188 kg gypsum dehydrate to produce each metric ton of gypsum hemihydrate. The Indian grid mix is used as the source of electricity.

B2: Gypsum products

Gypsum plaster

Gypsum plaster is used as an interior coating for masonry walls and to form columns and other building interior features.

Installing gypsum plaster involves mixing calcined gypsum with water, which rehydrates it to form the original gypsum dehydrate again. Installation for gypsum plaster having a coverage 10 m^2 per 25 kg bag with thickness of 2 mm is modeled. The water required for mixing during installation is 11.5 liters per 25 kg bag of gypsum plaster. No fuel and energy for installation is modelled as this is done manually. The area density of gypsum plaster is modeled as being 3.65 kg/m^2.

FaLG (fly ash/lime/gypsum) block

FaLG (Fly-ash Lime Gypsum), also referred to as Fal-G block or brick, is composed of fly ash, lime and gypsum. FaLG block is modeled with a constituent ratio by mass of PFA (23%), lime (18%), gypsum (5%), quarry dust (45%) and water (9%). The modeling of PFA and lime is outlined in part A above, and gypsum modeling is described in part B1. These products are modeled as mechanically mixed (as for mortar) and molded before being water cured; water use for curing is equivalent to 12% of the mass of the block. The density of FaLG blocks is modeled as being 1760 kg/m^3.

Plasterboard

Plasterboard, also called drywall or gypsum board, is a panel made of a layer of gypsum plaster that is sandwiched between two layers of paper. It is manufactured and used in India. Plasterboard is commonly used for wall partitions with timber or galvanized steel studs, ceilings and also to reduce sound transmission. 12.5 mm plasterboard comprises calcined gypsum (from natural stone) (80%), water (15%), paper liner (4%) and additives (0.8%) (Gyproc Saint Gobain, 2016). Calcining the gypsum is described in the section on gypsum. The model for plasterboard is based on the existing EDGE model (thinkstep, 2016) and the EPD for plasterboard (Gyproc Saint Gobain, 2016) in which the energy inputs are adapted to use the Indian electricity grid mix and thermal energy from hard coal. The density of plasterboard is modeled as being 700 kg/m^3.

Gypsum panel

Gypsum panels are made of fiber reinforced gypsum, with the main raw material inputs being calcined gypsum, glass fiber reinforcement, water, thermal insulation and a range of additives present in small quantities. The gypsum panel represented in the model has a density of 35 kg/m^2 (Omahen, 2002). Gypsum panels may also be referred to as Rapidwall or Gypcrete panel in India (FACT RCF Building products Ltd. (FRBL), 2012).

Input material masses are adapted from a European model for production of gypsum panel but with India-specific fuel and energy inputs (thinkstep, 2016). The input material mix is calcined gypsum (78%), clay (5%), liquefier (0.8%), accelerator (0.6%), glass fiber (0.2%), boric acid (0.1%). Energy consumption is 46 MJ/m2 heavy fuel oil and 0.035 kWh/m2 electricity from the Indian grid mix (Omahen, 2002).

Phosphogypsum panel

Phosphogypsum panels have been modelled using the same assumptions as for gypsum panels (see above), but using phosphogypsum as the source of gypsum rather than natural gypsum.

C. Metals and metal products

C1: Steel products

Three production routes are widely used in steel making: (1) blast furnace and basic oxygen furnace (BF/BOF), used for primary steel production, (2) electric arc furnace (EAF), used in production of steel from scrap, and (3) EAF production of primary steel from direct reduced iron (DRI). To model the Indian steel mix the following combination of production routes has been used: DRI (32%), EAF (24%), BF/BOF (44%) (Ministry of Steel, India, 2011).

For BF/BOF a modern integrated steel plant has been used as the base model with upstream processes adapted to India-specific datasets. EAF technology for both the scrap and DRI production routes is modeled based on an average arc furnace installed in the last 10-15 years with the electricity source reflecting the likely route for scrap and DRI EAFs operating in India.

BOF Steel

For making BOF steel, iron ore is reduced to iron (also called “hot metal” or “pig iron”). The iron is then converted to steel in the BOF. After casting and rolling, the steel is delivered as coil, plate, sections or bars. Economic allocation has been applied for BF/BOF slag and steel. The price of pig iron is taken as 23000 INR/metric ton (Business Standard, 2015). The slag generated in the BF/BOF process is pulverized and screened for use in various applications, particularly cement production due to its pozzolanic characteristics. Hence this slag is considered a valuable co-product and is allocated an average price of 660 INR/metric ton (Slag-Iron and Steel, 2015). Applying these values for pig iron and BF slag results in 99.1% of the impacts of the blast furnace being allocated to the pig iron with 0.9% allocated to the BF slag.

EAF Steel

Electric arc furnaces use an electric discharge (arc) to melt scrap steel. Alloys are used as additives to adjust the chemical composition of the steel. Downstream process stages, such as casting, and rolling and finishing, are similar to those found in the BF-BOF route. The economic value of EAF slag in India is not significant as, unlike BF slag, it is not used as a cement substitute. EAF slag produced in India is generally either disposed of or may be used as a low secondary fill material. Hence no allocation has been applied in the EAF steel model and inert landfill is used for the disposal of slag generated in the EAF.

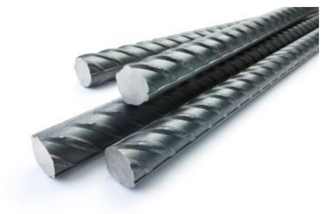
DRI Steel

In DRI steel production "sponge iron" is produced by reacting a reducing gas made from hard coal with iron ore pellets. This is then converted into steel using an EAF as described above, although in this case the electricity is generated from waste heat captured from the DRI process flue gases using a waste heat recovery boiler. In the model economic allocation is used for electricity (4.4 INR/kWh) and sponge iron (24000 INR/metric ton). Applying these allocation values results in 89% of the impacts being allocated to sponge iron with 11% allocated to electricity production.

Steel section

Structural steel cross-sections are typically formed using hot rolling. The Indian steel mix of BF/BOF, EAF and DRI steel billet has been used to model production of steel sections. A section rolling process has been adapted to the Indian situation using electricity from the Indian grid mix (0.183 kWh/kg) and thermal energy from hard coal (1.5 MJ/kg).

Steel reinforcement (steel rebar)



Reinforcing steel can be a steel bar or a mesh of steel wires that is used in reinforced concrete and reinforced masonry structures strengthening the structure by and holding the concrete in tension. The surface of rebar is often patterned to form a better bond with the concrete. Due to rapid infrastructural development in India, the demand from the construction industry is largely for long products in the form of rebar and H-beams. The steel rebar model includes the Indian steel mix of BF/BOF, EAF and DRI steel billet as input. This steel billet is rolled and formed using electricity (0.142 kWh/kg) and reheated using thermal energy from hard coal (1.2 MJ/kg). The output of this process is steel rebar.

Electrogalvanized steel sheet ("corrugated zinc")

Corrugated electrogalvanized steel sheet (also known as corrugated galvanized iron and corrugated zinc) is produced from hot rolled coil which is in turn produced from steel slab. It has been assumed that slab is produced from the Indian steel mix of BF/BOF, EAF and DRI steel. The semi-finished hot rolled coil is pickled and coated on a continuous plating line with a layer of zinc which is typically 2.5 µm to 7.5 µm thick. The electrogalvanized steel sheet is passed through a roll former to produce the corrugated form. Corrugated electrogalvanized steel sheet is most commonly used for roofing or shelters, but may be used for a variety of other applications where strong, thin, weather-proof materials are required. India-specific fuel and energy datasets have been used to represent Indian production.

Galvanized steel stud

Galvanized steel studs are produced from galvanized steel sheet which is produced as described above for electrogalvanized steel sheet. The studs are produced by passing the sheet through one or more roll formers. For more complex stud shapes, multiple roll forms are required to produce the required shape. Some stamping of the sheet may also be required to produce holes for fixing studs into place at the construction site. Steel recovered from stamping is collected and recycled internally. India-specific fuel and energy datasets have been used to represent Indian production. The density of galvanized steel stud is modeled as being 7850 kg/m^3.

Steel window frame

Steel window frames are produced from galvanized steel sheets as produced above. The shapes required for producing window frames are relatively complex compared to those used to produce corrugated steel sheet or steel studs and generally require additional stamping processes to allow the various component parts of the window to be slotted together. Each kg steel window frame includes galvanized steel sheet (0.802 kg), an ethylene propylene diene monomer polymer (EPDM) gasket (0.156 kg), polyamide to provide a thermal break and reduce heat transfer (0.005 kg) and stainless steel fittings (0.032 kg/kg) based on the equivalent inputs required for aluminum window frames after adjusting for the density and gauge of steel (Schüco International KG, 2011). The model represents a production process based on European models for these processes but Indian specific fuel and energy inputs are used to account for production in India (thinkstep, 2016).

C2: Aluminum

India is currently the fifth largest consumer of aluminum in the world and, at 2.3 billion metric tons, has about 7% of global deposits of bauxite. Due to India’s large production volume, aluminum ingot and aluminum fabricated parts (sheet, profile) are modeled as produced within India rather than being imported.

Aluminum ingot

Production of aluminum ingot comprises two primary sub-processes: bauxite refining for production of alumina, and smelting for production of aluminum metal. Considerable energy is also used in anode production; this is also accounted for in the model. Petroleum coke is the main energy source for manufacturing the anode. Thermal energy sourced from hard coal and heavy fuel oil is used for digestion and calcination in the refining process.

In large scale smelting plants in India, about 97% of the electricity consumed is generated from coal (Centre for Science and Environment, India, 2010). Therefore, electricity from hard coal is used in the smelter process, which accounts for roughly 70% of the energy consumed in production of the ingot, considering all activities from cradle-to-gate. Thermal energy for the most energy intensive processes, such as alumina production, is modeled based on generation from hard coal. For less energy intensive production processes such as die casting, pre-heating and stress relieving thermal energy is modeled based on generation from fuel oil. Electrical energy from the Indian grid mix is used for rolling and extrusion (thinkstep, 2016).

The theoretical minimum energy needed for the smelting process has been estimated using thermodynamic analysis to be about 9.03 kWh/kg of aluminum metal. Globally, the actual benchmark achievement for this figure has been around 14 kWh/kg of aluminum (Centre for Science and Environment, India, 2010). The aluminum industry in India has made considerable progress in improving the energy efficiency of production and currently, aluminum smelting in India requires 14.56 kWh/kg of aluminum; close to the global benchmark (Centre for Science and Environment, India, 2010).

Aluminum sheet

In India, aluminum sheet finds a variety of applications as roofing or cladding materials. Aluminum sheets are produced via a rolling process, from aluminum ingots. The thickness of aluminum sheets typically falls between 0.2 and 4 mm. The starting slabs are produced by direct chill casting in cast houses and the resulting coil is cut into aluminum sheets (thinkstep, 2016). The processes for casting, rolling and cutting using Indian fuels and electricity are representative of technology used in India.

Aluminum extruded profile

The aluminum extruded profile is made from aluminum ingot. As for aluminum sheets, the starting billets are produced by direct chill casting. The ends (tops and tails) of the billets are sawn at the cast house during direct re-melting. The billet is pre-heated to 450°C - 500°C, before extrusion and roughly 320 kg scrap/metric ton of extruded profile product is generated, which is recycled into new ingot through re-melting either on-site or externally. The recycling of this process scrap is included in the model for the material (thinkstep, 2016). The overall production process is modeled based on technology representative of production in Europe with upstream materials and energy adapted with India specific datasets.

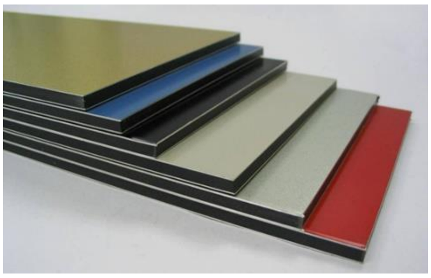
Aluminum profiled cladding

Aluminum profiled cladding is formed by bending aluminum sheet into curved or zig-zag profiles. The most common use of this product in the Indian construction industry is as the roofing material of industrial sheds and rural houses though it forms only 0.50% of roofing material in India (Vala, 2010). Profiled cladding is made from aluminum sheets (described above). The production process includes stamping and bending aluminum sheets to produce corrugated sheet and then laser cutting them to the required size. Nitrogen is used as the cutting gas for the laser cutting process. The Indian production scenario is represented using India-specific datasets for energy, fuel inputs and aluminum sheet in the model. The Indian grid mix is used as source of electricity. The density of aluminum profiles cladding is modeled as being 2800 kg/m^3.

Aluminum extruded profile - window frame

Aluminum window frame is manufactured from aluminum extruded profiles which are formed, stamped and cut to the required lengths. Each 1 kg aluminum window frame includes the following materials: aluminum extrusion (0.74 kg), ethylene propylene diene monomer (EPDM) gasket (0.2 kg/kg), polyamide to provide a thermal break and reduce heat transfer (0.0067 kg) and stainless steel fittings (0.043 kg) (Schüco International KG, 2011). The Indian production scenario is represented using India-specific datasets for energy, fuel inputs and aluminum sheet in the model. The Indian grid mix is used as source of electricity. Each meter of aluminum window frame is modeled as having a mass of 2.03 kg.

Aluminum thin composite cladding



The LCA model is based on a European EPD of aluminum thin composite panel (IBU, 2016) that has been adapted based on Indian production of aluminum sheet, polyethylene and 1.39 kWh electricity/kg. This assumes that 3 mm of polyethylene is extruded between two 0.5 mm sheets of aluminum, with the outer aluminum surface coated with polyethylene foil and that the Indian grid mix is used as source of electricity. The area density of aluminum thin composite cladding is 5.5 kg/m^2.

C2: Copper

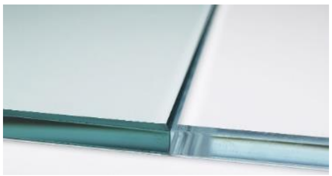
Copper sheet

Sterlite Industries, Hindalco, and Hindustan Copper are the three major producers of copper in India. Having previously been a net exporter of refined copper, India is expected to become a net importer in the near future (perhaps as soon as 2017) due to a significant rise in domestic demand. Electric and electronic products have driven this growth and now account for 36% of the total refined copper consumption in India, the most for any sector. Telecoms remains India's second largest copper consuming sector, accounting for 20% of the total (MCX, 2016)

The building and construction industry accounts for only a 5% of share of the total consumption of refined copper mostly in the form of copper sheet, which has a wide variety of uses in the Indian construction industry. India imports copper products in a variety of forms including ores, concentrate, alloys and scrap. A large share of the copper ores and concentrates come from Chile, with Australia being the other major country of origin. Only 4% is from domestic ore production. Thus the modeling of copper concentrates includes India-specific smelter and refining processes, while for mining and beneficiation a global mix with Chile and Australia as the major producers has been used. Electrorefining is modeled based on the Xstrata Technology used by the top two major copper producing companies in India (Hindalco and Sterlite). The thermal energy generation is assumed to be from coal and light fuel oil (Xstrata, 2004). For copper sheet production, the model is based on a European process for copper sheet production with Indian upstream precursors and an Indian fuel and energy mix.

D. Glass

Float glass



Flat glass, commonly called float glass after the process by which most of it is made, plays a dominant role in India's building construction and vehicles manufacturing industries. The material composition of the batch materials for construction is sand (59%), soda ash (19%), dolomite (15%), limestone (5%) and feldspar (2%) (HNG, 2016). The model assumes a recycled glass content of 15% (NSG group, 2010). The glass industry is highly energy intensive and energy consumption is major cost driver. The total energy consumption in the Indian glass industry is about 1.17 million metric tons of oil equivalent. The average energy cost as a percentage of manufacturing cost is about 40%. Melting and refining are the most energy-intensive steps of the glass making process accounting for 60–70% of total energy use in the glass industry. Thermal energy accounts for about 80% of total energy consumption in the glass industry (TERI, 2012). In the model this energy mix is modeled using 0.4 kWh/kg electricity from the Indian grid mix and 5.76 MJ/kg thermal energy from natural gas. The density of float glass is modeled as being 2500 kg/m^3.

E. Ceramics and clay-based products

Brick (common/facing)

India is a large producer of fired clay products and therefore brick, as well as clay tile, are modeled to represent the production mix of each product in India. The brick production process includes clay extraction and processing, brick forming, drying, and firing.

India is estimated to produce around 260 billion bricks/year with over 70% production from Bull's Trench kilns (Swiss Agency for Development and Cooperation, 2014). The mixture of kiln types for brick is based on the production capacity by brick kiln type within India, including small-scale and rural production (UNEP, 2014), as shown in Table 10 below.

Table 10: Production capacity by kiln type for India, in billion bricks per year

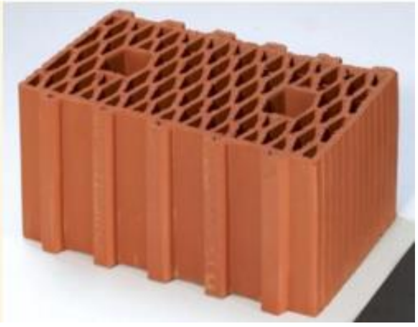
Kiln Type	Capacity (billion bricks/year)
Bull's Trench, Fixed Chimney Bull's Trench Kiln (FCBTK)	185
Clamp kiln, Intermediate clamp kiln, Scotch kiln	50
High draught zigzag	20.5
Hoffman and hybrid Hoffman	2

The model for brick begins with clay extraction using diesel-fueled machinery. Since the fuels used for brick kilns differ substantially from other industrial fuel mixes in India, a custom fuel mix has been used for brick kilning. This primarily comprises coal but also includes firewood and other biomass fuels (Kamyotra, 2015; Asian Institute of Technology, 2003). It is estimated that the Indian brick industry consumes more than 24 million metric tons of coal annually, in addition to several million tons of biomass fuels (Tata Energy Research Institute, 2001). The fuel mix for brick kilning thus reflects 85% coal and 15% biomass fuel, by mass. The fuel consumption for each kiln type is based on literature, and is presented in Table 11. Direct emissions reflect the regionally representative combustion emissions produced by the different fuels. Brick density is assumed to be 1760 kg/m^3 based on the range of densities given for common burnt clay bricks (IS875-1, 1987).

Table 11: Specific energy consumption by kiln type

Kiln Type	Energy consumption (MJ/kg)
Bull's Trench, Fixed Chimney Bull's Trench Kiln (FCBTK)	3
Clamp kiln, Intermediate clamp kiln, Scotch kiln	5.6
High draught zigzag	5.8
Hoffman and hybrid Hoffman	2.9

Honeycomb brick



Honeycomb Bricks are modular and stackable, creating different forms based on their configuration. As the honeycomb brick is similar in material composition to a normal brick and varies only in density due to its form, the normal brick production process is taken as the basis for the model. It is assumed that only kilns using more modern production technology are likely to produce honeycomb bricks, so the bricks have modeled as being produced using Hoffman kilns as described in the section on facing brick. Honeycomb bricks have higher thermal resistance than normal bricks due to the voids, require less mortar to bond them, and are manufactured with a density in the range of 650-700 kg/m^3.

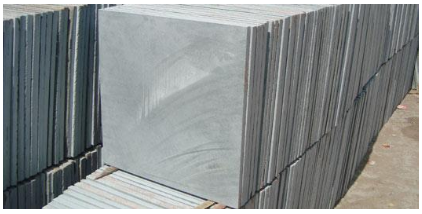
Clay roof tile

Clay roof tiles are modeled based on representative clay extraction followed by industrialized tile formation and firing processes. The starting material for production is natural clay. Clay is extracted using diesel equipment. Formation of the clay tiles entails de-airing (removal of air bubbles), followed by pressing or extrusion into tile form. Clay tile production in India is mostly mechanized although a small proportion is still produced by hand (Vadlamani, 2014). Fuels used in clay tile production are typically coal or, in some cases, wood biomass. A conservative assumption has been made based on the use of a mechanized process for the formation of the clay tile, with firing using coal, light fuel oil and heavy fuel oil. Electricity used is sourced from the Indian grid. Direct emissions are based on combustion emissions associated with each fuel type. The raw material inputs are given in Table 12 below. The area density of clay roof tile is modeled as being 54 kg/m^2.

Table 12: Raw material and energy inputs for clay roof tiles

Material Name	Quantity	Unit
Sand	0.0147	kg/kg
Limestone	0.00243	kg/kg
Gypsum plaster	0.00153	kg/kg
Clay	1.35	kg/kg
Water	0.103	kg/kg
Electricity	0.16	kWh/kg
Coal	3.72	MJ/kg
Heavy fuel oil	0.0231	MJ/kg
Light fuel oil	0.346	MJ

Stone floor tile



Stone floor tiles are assumed to be produced from Kota stone, a fine-grained variety of limestone quarried in the Kota district of Rajasthan in India. Stone floor tiles may be used for exteriors, pathways, corridors, driveways, balconies and commercial buildings. The production of Kota stone according to the Director of Mines and Geology Rajasthan, is approximately 2.8 million metric tons/year (Pawan Kalla, 2006). The density of the modelled Kota stone slabs is 2600 kg/m^3. As well as modeling the quarrying, cutting and finishing of the Kota stone the dataset also includes the installation, which is assumed to require 0.0678 kg/kg cement and 0.271 kg/kg sand.

Asphalt shingles

An asphalt shingle is a type of wall or roof shingle and can be applied to any sloped surface. Asphalt shingles have a relatively low up-front cost and are generally easy to install, leading to an increase in in the Indian market (MB Bureau Report, 2014). Shingles can be applied to any sloped roof. Asphalt shingles are composites of high grade asphalt (also referred to bitumen) reinforced with fiberglass mesh, which is overlaid with high-strength ceramic coated granules.

The production process to model production of asphalt shingles in India is adapted from an EPD of asphalt shingles by Owens Corning, which uses a fiberglass mat as the core substrate material coated on both sides with weathering-grade asphalt. The raw material composition for the production of asphalt shingles is as follows: fiberglass 2%, asphalt (bitumen) 20%, limestone 37%, granules 25%, coal slag 8%, sand 6%, dolomite 1% (Owens Corning, 2015). A standard sized shingle 12" x 36" shingle

(30.5 cm x 91.4 cm) weighs 1.22 kg (Certainteed Saint Gobain, 2015). Production in India is represented using India-specific upstream models and datasets. The area density of asphalt shingles is modeled as being 14 kg/m^2.

Ceramic tiles

The heart of the Indian ceramic industry centers around Morbi, about 250 km from Ahmedabad in Gujarat with producers in this cluster commanding about 70% of the market share for wall tiles, floor tiles, vitrified tiles, and sanitary ware (SEE-Tech Solutions Pvt. Ltd and TERI). Detailed energy consumption data for the Morbi cluster has been used to represent ceramic tile production in India (Bureau of Energy Efficiency, 2010). The ceramic units use roller kilns for tile manufacturing. Natural gas, charcoal and lignite are used as fuels in the firing process.

Existing models for stoneware tiles (thinkstep, 2016) have been used as the basis for raw materials for both vitrified and glazed ceramic tiles, with adaptation of both raw materials and energy datasets to reflect Indian production.

Vitrified ceramic floor tiles

Vitrified tiles are unglazed tiles with a high level of hardness and polish achieved through hydraulic pressing of clay, and other minerals including quartz and feldspar. Vitrified tiles are extremely strong and durable and processed in such a way that they allow for very little water absorption. The assumed mass of vitrified tiles is 24.2 kg/m2 at 11 mm thickness. Raw materials are modelled based on Indian production, with material quantities based on existing GaBi data for unglazed stoneware tiles.

22 out of 26 vitrified tile factories in the Morbi cluster are medium units, which use 3.47 kWh electricity, 57.6 MJ natural gas and 40.3 MJ lignite per m2 of vitrified tiles. Energy datasets are based on Indian production and electricity grid mix.

Glazed ceramic floor tiles

Glazed ceramic floor tiles are assumed to be 11 mm thick and have a mass of 17.7 kg/m2.

38 out of 52 glazed floor tiles factories in the Morbi cluster are medium units, which use 1.25 kWh electricity, 0.95 Nm3 natural gas (5% reduction in natural gas assumed due to efficiency improvements recommended by the source report) and 3.5 kg lignite per m2 of finished tile. Energy datasets and raw materials are modelled based on Indian production, with material quantities based on existing GaBi data for glazed stoneware tiles.

Polished stone cladding

Production of polished stone cladding is based on the GaBi dataset for a natural stone slab flexible façade, adapted for Indian production with Indian energy datasets (thinkstep, 2016). The dataset is based on limestone and assumes a 20 km transport distance between quarry and processing. The stone façade cladding is assumed to have a mass of 120 kg/m^2.

F. Plastics and polymer-based products

Carpet (nylon) tile

Carpet tiles are modular sections of carpet typically cut into squares or rectangles. Demand for carpet tiles is strongest in the corporate and institutional sectors. Carpet tiles are also gaining market share in the retail, healthcare, educational, institutions and sports segments. Carpet tiles offer design flexibility, durability, functionality and ease of maintenance, carpet tiles and so have even become increasingly popular in the residential sector. The carpet tile is a comparatively new product in India. Globally, commercial offices, airports, healthcare institutions, retail leisure are big markets for carpet tiles along with emerging markets such as schools and residential buildings. A similar market situation is also seen in India.

For modeling the carpet tile the following raw material mix has been assumed: polyamide (11.9%), polyester (3.9%), limestone (62.3%), bitumen (16.7%), SBR latex (4.1%), glass fiber (0.9%), additives (0.2%). The area density of carpet tile is modeled as being 4.04 kg/m^2.

Energy and fuel consumption in manufacturing of carpet tile is: electricity (0.61 kWh/m^2), fuel oil (3.5 MJ/m^2), heating steam (2.4 MJ/m^2). In addition to this, the water consumption is 0.93 kg/m^2.

In this model, cradle to gate production processes are considered along with ancillary materials used for installation. Installation is carried out manually so no energy or fuel is considered, but adhesive consumption of 0.2 kg/m^2 has been considered. The loss during installation is assumed to be 2%.

Carpet (nylon)

Broadloom carpets are woven on a wide loom with standard widths ranging from 12 ft to 15 ft (3.7m to 4.6m). They are laid from wall-to-wall and are well suited for large rooms with wide spans, finding use in a broad range of commercial and residential buildings.

For modeling broadloom carpet production, the following raw material mix has been assumed: polyamide (42.3%), limestone (37.4%), polypropylene (9.3%), SBR latex (10.8%) and additives (0.1%). The area density of carpet tile is modeled as being 2.2 kg/m^2 (NIST, 2010).

Energy and fuel consumption in the manufacture of carpet is: electricity (0.39 MJ/m^2), fuel oil (5.0 MJ/m^2) and steam (1.67 MJ/m^2). The water consumption is 0.96 kg/m^2.

In this model, cradle to gate production processes are considered along with ancillary materials used for installation. Installation is carried out manually so no energy or fuel is considered, but two adhesive applications are required – one to the product backing and one as spots on the floor surface, resulting in a total adhesive consumption of 0.65 kg/m^2. The installation loss is assumed to be 5.7%.

Polyurethane rigid insulation foam (pentane blown)

Polyurethane rigid (PUR) insulation foam has a high thermal resistance and is commonly used for insulation of roofs, walls, floors, ceilings and retrofit of residential and commercial buildings.

For a rigid PU-foam blown with pentane to be used in insulation applications, the input raw material used are methylene di-isocyanate (MDI) (62%), pentane (5.4%) and polyether polyol (39%) (PlasticsEurope, 2005). The electricity required is 0.42 kWh/kg. Small amounts of pentane are emitted to atmosphere (0.003 kg/kg) and some waste foam is also generated (0.020 kg/kg). Raw materials and energy datasets are adapted for Indian production. The density of polyurethane foam is modeled as being 32 kg/m^3.

Polyurethane rigid insulation foam (HCFC blown)

PUR foams were originally blown using chlorofluorocarbons (CFCs) until these were banned by the Montreal Protocol because of their high ozone depletion potential. HCFC 141b was substituted for CFCs, as it has a much lower ozone depletion potential. In Europe, HCFC use is now also restricted and pentane is more commonly used as a blowing agent. However, in India, the use of HCFC 141b is still allowed. HCFC blown PU insulation is produced in the same way as the pentane blown PU rigid foam (described above) but HFCF 141b is used instead of pentane.

The following assumptions have been used to model this process. R22 has been used as a proxy material for the HCFC blowing agent as no LCA data for HCFC 141b production are available. The input of R22 is based on the volume of the input 0.054 kg pentane/kg, adapted for the volume of HCFC 141b using the relative molecular mass ratio of HCFC 141b (117 g/mol) and pentane (72 g/mol), so 0.0878 kg of R22 has been modeled. 5.5% of the input mass of R22 (0.0048 kg) is assumed to be emitted as HCFC 141b during production, the same proportion as for pentane blown PU foam production (PlasticsEurope, 2005). The density of polyurethane foam is modeled as being 32 kg/m^3.

Rubber flooring

Rubber flooring is strong, tough, and resilient against a variety of conditions making it a suitable flooring choice for commercial, high traffic environments. Now with a wide selection of colors, patterns, and textures available, this material is also finding its way into residential interior and exterior applications. Depending on the type of tile used, and the environment it is installed in, a properly cared for rubber floor should for last twenty years or more.

The modeled flooring product is assumed to be 2 mm thick with a mass of 3.3 kg/m^2. The composition of the flooring is filler (53%), styrene butadiene rubber (27%), pigments (11%), additives (7%) and auxiliaries (2%) (ERFMI , 2013). Styrene butadiene production has been adapted to fit Indian production conditions.

For installation, 0.3 kg/m^2 of adhesive is used. No energy consumption has been considered as installation is predominantly manual.

u-PVC window frame

u-PVC, also known as unplasticized or rigid PVC, is extensively used in the Indian building industry as a low-maintenance material option. The material comes in a range of colors and finishes, including a photo-effect wood finish, and is used as a substitute for painted wood, mostly for window frames and sills when installing double glazing in new buildings, or to replace older single-glazed windows. Other uses include fascia, and siding or weatherboarding. u-PVC does not contain phthalates, which are only required for flexible PVC, nor does it contain bisphenol A (BPA). u-PVC Windows can be used for all climatic conditions found across India (Sathish Kumar, 2010)

The model is based on the European production of 1 linear meter of u-PVC frame with metal bracing. The mass of the u-PVC frame modeled is 2.8 kg/linear meter comprised of 1.3 kg PVC extrusion and 1.5 kg galvanized steel (thinkstep, 2016). As the technology is similar to European production process, the model has been adapted with materials (u-PVC and galvanized steel) and grid electricity based on Indian production.

Vinyl (PVC) flooring

Vinyl flooring is most commonly used in applications such as hospitals and schools, where there is relatively little exposure to abrasion from tracked-in grit and dirt. Based on historical observations, it is estimated that vinyl (PVC) flooring in such applications lasts an average of 40 years before it is replaced due to wear. In extremely heavy traffic areas (which are normally much smaller in area), such as entryways in a school, the tile has a shorter life expectancy.

Because of differing manufacturers' maintenance recommendations there is no single industry standard for maintenance of the product over its lifetime. Typically, vinyl (PVC) flooring is stripped and polished annually. Many of the acrylic finishes used after the floor is installed consists of the same general materials as the factory-applied finishes.

The manufacturing process for homogeneous PVC flooring in India uses similar technology as in Europe and so has been modeled based on data from the European Resilient Flooring Association (thinkstep, 2016). For installation, 0.3 kg/m^2 of flooring adhesive has been modeled. No energy consumption has been considered as installation is predominantly manual.

Underlay/fixing for laminate flooring

Various underlay materials are available in the market for laminate flooring. The modeled product consists of a 3 mm layer of polyethylene foam with a density of 22 kg/m^3 (Bestlaminate Products, 2012). Polymer underlay used in India is mostly imported from China (Ministry of Commerce & Industry, 2016). The model represents an import of underlay from China including the average ocean freight distance and road transport.

Flooring adhesive for vinyl/carpet/linoleum

Flooring adhesive is modelled based on a synthetic resin made from polyvinyl acetate.

The composition of tile adhesive is water (50%), vinyl acetate (40%), polyvinyl alcohol granulate (3%), maleic anhydride (2.5%), calcium carbonate (2%), n-butyl acrylate (2%), ethyl acetate (0.5%) and polybutylene terephthalate (0.5%). 0.41 kWh electricity is also required. (NIC, 2016).

The geographical area of production is India with raw materials and energy datasets adapted to reflect Indian conditions.

Tile adhesive for ceramic/concrete tiles

Tile adhesive is a cement based polymer for fixing ceramic and stone tiles to floors and walls in both interior and exterior settings. The materials required to produce tile adhesive are cement, silica sand, calcium carbonate and polymer powder. The different classes of tile adhesive can be prepared by varying the ratio of these materials.

The modelled product is for internal use and consists of 38% ordinary Portland cement, 48% silica sand, 7% limestone, 2.4% polymer powder (in the form of adhesive system polyurethane-prepolymer) and 4.7% water. (Felixberger, 2008).

The geographical area of production is India with raw materials and energy datasets adapted to reflect Indian conditions.

Adhesive for parquet

Adhesive for parquet is modelled based on epoxy resin. The raw materials and energy inputs required to produce 1 kg of epoxy resin, are bisphenol A (BPA) (0.675 kg), epichlorohydrin (0.56 kg), hydrochloric acid (0.004 kg), sodium hydroxide (0.252 kg), isopropanol (0.055 kg), light fuel oil (3.92 MJ), power (0.123 kWh) and water (4.65 liters). The geographical area of production is India with raw materials and energy datasets adapted to reflect Indian conditions.

G. Timber and wood-based products

The total production of timber in India was estimated to be 46.6 million m^3 in 2010. 20% of the logs required to produce timber products in India are imported with the main importing counties being Malaysia (57%) and Myanmar (18%) (Yadav & Basera, 2013). Indian timber has many industrial uses apart from structural applications in the construction industry. Timber used in India is dried or seasoned and treated to avoid development of defects like warping, cracking, splitting or decay and insect attack in products. The following drying processes are considered in making the models.

Air-dried sawn timber

In this model, the lumber is allowed to passively dry out and reduce moisture content, this is the simplest and least expensive method of seasoning wood. Drying times vary significantly depending upon wood species, initial moisture level, lumber thickness, density, ambient conditions, and processing techniques (e.g. stacking). Teak wood is used as the raw material with a final density of 655 kg/m^3 at a moisture content of 15%. Standard sawing techniques are used in the model with Indian energy datasets. Several co-products are generated at the saw mill including sawn wood, woodchips, saw dust, hog fuel and bark. Impacts are allocated based on price, although primary energy content and carbon sequestration are allocated based on mass. 0.103 kWh/kg electricity and 0.21 MJ/kg diesel are allocated to the sawn wood. These are modeled based on Indian grid mix and diesel supply (thinkstep, 2016).

Kiln-dried timber

In kiln drying, lumber is placed in a chamber where airflow, temperature, and humidity are controlled. This provides rapid drying without increasing defects in the lumber. Timber is kept in this chamber for 6 to 12 days, depending on its fiber properties, initial moisture content and final target characteristics. The overall energy consumption is higher than air dried timber but the time required for drying is significantly reduced.

The saw mill impacts are the same as for air dried sawn timber but kiln operation requires an additional 0.33 kWh/kg of timber at 15% moisture content (NIGOS, 2011). 5 MJ/kg of thermal energy is also required in the drying chamber which is generated using an equal share of coal, fuel oil and waste wood as fuel (Indian Standards, 2010).

Particleboard/chipboard

Particleboard (also sometimes known as chipboard) is an engineered wood product produced primarily from wood chips, shavings and saw dust, but may also contain bagasse, coconut shell waste, cotton stalk rice husk and other cellulosic co-products or wastes bound together with a suitable binder resin. The majority of Indian particleboard manufacturers use woodchips, shavings and sawdust collected from saw mills and other woodworking factories. For uncoated particleboard with an average density of 710 kg/m^3, the composition used in the model is wood chips (91%), urea formaldehyde (8%),urea (0.2%), slack wax (0.3%), melamine resin (0.04%), catalyst (0.1%) and ammonium sulfate (0.06%) (Composite Panel Association, 2014). The energy demand for production (Glunz, 2010) of the uncoated particleboard is assumed to be 642 MJ/m^3, modelled as thermal energy from heating oil.

Plywood

Plywood produced in India can be made from hardwood (such as teak or gurjan wood) as well as from softwood (such as pine, cedar or mango wood). Hardwood plywood is usually stronger and of better quality compared to that made from softwood. Plywood is made by bonding several layers of wood veneers (thin slices/layers of wood) to each other, with an alternating grain direction in each layer to increase the strength of the product. The veneer layers are obtained either by rotary-cutting or slicing timber logs. Rotary-cutting is more common and involves shearing layers off the logs while they are rotated. These veneers are then cut to desired sizes, graded based on their quality, dried using mechanical dryers, and then placed and pressed over one another under high pressure and temperature (Positive

Indians, 2016). The inputs used in the model are drawn from an LCA undertaken for the International Tropical Timber Organization, covering plywood produced with Meranti in Indonesia and Malaysia and shown in Table 13 below. The model has been adapted to take account of Indian inputs (including teak forestry) and energy. The density of plywood is modeled as being 600 kg/m^3.

Table 13: Raw material and energy inputs for plywood

Material Name (ITTO, 2014)	**Quantity**	**Unit**
Sand	0.0147	kg/kg
Log	1.69	m^3/m^3
Urea formaldehyde resin	134	kg/m^3
Hardener	17	kg/m^3
Water	8.28	m^3/m^3
Electricity	60.7	kWh/m^3
Diesel	4.86	MJ/m^3

Timber window frame

Production of timber window frames is based on the air dried sawn timber model described above. This timber undergoes further cutting and finishing to produce the final product. Following painting and the addition of an aluminum rain rail the composition of the finished product is wood (98%) and aluminum (2%). Raw materials and energy datasets are adapted to reflect Indian conditions.

Wood laminate/multi-layer parquet flooring

The model for multi-layer parquet including water-based primer and clear coat finish (thinkstep, 2016) has been adapted for Indian raw materials and energy. The floor consists of a number of layers of veneer, wood, particle board and ply glued and compressed together. Coating is also applied to protect the surface.

1 m^2 of multilayer parquet flooring requires 6.49 kg wood, 0.025 kg primer, 0.075 kg clear coat, 0.2 kg underlay (described in section F – Plastics and polymer-based products) and 1 kg adhesive (Wickes, 2016). Manufacturing requires 1.03 kWh/kg electricity and 10.7 MJ/kg thermal energy from biomass based on Indian datasets.

The reported results are per kg wood used, not per kg complete flooring system.

Wood block flooring

Wood flooring is more expensive than carpet, linoleum, rubber or vinyl flooring but is attractive and hard-wearing. Wood block flooring can be made from a wide range of woods. The model assumes that teak wood is used, which is sawn and kiln-dried before being processed into wood block flooring. Primer and clear coat varnish, PE foam underlay and adhesive are also included (thinkstep, 2016).

1 m^2 of installed wood flooring requires 14.4 kg wood, 0.025 kg primer, 0.075 kg clear coat, 0.2 kg underlay (described in section F – Plastics and polymer-based products) and 1 kg adhesive.

The reported results are per kg wood used, not per kg complete flooring system.

Bamboo flooring

Bamboo flooring is an alternative to wood block flooring. Bamboo flooring can be "natural" or "carbonized". The carbonizing process involves steaming under controlled pressure and heat. This imparts a much darker brown color to the light color of natural bamboo but also makes it much softer. Due to lack of available information on the carbonizing process the reported values are based on natural bamboo (thinkstep, 2016).

Production of bamboo flooring from cut and sawn bamboo is adapted from the model for wood block flooring. As for wood block flooring the model includes primer and clear coat varnish, PE foam underlay and adhesive.

1 m^2 of installed natural bamboo flooring requires 5.25 kg bamboo, 0.025 kg primer, 0.075 kg clear coat, 0.2 kg underlay (described in section F – Plastics and polymer-based products) and 1 kg adhesive. The area density of bamboo flooring is modeled as being 5.25 kg/m^2 (based on 15 mm thick bamboo planks).

The reported results are per kg bamboo used, not per kg complete flooring system.

Cork flooring tile

Cork flooring is produced of cork and binders. The cork is produced by stripping the bark from cork oak trees every nine years. Primarily this cork is used for wine cork stoppers. Co-products or off-cuts from the wine cork industry and bark cork from pruning are granulated to a range of different sizes to be used for cork flooring and cork insulation. For flooring production the cork granules are mixed with an adhesive. This mixture is cured using a mixture of temperature and pressure. Cork flooring can be bonded to fiberboard to produce a multilayered floor or as modelled here, have color and a UV varnish applied to it to improve wear resistance of the surface. As nearly all cork is grown in Europe, cork flooring production is modeled using existing European EPD data (ERFMI , 2013) with shipping of the finished product to India. Cork flooring is modeled including installation with adhesive in a similar way to linoleum and vinyl flooring.

1 m^2 of installed cork floor tiles (4 mm thick) requires 2 kg bamboo, 0.075 kg varnish and 0.3 kg adhesive. The area density of cork flooring tile is modeled as being 2 kg/m^2.

The reported results are per kg cork used, not per kg complete flooring system.

Linoleum flooring tile

Linoleum flooring is produced from linseed oil, pine rosin, ground cork dust, wood flour with mineral fillers such as calcium carbonate, most commonly on a burlap or canvas backing. As linoleum is currently only produced in Europe, the US and China, we have modeled European linoleum flooring production using existing EPD data (ERFMI, 2013) with shipping of the finished product to India. The product mass is 2.9 kg/m^2 and is modeled including installation with adhesive in a similar way to cork and vinyl flooring.

H. Insulation materials

Mineral wool insulation (glass wool, stone wool)

Mineral wool insulation is extensively used for thermal insulation and energy conservation in various applications. The major production impacts of these products are associated with the energy required to melt and extrude the mineral wools. Both glass and stone wool are modeled based on European production processes powered by Indian energy sources.

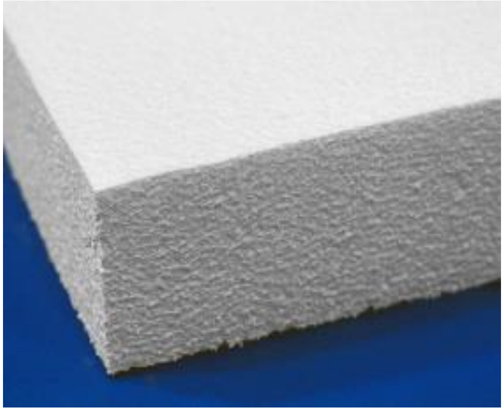
Glass wool

Glass wool is a widely used form of fiber glass with applications as a thermal and acoustic insulator (APTICO). The European process of manufacturing glass wool includes melting of mineral primary glass in a melting vat at approximately 1400°C. The energy required for this process is supplied by mix of electricity and natural gas. The liquid molten glass is then centrifuged by a rotating drum through a punched secondary container with fibers removed in a hot air-flow. Evaporation of the water causes the fibers to cool down and solidify. The solid fibers are fed through a tunnel oven using belt conveyors. At approx. 200°C, the binding agent hardens. The insulation is then cut to size and packed (thinkstep, 2016). Similar production technology is found in India, hence only energy inputs are changed to represent Indian scenario. As most manufacturers in India have small scale production plants, the Indian grid mix is used to represent electricity input. The density of the glass wool as modeled is 16 kg/m^3.

Stone wool

Stone wool is used for thermal and acoustic insulation. Stone wool has extremely low thermal conductivity and can be used across a wide temperature range (from -50°C to 750°C) (SIPLA Solutions , n.d.). Stone wool is manufactured from abundant pumiced sedimentary diabase rocks. The rocks are graded and crushed to suitable size, then mixed with the required percentage of blast furnace slag and fluidities/fluxes, and further melted in a furnace at a temperature of around 1450°C. Once the desired viscosity is reached, the melt is directed into a fiberizing unit where it is spun into a fine diameter wool. The wool is coated with thermosetting binder and collected in a negative pressurized chamber in the form of mattes of desired density and thickness. These are further compressed into various shapes & sizes (thinkstep, 2016). The European and Indian process use similar technology in the production of stone wool. Thus, the European model is adapted and inputs of thermal energy from natural gas and electricity from the Indian grid mix are used to represent the Indian scenario. The density of stone wool as modeled is 25 kg/m^3.

Expanded polystyrene insulation (EPS)



Expanded polystyrene is a rigid cellular plastic. It is a lightweight insulator that is durable and easy to process. EPS insulation foam is used in closed cavity walls, roofs, floor insulation and more. In India, packaging is currently the main application for EPS and forms a major part of domestic demand, with growth expected to come from block applications in cold storages and the construction industry. Ready mix concrete companies are also becoming interested in lightweight concrete where coated EPS beads are mixed with cement and water. Limitations on the availability of high quality sand may also drive this application in future. Small sized EPS beads can also be used in the manufacture of light weight insulating bricks and blocks. With India's focus on infrastructure development, EPS blocks could potentially also be used as geofoam material in the construction of roads and bridges.

In India, the raw material (styrene monomer) is mainly imported, with the majority of imports from Singapore. Pentane (4-6% w/w) is usually used as the blowing agent. India-specific datasets for energy and fuel are used to represent Indian production. To make 1 kg of EPS requires 0.115 kWh electricity, 0.77 MJ thermal energy from fuel oil and 1.23 MJ from natural gas (SPL, 2014). The density of EPS modelled is 20 kg/m^3.

Cellulose insulation

Cellulose insulation is currently rarely used in India and thus there are no data on imports or production of the material within India (Khan, 2009). However, because cellulosic insulation has the potential to be a greener alternative to other insulating materials, a prospective production scenario for India has been modeled. This assumes the use of European production technology with Indian fuels and electricity. The cellulose is sourced from 100% waste paper, which is assumed to have no value when it is disposed of by the consumer. The material content for the insulation is based on a materials safety data sheet (CIUR, 2016). Power consumption (0.00816 kWh/kg) for installation blowing is based on the technical specifications for a cellulosic material blowing machine (X-FLOC, 2015). The density of cellulose insulation as modeled is 50 kg/m^3.

Cork insulation

Cork insulation produced in India is produced from co-products or off-cuts of the European cork industry, with the majority (75%) imported from Spain (Ministry of Commerce and Industry, India, 2016). The model represents the production of 1 kg of cork insulation with a density 80 kg/m^3. The production process is modelled based on technology representative of production in Europe with raw materials and energy datasets adapted to reflect Indian conditions.

Woodwool board insulation

Woodwool insulation boards are made from long wood fibers of selected species, stabilized by chemical impregnation, mineralized and simultaneously compressed and heated. Woodwool insulation boards are used for partitioning and as false ceilings to provide acoustic and thermal insulation. The density of the modeled woodwool board is 11.52 kg/m^2.

The materials used for producing the woodwool board are wood (29%), magnesium oxide (36%), magnesium sulfate (6%), water (26%), sodium silicate (1.5%) and dye (1.5%) (Mineral Products Association, 2016). The electricity input is 0.403 kWh/kg and is modeled based on the Indian grid mix.

I. Soil, mud and earth-based products

OPC, PFA and Portland slag cement Stabilized Soil Blocks

Stabilized soil blocks (also referred to as compressed stabilized earth blocks (Auroville Earth Institute, 2016)) are produced using a variety of stabilizing materials. Three common options are modeled for India: the ordinary Portland cement (OPC) stabilized soil block, the pulverized fly ash (PFA) stabilized soil block and the Portland slag cement stabilized soil block. For all three block types, soil is extracted and sieved, separating soil from rocks and clay. The soil is then mixed with the stabilizing additive (cement or PFA) and water and compressed into blocks (Practical Action, 2007). As modeled, these steps of soil extraction, separation and block formation are completed using a mechanized process fueled by 1.26 kg/m^3 diesel. OPC, PFA and Portland slag cement stabilized blocks have a composition of 10% OPC or PFA and 90% soil by mass.

In the case of the OPC stabilized block, the blocks are removed from the press and set aside to cure for 4 to 5 days indoors, in natural air (without heating or cooling) (Practical Action, 2007). Over this period, water equal to 10% of the weight of the brick is added, which subsequently evaporates (Practical Action, 2007). The PFA stabilized soil block is also cured in natural air but without the addition of any water. The 10% Portland slag cement is assumed to require the same energy and water for curing as the OPC stabilized block. The density of all stabilized soil blocks is 2000 kg/m^3.

Rammed earth

Rammed earth is a construction technique where soil is taken from the ground and compacted to form structures. With low embodied energy for the material and minimal transportation costs, rammed earth offers a potentially low-cost and sustainable alternative to concrete.

There is significant variation in data on rammed earth production, so a conservative approach has been taken which assumes that raw materials for rammed earth (sand and clay) are extracted using diesel-powered machinery (rather than by hand) and are transported 10 km by truck. For the production of 1 kg of rammed earth, the input raw materials modelled are sand (0.677 kg), clay (0.375 kg), water (0.04 kg) and rice straw (0.078 kg) with electrical energy for compression provided by a diesel generator (0.336 MJ). The proportion of rice straw may be varied to yield a final product with a higher or lower compressive strength. (Mihir vora, 2009) (Standards, 2010). The density of rammed earth construction is 1900 kg/m^3.

J. Other natural products

Jute flooring

While India is a large producer of jute products, Bangladesh is by far the dominant producer of raw jute fiber worldwide. According to India's Department of Commerce statistics, India imported 32,444 metric tons of raw jute fiber, all from Bangladesh in the 2014-2015 fiscal year, meaning that India imported roughly 10% of global production of raw jute fiber in that year from Bangladesh (India Department of Commerce, 2016). Given the production and trade statistics, jute yarn is modeled to represent cultivation of raw jute fiber in Bangladesh followed by fiber processing in India (FAO, 2011).

Jute is modeled as being cultivated and dried in the field in Bangladesh before being processed in India where it is retted, dried, and willowed. The model assumes that water retting, rather than steam or chemical retting, has been used as this is the most widely used method of extracting the fiber from the stem or bast (Muthu, 2014). Water retting is conducted by soaking in water with microbial action. The fiber is then spun and woven into a finished product for floor covering applications. Electricity (0.78 kWh/kg) and thermal energy from natural gas (5.6 MJ/kg) are required for the spinning and weaving processes, based on the GaBi model for Jute Hessian net (thinkstep, 2016). The area density of jute flooring is modeled as being 1.9 kg/m^2.

Straw bale

Straw produced in India is primarily paddy straw (rice straw). In some cases, rice straw in India is used as a co-product, e.g. in paper-making or as an alternative fuel (Sood, 2013). Rice straw does not decay easily (Bhattarai, Dhakal, Neupane, & Chamberlin, 2012) and disposal by open burning can be problematic in certain regions due to the health impacts and smog resulting from uncontrolled emissions (Gadde, Bonnet, Menke, & Garivait, 2009). Use of rice straw in construction helps to reduce the negative health and environmental effects of field burning.

The rice model includes agricultural direct emissions, direct emissions from farming equipment as well as indirect emissions associated with production of fertilizer, fuel and other inputs, and baling of the straw by machine. The agricultural LCI model produces two outputs: rice grains and straw, with 50% of the output by mass as straw. The impacts from rice production associated with the straw are determined by economic allocation. The climatic conditions and allocation are representative of China rather than India, as a comprehensive model was not available for production in India. The model is the GaBi dataset for rice straw (thinkstep, 2016). The moisture content of the straw is 15%, which is appropriate for construction purposes (Bhattarai, Dhakal, Neupane, & Chamberlin, 2012).

VI. APPLICABLE STANDARDS

CEN/TR 15941	Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data; CEN/TR 15941:2010
CPR	Regulation (EU) No 305/2011 of the European parliament and of the council of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC
EN 15804	DIN EN 15804:2012+A1: Sustainability of construction works - Environmental Product Declarations - Core rules for the product category of construction products
EN ISO 14025	EN ISO 14025:2011: Environmental labels and declarations - Type III environmental declarations - Principles and procedures
EN ISO 14040	EN ISO 14040:2009: Environmental management - Life cycle assessment - Principles and framework
EN ISO 14044	EN ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines
GaBi 6	GaBi 6 dataset documentation for the software-system and databases, LBP, University of Stuttgart and thinkstep AG, Leinfelden-Echterdingen, 2016 (http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/)

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ANNEX A: EMBODIED ENERGY AND GLOBAL WARMING POTENTIAL RESULTS

Table 14: below presents the embodied energy and global warming potential results for the materials included in the India Construction Materials Database. Embodied energy results represent the total primary energy demand from renewable and non-renewable resources based on the net calorific value (lower heating value) and excluding any renewable feedstock energy. Global warming potential is calculated using the IPCC AR5 characterization factors over a 100-year time horizon and including biogenic carbon emissions - IPCC AR5 GWP100, including biogenic carbon (IPCC, 2014).

Table 14: Embodied energy and global warming potential results for India Construction Materials Database

Material Name	Embodied Energy (MJ)	GWP (kg CO_2 eq.)
Adhesive for parquet	130	6.7
Aggregate (mixed gravel/crushed stone)	0.11	0.0090
Aircrete (autoclaved aerated concrete)	3.7	0.50
Air-dried sawn timber	4.1	-1.3
Aluminum extruded profile	330	33
Aluminum extruded profile (window frame)	280	26
Aluminum ingot	310	31
Aluminum profiled cladding	360	35
Aluminum sheet	330	32
Aluminum thin composite cladding	220	18
Asphalt shingles	11	0.24
Bamboo flooring	110	2.3
BF slag	0.64	0.066
BOF Steel	24	2.8
Brick - Bulls trench kiln	3.6	0.32
Brick - Clamp kiln	6.3	0.57
Brick - High draught/zigzag kiln	6.5	0.59
Brick - Hoffman kiln	3.5	0.31
Brick (common/facing)	4.4	0.39
Calcined gypsum (gypsum hemihydrate, plaster of Paris)	1.7	0.13
Carpet (nylon)	130	7.0
Carpet tile (nylon)	47	2.3
Cellulose insulation	3.6	-1.1
Cement (ordinary Portland cement, OPC)	6.4	0.91
Cement based plaster	4.8	0.44
Cement floor screed (concrete screed)	1.3	0.18
Cement mortar	1.1	0.14

Material Name	Embodied Energy (MJ)	GWP (kg CO_2 eq.)
Cement/lime render for external wall finishes	1.5	0.27
Cement-based terrazzo (in-situ)	1.8	0.30
Cement-based terrazzo tile	4.6	0.51
Clay roof tile	7.5	0.69
Copper sheet	90	7.4
Cork flooring tile	62	0.41
Cork insulation	8.3	-1.4
Dense concrete block	1.3	0.16
DRI Steel	38	2.1
EAF Steel	9.9	0.83
Electrogalvanized steel sheet ("corrugated zinc")	35	3.0
Expanded polystyrene insulation (EPS)	85	2.9
FaLG (fly ash/lime/gypsum) block	0.83	0.20
Ferrocement roof panel	2.3	0.29
Ferrocement wall panel	2.3	0.29
Fiber cement board	4.3	0.41
Float glass	17	1.2
Flooring adhesive for vinyl/carpet/linoleum	38	1.9
Galvanized steel stud	37	3.1
Glass reinforced concrete	1.3	0.16
Glass wool	37	2.5
Glazed ceramic floor tiles	7.8	0.67
Gypsum	0.044	0.0037
Gypsum panel	3.3	0.26
Gypsum plaster	1.3	0.099
Honeycomb brick	3.5	0.31
Jute flooring	29	0.91
Kiln-dried timber	15	-0.43
Lightweight concrete block	3.6	0.37
Lime (hydrated lime needed for aircrete, FaLG blocks)	4.5	1.3
Lime mortar	1.6	0.43
Linoleum flooring tile	49	1.1
Medium density concrete block	2.7	0.29
Microconcrete roof tile	13	1.3
Mud plaster	0.46	-0.029
OPC stabilized soil block	0.70	0.096
Particle board/chipboard	12	-1.3
PFA	0.64	0.064
PFA (pulverized fuel ash)/fly ash cement (also known as pozzolana)	4.6	0.64
PFA stabilized soil block	0.11	0.010

Material Name	Embodied Energy (MJ)	GWP (kg CO_2 eq.)
Phosphogypsum	1.1	0.056
Phosphogypsum panel	3.7	0.25
Plasterboard	6.8	0.43
Plywood	18	-0.31
Polished stone cladding	3.7	0.31
Polymeric render for external walls	12	0.85
Polyurethane rigid insulation foam (HCFC blown)	120	12
Polyurethane rigid insulation foam (pentane blown)	120	8.1
Portland slag cement	4.9	0.69
Portland slag cement stabilized soil blocks	0.55	0.073
Precast concrete panels/flooring	2.6	0.27
Rammed earth	2.0	-0.0084
Ready mix concrete with fly-ash (30% pozzolana)	0.67	0.084
Ready mix concrete with ordinary Portland cement (OPC)	0.87	0.11
Ready mix concrete with Portland slag cement (25% GGBS)	0.70	0.089
Rubber flooring	67	3.6
Sand	0.11	0.0090
Shotcrete	2.7	0.24
Steel reinforcement (steel rebar)	30	2.6
Steel section	30	2.5
Steel window frame	51	3.5
Stone floor tile	0.44	0.056
Stone wool	15	1.4
Straw bale	0.63	-1.4
Tile adhesive for ceramic/concrete tiles	5.0	0.47
Timber window frame	63	2.4
Underlay/fixing for laminate flooring	98	3.1
u-PVC window frame	61	3.9
Vinyl (PVC) flooring	55	2.1
Vitrified ceramic floor tiles	8.2	0.68
Wood block flooring	64	1.5
Wood laminate/multi-layer parquet flooring	77	2.0
Woodwool board insulation	12	0.70

ANNEX B: DETAILED EMBODIED ENERGY RESULTS

Table 15: below presents a more detailed breakdown of the embodied energy results for the materials included in the India Construction Materials Database. The embodied energy results presented in the table below do not include renewable feedstock energy. These results have been derived by categorizing the various material/energy inputs and outputs required to produce each of the materials into one of nine categories.

Natural materials, chemicals, minerals, cement, metals and plastics represent the upstream raw materials and intermediate products used in producing the final product. Electricity, fuels and water & waste represent the energy and water consumed and waste generated on-site in producing the final product. Electricity, fuel and water & waste associated with the production of raw materials and intermediate products is grouped with the materials in question. For example, for cement production, electricity and fuels have the highest primary energy demand. However, for concrete production, all impacts from cement are categorized under "cement", allowing the user to see how cement, aggregates (minerals), chemical additives and the electricity/fuels consumed at the concrete production site contribute to the overall embodied energy.

Table 15: Detailed embodied energy results, MJ/kg

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Adhesive for parquet	130	0	130	0	0	0	0	1.2	5.5	1.0
Aggregate (mixed gravel/crushed stone)	0.11	0	0.00040	0	0	0	0	0.062	0.040	0.010
Aircrete (autoclaved aerated concrete)	3.7	0	0	1.3	1.2	0	0	0.35	0.78	0.0042
Air-dried sawn timber	4.1	1.1	0.0044	0	0	0	0	2.6	0.39	0
Aluminum extruded profile	330	0	6.8	19	0	2.3	0	270	33	2.4
Aluminum extruded profile (window frame)	280	0	0.67	0	0	240	21	14	2.5	0.21
Aluminum ingot	310	0	6.3	19	0	0.099	0	250	30	2.1
Aluminum profiled cladding	360	0	7.6	20	0	4.7	0	290	36	2.6
Aluminum sheet	330	0	6.6	19	0	3.1	0	260	33	2.2
Aluminum thin composite cladding	220	0	0	0	0	170	43	4.0	0	0.23
Asphalt shingles	11	0	9.4	0.85	0	0	0	1.2	0	0.0093

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Bamboo flooring	110	80	27	0	0	0	3.7	0.90	1.5	0.52
BF Slag	0.64	0	0.018	0.042	0	0	0	0.000067	0.58	0.0042
BOF Steel	24	0	1.1	1.5	0	0.59	0	0.21	21	0.31
Brick - Bulls trench kiln	3.6	0	0	0.42	0	0	0	0	3.1	0.065
Brick - Clamp kiln	6.3	0	0	0.42	0	0	0	0	5.8	0.065
Brick - High draught/zigzag kiln	6.5	0	0	0.42	0	0	0	0	6.1	0.065
Brick - Hoffman kiln	3.5	0	0	0.42	0	0	0	0	3.0	0.065
Brick (common/facing)	4.4	0	0	0.42	0	0	0	0	3.9	0.065
Calcined gypsum (gypsum hemihydrate, plaster of Paris)	1.7	0	0.0045	0	0	0	0	0.44	1.3	0.000045
Carpet (nylon)	130	0	8.2	0.23	0	0	120	2.7	3.9	0.068
Carpet tile (nylon)	47	0	9.9	0.6	0	0	34	2.0	0.82	0.066
Cellulose insulation	3.6	0.3	0.33	0.74	0	0	0	2.0	0.084	0.18
Cement (ordinary Portland cement, OPC)	6.4	0	0.011	0.041	0	0	0	1.4	5.0	0.0012
Cement based plaster	4.8	0	0	0.15	0.92	0	0	0	3.7	0.011
Cement floor screed (concrete screed)	1.3	0	0.0020	0.090	0	0	0	0.25	0.93	0.00022
Cement mortar	1.1	0	0	0.16	0.91	0	0	0	0.0075	0.019
Cement/lime render for external wall finishes	1.5	0	0	0.68	0.76	0	0	0	0	0.023
Cement-based terrazzo (in-situ)	1.8	0	0.068	0.59	1.1	0	0	0.010	0.0079	0.030
Cement-based terrazzo tile	4.6	0	0.60	0.32	2.5	0	0	1.2	0	0.043
Clay roof tile	7.5	0	0	0.42	0	0	0	2.6	4.4	0.12
Copper sheet	90	0	2.0	42	0	0	0	20	25	0.45
Cork flooring tile	62	54	8.1	0	0	0	0	0	0	0
Cork insulation	8.3	6.2	0	0	0	0	0	0	2.1	0
Dense concrete block	1.3	0	0.00012	0.16	0.98	0	0	0.064	0.072	0
DRI Steel	38	0	0.073	1.0	0	1.6	0	2.8	32	0.27
EAF Steel	9.9	0	0.22	0.092	0	0.50	0	7.6	1.4	0.058
Electrogalvanized steel sheet ("corrugated zinc")	35	0	0.55	1.0	0	1.2	0	11	22	0.28

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Expanded polystyrene insulation (EPS)	85	0	69	0	0	0	0	4.8	10	0.66
FaLG (fly ash/lime/gypsum) block	0.83	0	0	0.82	0	0	0	0	0.0075	0.00057
Ferrocement roof panel	2.3	0	0	0.059	1.7	0.56	0	0	0	0.020
Ferrocement wall panel	2.3	0	0	0.059	1.7	0.56	0	0	0	0.020
Fiber cement board	4.3	0.71	0.19	0.40	2.4	0	0	0.56	0.024	0.0089
Float glass	17	0	0	3.4	0	0	0	6.4	6.7	0.024
Flooring adhesive for vinyl/carpet/linoleum	38	0	28	0.014	0	0	3.6	6.5	0	0.051
Galvanized steel stud	37	0	0.56	1.0	0	1.2	0	12	22	0.28
Glass reinforced concrete	1.3	0	0.14	0.13	1.0	0	0	0	0	0
Glass wool	37	0	2.2	3.6	0	0	0	16	15	0.014
Glazed ceramic floor tiles	7.8	0	0.82	0.16	0.83	0	0	1.1	4.9	0.0017
Gypsum	0.044	0	0.0038	0	0	0	0	0.025	0.015	0
Gypsum panel	3.3	0.021	0.25	0.13	0.010	0	0	0.36	2.5	0.042
Gypsum plaster	1.3	0	0.0032	0	0	0	0	0.32	0.92	0.046
Honeycomb brick	3.5	0	0	0.42	0	0	0	0	3.0	0.065
Jute flooring	29	0.049	9.2	0	0	0	0	13	7.6	0
Kiln-dried timber	15	1.2	0.0051	0	0	0	0	8.3	5.9	0
Lightweight concrete block	3.6	0	0.093	1.5	1.8	0	0	0.20	0.052	0
Lime (hydrated lime needed for aircrete, FaLG blocks)	4.5	0	0.0061	0.017	0	0	0	1.7	2.8	0.000016
Lime mortar	1.6	0	0	1.6	0	0	0	0	0.0075	0.019
Linoleum flooring tile	49	43	5.7	0	0	0	0	0	0	0
Medium density concrete block	2.7	0	0.093	1.0	1.4	0	0	0.17	0.060	0
Microconcrete roof tile	13	0	0	0.17	1.7	0	0	11	0	0.069
Mud plaster	0.46	0.023	0	0.12	0	0	0	0	0.32	0
OPC stabilized soil block	0.70	0	0	0	0.64	0	0	0	0.048	0.012
Particle board/chipboard	12	0.19	11	0.0075	0	0	0	0.14	1.1	0
PFA	0.64	0	0	0	0	0	0	0	0.64	0

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
PFA (pulverized fuel ash)/fly ash cement (also known as pozzolana)	4.6	0	0.0072	0.050	0	0	0	0.92	3.6	0.00030
PFA stabilized soil block	0.11	0	0	0.064	0	0	0	0	0.048	0
Phosphogypsum	1.1	0	0.72	0.15	0	0	0	0.034	0.22	0.019
Phosphogypsum panel	3.7	0.021	0.72	0.23	0.010	0	0	0.27	2.4	0.090
Plasterboard	6.8	1.40	1.3	0	0.066	0.044	0	0.50	3.5	0.015
Plywood	18	0.94	15	0	0	0	0	1.6	0.0097	0.0020
Polished stone cladding	3.7	0	0	0	0	0	0	3.1	0.53	0.036
Polymeric render for external walls	12	0	6	0.14	1.4	0	0	0	4.2	0.025
Polyurethane rigid insulation foam (HCFC blown)	120	0	73	0	0	0	44	6.4	0	0.013
Polyurethane rigid insulation foam (pentane blown)	120	0	69	0	0	0	44	6.4	0	0.013
Portland slag cement	4.9	0	0.0076	0.049	0	0.16	0	0.98	3.7	0.00033
Portland slag cement stabilized soil blocks	0.55	0	0	0	0.49	0	0	0	0.048	0.012
Precast concrete panels/flooring	2.6	0	0.00011	0.15	0.93	1.4	0	0.022	0.069	0
Rammed earth	2.0	0.81	0.00027	0.032	0	0	0	0.042	1.1	0.052
Ready mix concrete with fly-ash (30% pozzolana)	0.67	0	0.00036	0.11	0.51	0	0	0.010	0.034	0.0079
Ready mix concrete with ordinary Portland cement (OPC)	0.87	0	0.00036	0.11	0.71	0	0	0.010	0.034	0.0079
Ready mix concrete with Portland slag cement (25% GGBS)	0.70	0	0.00036	0.11	0.54	0	0	0.010	0.034	0.0079
Rubber flooring	67	0	11	14	0	0	30	9.9	1.9	0.16
Sand	0.11	0	0.00040	0	0	0	0	0.062	0.040	0.010
Shotcrete	2.7	0	0.15	0.087	1.1	0.47	0.90	0.0066	0	0.012
Steel reinforcement (steel rebar)	30	0	0.58	1.1	0	0.95	0	5.3	22	0.41
Steel section	30	0	0.55	1.0	0	0.90	0	5.8	21	0.24
Steel window frame	51	0	0	0	0	35	16	0	0	0
Stone floor tile	0.44	0	0.0035	0.030	0.35	0	0	0.020	0.037	0
Stone wool	15	0	2.0	0.90	0	0	0	5.1	6.9	0.13
Straw bale	0.63	0.45	0	0	0	0	0	0.18	0	0

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Tile adhesive for ceramic/concrete tiles	5.0	0	2.4	0.13	2.4	0	0	0.013	0	0.0049
Timber window frame	63	15	4.2	0	0	7.4	0	26	9.3	0.0090
Underlay/fixing for laminate flooring	98	0	0	0	0	0	98	0	0	0
u-PVC window frame	61	0	6.5	3.5	0	19	27	4.8	0	0.0054
Vinyl (PVC) flooring	55	0	3.6	0	0	0	52	0	0	0
Vitrified ceramic floor tiles	8.2	0	0.60	0.10	0.61	0	0	2.3	4.6	0.0012
Wood block flooring	64	22	9.7	0	0	0	1.4	18	13	0.52
Wood laminate/multi-layer parquet flooring	77	20	25	0.000080	0	0.11	3.0	22	6.0	0.47
Woodwool board insulation	12	1.4	0.6	3.3	0	0	0	6.5	0	0.19

ANNEX C: DETAILED GLOBAL WARMING POTENTIAL RESULTS

Table 16: below presents a more detailed breakdown of the global warming potential results for the materials included in the India Construction Materials Database. Global warming potential is calculated using the IPCC AR5 characterization factors over a 100 year time horizon and including biogenic carbon emissions - IPCC AR5 GWP100, including biogenic carbon (IPCC, 2014). These results have been derived by categorizing the various material/energy inputs and outputs required to produce each of the materials into one of nine categories.

Natural materials, chemicals, minerals, cement, metals and plastics represent the upstream raw materials and intermediate products used in producing the final product. Electricity, fuels and water & waste represent the energy and water consumed and waste generated on-site in producing the final product. Impacts from electricity, fuel and water & waste used in the production of raw materials and intermediate products is grouped with the materials in question. For example, for steel production via the BOF, DRI or EAF routes, the largest contributions to GWP are from electricity and fuels. However, for the production of the steel window frame, steel and plastics are upstream products and so GWP is split between the steel and plastic components.

Table 16: Detailed Global Warming Potential Results, kg CO2e/kg

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Adhesive for parquet	6.7	0	5.9	0	0	0	0	0.10	0.41	0.33
Aggregate (mixed gravel/crushed stone)	0.0090	0	0.000012	0	0	0	0	0.0054	0.0029	0.00074
Aircrete (autoclaved aerated concrete)	0.50	0	0	0.24	0.17	0	0	0.031	0.058	0.0028
Air-dried sawn timber	-1.3	-1.5	0.00014	0	0	0	0	0.23	0.028	0
Aluminum extruded profile	33	0	0.56	0.78	0	2.0	0	26	3.0	0.19
Aluminum extruded profile (window frame)	26	0	0.038	0	0	24	0.86	1.2	0.15	0.024
Aluminum ingot	31	0	0.53	0.78	0	1.9	0	25	2.8	0.16
Aluminum profiled cladding	35	0	0.61	0.82	0	2.3	0	28	3.2	0.20
Aluminum sheet	32	0	0.54	0.78	0	2.1	0	26	3.0	0.17
Aluminum thin composite cladding	18	0	0	0	0	17	1.3	0.35	0	0.027

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Asphalt shingles	0.24	0	0.087	0.057	0	0	0	0.10	0	0.00067
Bamboo flooring	2.3	-1.3	1.3	0	0	0	0.12	0.078	0.019	2.1
BF Slag	0.066	0	0.0015	0.0040	0	0	0	0	0.0380	0.022
BOF Steel	2.8	0	0.093	0.15	0	0.052	0	0.018	1.7	0.78
Brick - Bulls trench kiln	0.32	0	0	0.031	0	0	0	0	0.29	0.0044
Brick - Clamp kiln	0.57	0	0	0.031	0	0	0	0	0.53	0.0044
Brick - High draught/zigzag kiln	0.59	0	0	0.031	0	0	0	0	0.55	0.0044
Brick - Hoffman kiln	0.31	0	0	0.031	0	0	0	0	0.28	0.0044
Brick (common/facing)	0.39	0	0	0.031	0	0	0	0	0.36	0.0044
Calcined gypsum (gypsum hemihydrate, plaster of Paris)	0.13	0	0.00042	0	0	0	0	0.039	0.094	0.000028
Carpet (nylon)	7.0	0	0.34	0.018	0	0	6.1	0.24	0.30	0.010
Carpet tile (nylon)	2.3	0	0.17	0.042	0	0	1.7	0.17	0.063	0.090
Cellulose insulation	-1.1	-1.5	0.021	0.042	0	0	0	0.17	0.0050	0.16
Cement (ordinary Portland cement, OPC)	0.91	0	0.00097	0.0030	0.74	0	0	0.12	0.050	0.0013
Cement based plaster	0.44	0	0	0.011	0.13	0	0	0	0.29	0.00091
Cement floor screed (concrete screed)	0.18	0	0.00018	0.0072	0.14	0	0	0.022	0.0097	0.00024
Cement mortar	0.14	0	0	0.012	0.13	0	0	0	0.00055	0.0013
Cement/lime render for external wall finishes	0.27	0	0	0.16	0.11	0	0	0	0	0.0017
Cement-based terrazzo (in-situ)	0.30	0	0.0031	0.14	0.15	0	0	0.00089	0.00058	0.0021
Cement-based terrazzo tile	0.51	0	0.027	0.022	0.35	0	0	0.10	0	0.0033
Clay roof tile	0.69	0	0	0.031	0	0	0	0.22	0.42	0.0081
Copper sheet	7.4	0	0.17	3.5	0	0	0	1.8	1.9	0.030
Cork flooring tile	0.41	0.020	0.39	0	0	0	0	0	0	0
Cork insulation	-1.4	-1.6	0	0	0	0	0	0	0.21	0
Dense concrete block	0.16	0	0.0000036	0.014	0.14	0	0	0.0054	0.0013	0
DRI Steel	2.1	0	0.0051	0.11	0	0.17	0	0.25	1.6	0.021
EAF Steel	0.83	0	0.019	0.0043	0	0.047	0	0.66	0.092	0.0044

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Electrogalvanized steel sheet ("corrugated zinc")	3.0	0	0.048	0.10	0	0.10	0	0.93	1.5	0.36
Expanded polystyrene insulation (EPS)	2.9	0	1.6	0	0	0	0	0.38	0.69	0.14
FaLG (fly ash/lime/gypsum) block	0.20	0	0	0.20	0	0	0	0	0.00055	0.000089
Ferrocement roof panel	0.29	0	0	0.0047	0.24	0.047	0	0	0	0.0017
Ferrocement wall panel	0.29	0	0	0.0047	0.24	0.047	0	0	0	0.0017
Fiber cement board	0.41	-0.013	0.0087	0.026	0.34	0	0	0.049	0.0018	0.0018
Float glass	1.2	0	0	0.29	0	0	0	0.56	0.40	0.0016
Flooring adhesive for vinyl/carpet/linoleum	1.9	0	1.2	0.00080	0	0	0.14	0.57	0	0.0042
Galvanized steel stud	3.1	0	0.048	0.10	0	0.10	0	1.0	1.5	0.36
Glass reinforced concrete	0.16	0	0.0063	0.010	0.14	0	0	0	0	0
Glass wool	2.5	0	0.030	0.92	0	0	0	1.4	0.17	0.0095
Glazed ceramic floor tiles	0.67	0	0.036	0.012	0.12	0	0	0.099	0.41	0.00014
Gypsum	0.0037	0	0.00035	0	0	0	0	0.0022	0.0011	0
Gypsum panel	0.26	-0.00091	0.021	0.0088	0.0015	0	0	0.032	0.19	0.0035
Gypsum plaster	0.099	0	0.00030	0	0	0	0	0.028	0.068	0.0036
Honeycomb brick	0.31	0	0	0.031	0	0	0	0	0.28	0.0044
Jute flooring	0.91	-1.2	0.39	0	0	0	0	1.1	0.40	0.20
Kiln-dried timber	-0.43	-1.5	0.00016	0	0	0	0	0.72	0.36	0
Lightweight concrete block	0.37	0	0.0056	0.095	0.25	0	0	0.017	0.0010	0
Lime (hydrated lime needed for aircrete, FaLG blocks)	1.3	0	0.00074	1.1	0	0	0	0.15	0.022	0.000025
Lime mortar	0.43	0	0	0.43	0	0	0	0	0.00055	0.0013
Linoleum flooring tile	1.1	0.87	0.28	0	0	0	0	0	0	0
Medium density concrete block	0.29	0	0.0056	0.065	0.20	0	0	0.014	0.0010	0
Microconcrete roof tile	1.3	0	0	0.012	0.25	0	0	1.0	0	0.0048
Mud plaster	-0.029	-0.073	0	0.019	0	0	0	0	0.025	0
OPC stabilized soil block	0.096	0	0	0	0.091	0	0	0	0.0037	0.0010
Particle board/chipboard	-1.3	-1.5	0.15	0.00041	0	0	0	0.0045	0.081	0

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
PFA	0.064	0	0	0	0	0	0	0	0.064	0
PFA (pulverized fuel ash)/fly ash cement (also known as pozzolana)	0.64	0	0.00065	0.0036	0.51	0	0	0.081	0.050	0.000022
PFA stabilized soil block	0.010	0	0	0.0064	0	0	0	0	0.0037	0
Phosphogypsum	0.056	0	0.023	0.011	0	0	0	0.0029	0.017	0.0020
Phosphogypsum panel	0.25	-0.00091	0.036	0.016	0.0015	0	0	0.024	0.17	0.0076
Plasterboard	0.43	-0.014	0.067	0	0.0042	0.0034	0	0.044	0.32	0.0013
Plywood	-0.31	-1.2	0.76	0	0	0	0	0.14	0.00071	0.0036
Polished stone cladding	0.31	0	0	0	0	0	0	0.27	0.039	0.0024
Polymeric render for external walls	0.85	0	0.30	0.0095	0.20	0	0	0	0.33	0.0018
Polyurethane rigid insulation foam (HCFC blown)	12	0	4.2	0	0	0	7.5	0.56	0	0.044
Polyurethane rigid insulation foam (pentane blown)	8.1	0	3.8	0	0	0	3.7	0.56	0	0.044
Portland slag cement	0.69	0	0.00070	0.0024	0.55	0.017	0	0.086	0.034	0.000024
Portland slag cement stabilized soil blocks	0.073	0	0	0	0.069	0	0	0	0.0037	0.0010
Precast concrete panels/flooring	0.27	0	0.0000035	0.013	0.13	0.12	0	0.0017	0.0012	0
Rammed earth	-0.0084	-0.1	0.0000085	0.0023	0	0	0	0.0036	0.085	0.0036
Ready mix concrete with fly-ash (30% pozzolana)	0.084	0	0.000011	0.0094	0.072	0	0	0.00089	0.00087	0.00053
Ready mix concrete with ordinary Portland cement (OPC)	0.11	0	0.000011	0.0094	0.10	0	0	0.00089	0.00087	0.00053
Ready mix concrete with Portland slag cement (25% GGBS)	0.089	0	0.000011	0.0094	0.077	0	0	0.00089	0.00087	0.00053
Rubber flooring	3.6	0	0.47	0.68	0	0	1.2	0.86	0.11	0.29
Sand	0.009	0	0.000012	0	0	0	0	0.0054	0.0029	0.00074
Shotcrete	0.24	0	0.0076	0.0068	0.16	0.039	0.030	0.00037	0	0.00096
Steel reinforcement (steel rebar)	2.6	0	0.050	0.11	0	0.093	0	0.46	1.5	0.39
Steel section	2.5	0	0.047	0.10	0	0.088	0	0.50	1.4	0.35
Steel window frame	3.5	0	0	0	0	2.9	0.64	0	0	0
Stone floor tile	0.056	0	0.00042	0.0025	0.049	0	0	0.0017	0.0027	0
Stone wool	1.4	0	0.071	0.099	0	0	0	0.42	0.78	0.023

Material Name	Total	Natural materials	Chemicals	Minerals	Cement	Metals	Plastics	Electricity	Fuels	Water & Waste
Straw bale	-1.4	-1.5	0	0	0	0	0	0.016	0	0
Tile adhesive for ceramic/concrete tiles	0.47	0	0.11	0.0079	0.35	0	0	0.0012	0	0.00040
Timber window frame	2.4	-1.4	0.20	0	0	0.74	0	2.3	0.63	0.0052
Underlay/fixing for laminate flooring	3.1	0	0	0	0	0	3.1	0	0	0
u-PVC window frame	3.9	0	0.30	0.14	0	1.6	1.4	0.42	0	0.00075
Vinyl (PVC) flooring	2.1	0	0.18	0	0	0	2.0	0	0	0
Vitrified ceramic floor tiles	0.68	0	0.026	0.0067	0.087	0	0	0.20	0.36	0.00010
Wood block flooring	1.5	-3.5	0.48	0	0	0	0.043	1.6	0.78	2.1
Wood laminate/multi-layer parquet flooring	2.0	-3.2	1.2	0.0000044	0	0.0063	0.096	1.9	0.079	1.9
Woodwool board insulation	0.70	-0.42	0.030	0.50	0	0	0	0.56	0	0.019

ANNEX D: RESULTS FOR OTHER IMPACT CATEGORIES

Table 17 below presents the ozone depletion potential (ODP), acidification potential (AP), eutrophication potential (EP) and photochemical ozone creation potential (POCP, also known as smog creation potential) impact category results for the materials included in the India Construction Materials Database. These indicators are based on characterization factors provided in CML–IA version 4.1, as used in EN 15804. Also included in the table below are embodied energy results including renewable feedstock energy. Results from these impact categories are not intended for use as a component of public communication.

Table 17: Additional impact assessment results for India Construction Materials Database

Material Name	ODP (kg R11 eq.)	AP (kg SO_2 eq.)	EP (kg PO_4 eq.)	POCP (kg ethene eq.)	Embodied energy inc. ren. Feedstock (MJ)
Adhesive for parquet	2.2E-10	0.018	1.9E-03	2.3E-03	130
Aggregate (mixed gravel/crushed stone)	1.2E-13	0.000094	8.8E-06	6.9E-06	0.11
Aircrete (autoclaved aerated concrete)	5.5E-12	0.0018	1.7E-04	5.2E-05	3.7
Air-dried sawn timber	4.8E-12	0.0035	3.1E-04	1.6E-04	21
Aluminum extruded profile	8.9E-11	0.29	1.7E-02	1.4E-02	330
Aluminum extruded profile (window frame)	3.6E-08	0.22	1.4E-02	1.1E-02	280
Aluminum ingot	6.2E-11	0.27	1.7E-02	1.3E-02	310
Aluminum profiled cladding	1.1E-10	0.31	1.9E-02	1.5E-02	360
Aluminum sheet	8.1E-11	0.28	1.7E-02	1.4E-02	330
Aluminum thin composite cladding	7.8E-11	0.15	9.3E-03	7.6E-03	220
Asphalt shingles	3.8E-12	0.0022	1.2E-04	1.7E-04	11
Bamboo flooring	1.0E-10	0.033	2.3E-03	2.1E-03	130
BF slag	1.0E-13	0.034	1.4E-03	1.5E-03	0.64
BOF Steel	5.7E-12	0.0073	4.8E-04	4.3E-04	24
Brick - Bulls trench kiln	2.6E-13	0.0027	2.0E-04	9.6E-05	3.6
Brick - Clamp kiln	4.2E-13	0.0049	3.4E-04	2.1E-04	6.3
Brick - High draught/zigzag kiln	4.3E-13	0.0050	3.5E-04	2.2E-04	6.5
Brick - Hoffman kiln	2.6E-13	0.0026	1.9E-04	9.2E-05	3.5

Material Name	ODP (kg R11 eq.)	AP (kg SO_2 eq.)	EP (kg PO_4 eq.)	POCP (kg ethene eq.)	Embodied energy inc. ren. Feedstock (MJ)
Brick (common/facing)	3.1E-13	0.0033	2.4E-04	1.3E-04	4.4
Calcined gypsum (gypsum hemihydrate, plaster of Paris)	8.8E-13	0.00076	6.3E-05	5.1E-05	1.7
Carpet (nylon)	7.5E-10	0.023	2.4E-03	2.9E-03	130
Carpet tile (nylon)	2.1E-10	0.0079	7.5E-04	9.2E-04	47
Cellulose insulation	9.0E-12	0.0025	1.7E-04	1.2E-04	20
Cement (ordinary Portland cement, OPC)	2.8E-12	0.0027	3.4E-04	1.9E-04	6.4
Cement based plaster	6.8E-13	0.0030	5.1E-04	2.6E-04	4.8
Cement floor screed (concrete screed)	6.0E-13	0.00058	7.0E-05	4.0E-05	1.3
Cement mortar	5.2E-13	0.00051	6.4E-05	2.1E-05	1.1
Cement/lime render for external wall finishes	8.5E-13	0.00066	6.7E-05	2.9E-05	1.5
Cement-based terrazzo (in-situ)	1.0E-12	0.00078	7.9E-05	6.9E-05	1.8
Cement-based terrazzo tile	4.0E-12	0.0025	2.1E-04	3.1E-04	4.6
Clay roof tile	5.0E-12	0.0063	3.8E-04	2.7E-04	7.5
Copper sheet	9.3E-11	0.075	3.2E-03	3.8E-03	90
Cork flooring tile	7.8E-09	0.0095	1.4E-03	9.3E-04	81
Cork insulation	3.4E-11	0.0046	6.3E-04	-1.5E-04	30
Dense concrete block	6.5E-13	0.00062	7.6E-05	1.3E-05	1.3
DRI Steel	1.2E-11	0.0066	4.4E-04	3.8E-04	38
EAF Steel	1.5E-11	0.0087	4.0E-04	4.7E-04	9.9
Electrogalvanized steel sheet (“corrugated zinc”)	2.5E-11	0.017	9.2E-04	9.7E-04	35
Expanded polystyrene insulation (EPS)	5.0E-11	0.012	9.0E-04	1.2E-03	85
FaLG (fly ash/lime/gypsum) block	5.4E-13	0.00045	2.9E-05	2.5E-05	0.83
Ferrocement roof panel	1.1E-12	0.00099	1.1E-04	6.5E-05	2.3
Ferrocement wall panel	1.1E-12	0.00099	1.1E-04	6.5E-05	2.3
Fiber cement board	3.0E-12	0.0024	2.0E-04	1.9E-04	4.8
Float glass	1.4E-11	0.0092	6.8E-04	5.4E-04	17
Flooring adhesive for vinyl/carpet/linoleum	8.7E-11	0.014	7.7E-04	1.4E-03	38
Galvanized steel stud	2.7E-11	0.018	9.8E-04	1.0E-03	37

Material Name	ODP (kg R11 eq.)	AP (kg SO_2 eq.)	EP (kg PO_4 eq.)	POCP (kg ethene eq.)	Embodied energy inc. ren. Feedstock (MJ)
Glass reinforced concrete	1.5E-12	0.00054	6.3E-05	3.7E-05	1.3
Glass wool	3.7E-11	0.023	1.9E-03	1.1E-03	37
Glazed ceramic floor tiles	3.8E-12	0.0090	2.5E-04	4.3E-04	7.8
Gypsum	6.3E-14	0.000037	3.8E-06	2.6E-06	0.044
Gypsum panel	1.2E-12	0.0024	1.5E-04	1.3E-04	3.4
Gypsum plaster	7.0E-13	0.00058	4.7E-05	3.8E-05	1.3
Honeycomb brick	2.6E-13	0.0026	1.9E-04	9.2E-05	3.5
Jute flooring	3.7E-11	0.017	3.5E-04	8.9E-04	44
Kiln-dried timber	1.6E-11	0.012	8.0E-04	6.3E-04	32
Lightweight concrete block	3.1E-12	0.0016	1.5E-04	8.8E-05	3.6
Lime (hydrated lime needed for aircrete, FaLG blocks)	3.4E-12	0.0019	1.1E-04	1.1E-04	4.5
Lime mortar	1.2E-12	0.00074	5.1E-05	2.8E-05	1.6
Linoleum flooring tile	3.2E-09	0.014	4.0E-03	9.5E-04	61
Medium density concrete block	2.5E-12	0.0012	1.2E-04	6.1E-05	2.7
Microconcrete roof tile	2.2E-11	0.013	6.4E-04	6.0E-04	13
Mud plaster	1.9E-13	0.00032	6.3E-05	2.7E-05	1.1
OPC stabilized soil block	3.0E-13	0.00030	3.7E-05	2.2E-05	0.70
Particle board/chipboard	4.0E-12	0.0015	1.4E-04	1.1E-04	28
PFA	2.9E-14	0.00055	3.7E-05	2.7E-05	0.64
PFA (pulverized fuel ash)/fly ash cement (also known as pozzolana)	1.9E-12	0.0020	2.4E-04	1.3E-04	4.6
PFA stabilized soil block	5.2E-15	0.000070	6.4E-06	5.4E-06	0.11
Phosphogypsum	1.6E-12	0.0010	2.8E-05	4.5E-05	1.1
Phosphogypsum panel	2.0E-12	0.0028	1.5E-04	1.4E-04	3.8
Plasterboard	7.0E-12	0.0037	2.5E-04	2.0E-04	6.9
Plywood	2.2E-11	0.0044	8.0E-04	8.9E-04	31
Polished stone cladding	5.8E-12	0.0033	1.7E-04	1.4E-04	3.7
Polymeric render for external walls	1.1E-11	0.0043	6.8E-04	4.0E-04	12

Material Name	ODP (kg R11 eq.)	AP (kg SO_2 eq.)	EP (kg PO_4 eq.)	POCP (kg ethene eq.)	Embodied energy inc. ren. Feedstock (MJ)
Polyurethane rigid insulation foam (HCFC blown)	5.9E-04	0.052	3.3E-03	4.7E-03	120
Polyurethane rigid insulation foam (pentane blown)	1.1E-10	0.050	3.2E-03	5.8E-03	120
Portland slag cement	2.0E-12	0.011	5.9E-04	5.0E-04	4.9
Portland slag cement stabilized soil blocks	2.3E-13	0.0011	6.2E-05	5.3E-05	0.55
Precast concrete panels/flooring	1.3E-12	0.0011	1.0E-04	3.9E-05	2.6
Rammed earth	3.8E-13	0.00088	2.2E-04	7.1E-05	2.5
Ready mix concrete with fly-ash (30% pozzolana)	3.4E-13	0.00035	4.0E-05	1.5E-05	0.67
Ready mix concrete with ordinary Portland cement (OPC)	4.4E-13	0.00042	5.1E-05	2.1E-05	0.87
Ready mix concrete with Portland slag cement (25% GGBS)	3.6E-13	0.0013	7.9E-05	5.6E-05	0.70
Rubber flooring	1.8E-10	0.022	1.3E-03	1.6E-03	67
Sand	1.2E-13	0.000094	8.8E-06	6.9E-06	0.11
Shotcrete	2.5E-12	0.00086	8.7E-05	6.1E-05	2.7
Steel reinforcement (steel rebar)	1.5E-11	0.011	6.5E-04	6.1E-04	30
Steel section	1.5E-11	0.012	6.7E-04	6.3E-04	30
Steel window frame	2.7E-08	0.018	1.1E-03	1.1E-03	51
Stone floor tile	2.4E-13	0.00022	2.7E-05	1.6E-05	0.44
Stone wool	3.3E-11	0.016	1.2E-03	9.4E-04	15
Straw bale	1.5E-12	0.0006	3.6E-04	3.8E-05	14
Tile adhesive for ceramic/concrete tiles	3.5E-12	0.0013	1.7E-04	1.1E-04	5.0
Timber window frame	5.5E-11	0.041	2.6E-03	4.5E-03	79
Underlay/fixing for laminate flooring	6.1E-10	0.0078	8.7E-04	1.3E-03	98
u-PVC window frame	1.2E-10	0.027	1.6E-03	1.9E-03	61
Vinyl (PVC) flooring	2.3E-09	0.0060	6.5E-04	1.5E-03	55
Vitrified ceramic floor tiles	5.5E-12	0.0082	2.7E-04	3.9E-04	8.2
Wood block flooring	5.9E-11	0.027	1.9E-03	1.6E-03	81
Wood laminate/multi-layer parquet flooring	9.9E-11	0.029	2.0E-03	1.7E-03	92
Woodwool board insulation	1.7E-11	0.0084	5.1E-04	3.2E-04	17

ALUMINUM

Consultee	Hindalco Industries Limited Dr. Pradip Banerjee Chief Technology Officer
Are the aluminum products listed relevant to the Indian construction industry? Are there any additional major aluminum products that should be included?	Yes, they are
Geographical representativeness: Aluminum products are currently modelled as being produced in India. The bauxite used to produce the aluminum is also assumed to be produced in India. **a. Is it a fair assumption that the majority of aluminum used in construction in India is produced domestically?** **b. If not, which are the major importing countries that should be considered and what proportion of total production do they represent?**	Major production of aluminum which gets consumed in India happens in India
Technological representativeness: The energy consumption of alumina production and electrolysis is shown in table 1. These values come from the following source (Centre for Science and Environment, India, 2010). Are these values representative for the Indian industry? If not, which values should be used?	These values are very close to the actual values
Technological representativeness: According to the Centre for Science and Environment, India 97% of large scale aluminum smelting plants use electricity from hard coal. Consequently all smelters are modelled as using electricity from hard coal. Is this a reasonable assumption?	Yes, most of the plants in India have captive based power generation with hard coal as the source of fuel
Technological representativeness: Finished aluminum products are assumed to be produced from primary aluminum, with the only secondary content coming via scrap recycled from manufacturing processes (extrusion, cutting, bending etc.), i.e. no post-consumer scrap content. On-site scrap is assumed to be 100% recycled. Are these reasonable assumptions? If not, what scrap content should be used for final products (provide evidence/references if possible)	Yes, the aluminium usage in construction industry is not a very old industry in India and so far the scrap aluminium from buildings are not generated in considerable quantity
Any other comments?	None

No response received from Vedanta Resources- Balco, Mr. Mitesh Pandya, General Manager- Environment

BRICK

Consultees	Godavari Power and Ispat Limited Mr. Lakshman Prasad Senior Advisor	Godrej Construction Ms Tejashree Joshi Senior Manager- Environment
1. Geographical representativeness: Bricks consumed in India are assumed to be produced in India. Is there likely to be any significant proportion of imported brick?	No import of brick takes place in India	Import of concrete blocks/bricks does not take place in India
Technological representativeness: The production capacity in India by kiln type is shown in table 1. These values are drawn from the Swiss Agency for Development and Cooperation (2014). Do these seem representative? If not, what alternative values and references might be used?	Yes	Yes, the reference source is good, we can use this information
Technological representativeness: The specific energy requirement in in India for each kiln type is shown in table 1. Do these seem representative for each of the kiln types? If not, which kiln types may need adjusting and what alternative values should be used?	Yes	Yes, more or less fine
Technological representativeness: The fuel mix for each kiln is assumed to be 85% hard coal and 15% biomass, based on information provided by Tata Energy Research (Tata Energy Research Institute, 2001). a. Should there be any variation in fuels between kiln types? b. If so, please provide details of suggested mixes and references.	Yes, this is fine.	Yes, this is fine.
Any other comments?	None	none

No response received from Godrej Green Building Consultancy, Mr. Rumi Engineer,Head- Greener India

CEMENTITIOUS MATERIALS

Consultees	ACC Cement/ Ambuja Cement Mr. Sandeep Shrivastava Head - Environment and Sustainability	Ultra Tech Cement Mr. Akhileshwar Upadhyay Senior Manager- Regulatory Affairs
Are the cementitious materials listed relevant to the Indian construction industry? Are there any other major cementitious materials/additions that should be included?	Portland Pozzolana Cement (PPC) may be added which is more widely used term. PPC utiilises two types of pozzolanas: • Fly ash - Covered under IS 1489 (part I) • Calcined clay - Covered under IS 1489 (part II) PPC with fly ash, as Pozzolana, is more popular in the country owing to the comparatively easy availability of quality fly ash from modern coal-based thermal power plants	Yes
Geographical representativeness: Cement, granulated blast furnace slag and PFA are currently modelled as being produced in India. a. Is this a fair assumption for all three products? b. If not, are the differences between the production methods for the domestic and imported product likely to be significant?	a. Yes b. Property / composition may be different	Yes
Technological representativeness: Hard coal is assumed to be the main source of thermal energy for OPC production, with electricity modelled as the Indian grid average. This is considered representative of the cement industry's electricity mix which mainly uses coal / lignite and petroleum coke-based captive power plants. Are these reasonable assumptions?	Yes. But now petcoke is increasingly being used also for kiln operation.	Yes
Technological representativeness: The key assumptions for Portland slag cement are listed below. Are these reasonable?	Pl re-check CMA or manufacturers as Ambuja has no PSC. Normal composition of PSC is 30 % clinker, 5 % gypsum and 70 % blast furnace granulated slag. The quality of slag used in cement manufacturing is governed by IS 12089:1987. The slag constituent shall not be less than 25 per cent and not more than 70 per cent in PSC as per IS:455-1989 (as amended). PFA - economic value: Not sure. Pl check other sources.	Yes
Technological representativeness: The key assumptions for PFA are listed below. Are	Not sure. Pl check other sources.	Yes

these reasonable? **a. For allocating impacts between PFA and the coal fired electricity production process, the income derived from PFA relative to other outputs produced was less than 0.3%.**		
Any other comments?	None	None

No response received from ACC Cement, Mr. KN Rao, Director Environment.

CONCRETE

Consultee	ACC Cement Mr. KN Rao Director Environment	Ultra Tech Cement Mr. Akhileshwar Upadhyay Senior Manager- Regulatory Affairs
Are the ready mix and precast concrete products listed relevant to the Indian construction industry? Are there any additional major ready mix concrete types or precast products that should be included?	Yes, they are relevant	Yes, included in the list. We may also consider limestone calcined clay cement.
Geographical representativeness: Concrete products and the constituent materials used in concrete production are currently modelled as being produced in India. a. Is this a fair assumption for both ready mix and precast products? b. If not, are the differences between the production methods for the domestic and imported product likely to be significant?	Yes	Yes
Technological representativeness: C30/37 or M40 have been used as the representative strength of ready mix concrete produced in India for use in the India database. Is this a suitable mix to use?	Yes, this is absolutely alright	Yes
Technological representativeness: The following constituents have been assumed for the ready mix concretes. Do these assumptions seem reasonable? a. OPC Ready mix concrete (C30/37 M40): 10.7% OPC, 46.7% gravel, 36.7% sand and 5.7% water b. 30% fly-ash ready mix concrete (C30/37 M40): 7.5% OPC, 3.2% fly ash/pozzolana, 46.7% gravel, 36.7% sand and 5.7% water c. Portland slag cement ready mix concrete (C30/C37): 10.7% Portland slag cement (25% granulated slag), 2.7% GBS, 46.7% gravel, 36.7% sand and 5.7% water	The technological representativeness is ok	Yes
Technological representativeness: The following constituents have been assumed for precast concrete products. Do these assumptions seem reasonable? a. Lightweight concrete block: 28% OPC, 26% expanded clay, 32% sand and 14% water b. Medium density concrete block: 22% OPC, 16% expanded clay, 51% sand and 11% water c. Precast concrete panel: 95% OPC	They are in line with the standard design practices in India	Yes

C30/C37 concrete as described above, 5% wire mesh.		
Any other comments?	None	None

No response received from:

Godrej Construction, Ms Tejashree Joshi, Senior Manager- Environment

TERI, Mr. Tarun Garg, Junior Scientist.

GLASS

Consultee	AIGMF Mr. Vinit Kapur Secretariat	Hindusthan National Glass Mr. Arindom Chakraborty Senior Manager- Environment
It is assumed that flat glass accounts for the vast majority of the glass used in Indian construction. Are there any other significant glass products such as coated flat glass, laminated flat glass or toughened flat glass that should be included and are the production impacts of these products likely to be significantly different?	Yes, but there are different varieties of flat glass	Flat glass are of various categories like clear glass, tinted glass, mirror, frosted glass, Lacquered glass, coated glass. In addition to this there are various type of processed glass also like toughened glass, insulated glass, laminated glass, safety glass etc. For all these value added glass, raw glass can be any of the above mentioned flat glass. Due to lack of regulations and additional cost of processing there is not a wide usages of processed glass in India. We may take up for proper regulations of usage of processed glass based on the requirements at intended place of usage.
Geographical representativeness: Flat glass consumed in India is assumed to be produced in India. Is this a reasonable assumption?	Yes, a very small amount is imported but majorly local production	There are both Imports and exports of flat glass, though not a very big chunk of total quantity manufactured in India. Quantity wise Import and Export may be compensating each other.
Technological representativeness: The batch material composition used to produce flat glass is assumed to be as follows: 73% sand, 14% soda, 8% limestone, 4% dolomite and 1% alumina. Are these values representative?	Composition: Broadly these values are representative	Batch material standard composition is as below Sand 59%, Soda Ash 19%, Dolomite 15%, Lime Stone 5%, Feldspar 2%.
Technological representativeness: The energy consumption for glass production is modelled as 0.4 kWh/kg of grid electricity and 5.76 MJ/kg of thermal energy from natural gas. Are the values and the fuel used representative of Indian production?	Yes	Grid electricity is 0.15 kwh/Kg of glass production and 5.76 MJ/Kg of thermal energy.
Any other comments?	None	All the above data are based on production of clear float glass which has the maximum share in the various type of flat glass available.

No response received from : AIS Glass, Mr. Sanjay Ganjoo, COO.

GYPSUM

Consultee	Tata Chemicals Limited Mr. Abhishek Gupta Senior Manager- Environment
Are the gypsum products listed relevant to the Indian construction industry? Are there any other gypsum products that should be included?	Yes the above mentioned products are relevant to Indian construction industry. Majorly false ceiling, drywalls and gypsum plasters hold the major share in the market.
Geographical representativeness: It is assumed that natural gypsum, calcined gypsum and plasterboard all produced in India. a. Is this a fair assumption for all products? b. If not, are the differences between the production methods for the domestic and imported products likely to be significant?	Yes is seems to be a fair assumption
Technological representativeness: Natural gypsum is assumed to be produced via manual open-cast mining, as it is believed the majority of natural gypsum produced in India is produced manually with only a few semi-mechanized mines operating in Rajasthan. Is this a reasonable assumption? If not, what technology mix should be used?	Yes
4. Technological representativeness: The key assumptions for phosphogypsum are listed below. Are these reasonable? a. Phosphogypsum is assumed to be produced as calcium sulfate di-hydrate. b. For allocating impacts between phosphogypsum and P2O5 (used in fertilizer production), the following prices have been used – phosphogypsum = 1 IRN/kg, P2O5 = USD 805/t = 54 INR/kg, meaning 9% of the process is allocated to phosphogypsum by value.	Yes
Technological representativeness: The energy required to produce 1 tonne of calcined gypsum (calcium sulfate hemi-hydrate) is 1300 kWh electricity and 120 litres of heavy fuel oil (Ministry of MSME, Govt. of India, 2002). Does this seem reasonable?	This is very reasonable
Technological representativeness: The constituent materials for plasterboard are as follows: Gypsum = 95.2%, paper liner = 3.7%, additives =1.1%. Does this material mix seem reasonable for Indian-produced plasterboard products?	Seems reasonable
Any other comments?	None

No response received from Saint Gobain India Limited, Mr. N Murali. Head - Design & Sustainability.

INSULATION

Consultee	Reliance Industries Mr. Sanjay Kesarwani Senior Manager- R&D
Are the insulation products listed relevant to the Indian construction industry? Are there any additional major insulation products that should be included?	Yes they seem relevant
Geographical representativeness: EPS, stone wool and glass wool are modelled as being produced in India assuming European-average technology with Indian electricity and fuels **a. Is it reasonable to assume that insulation products used in Indian construction are also produced in India?** **b. Is it reasonable to assume that the technology used to produce these products in India is likely to be the same as that used in Europe? If not, what are the differences?**	Yes it's a fair assumption
Technological representativeness: The following product densities have been assumed: EPS = 20 kg/m3, glass wool = 16 kg/m3, stone wool = 25 kg/m3. Are the densities reasonable? If not, what densities should be used and why?	These densities are appropriate
Technological representativeness: For EPS, 4-6% pentane by mass is used as a blowing agent. The fuels consumed to produce 1kg of EPS are 0.115 kWh electricity, 0.019 kg furnace oil and 0.028 kg natural gas. Are the values for the pentane blowing agent, electricity and fuels reasonable?	Yes
Technological representativeness: For both glass and stone wool, the energy used is assumed to be natural gas. Is this assumption reasonable?	Yes
Technological representativeness: For pentane blown PU rigid insulation foam, the product is assumed to be made of Methylene di-isocyanate (MDI) (0.616 kg), pentane (0.054 kg) and polyether polyol (0.386 kg). The electricity required is 0.42 kWh/kg. Small amounts of pentane are emitted to atmosphere (0.003 kg) the thermal energy used is assumed to be generated from natural gas. Are these assumptions reasonable?	Seems reasonable
Technological representativeness: For HCFC blown PU rigid insulation foam, the product is assumed to be made of Methylene di-isocyanate (MDI) (0.616 kg), R22 (as a proxy for R141b (0.08775 kg) and polyether polyol (0.386 kg). The electricity required is 0.42 kWh/kg. 0048 kg HCFC 141b is assumed to be emitted to atmosphere (5% by mass) and the thermal energy used is assumed to be generated from natural gas. Should we include HCFC blown PU foam in the database? Are the manufacturing assumptions reasonable?	The assumptions seem reasonable. India is currently having a HCFC Phase-out but not completely achieved so HCFC blown PU foam is also available in the market.
Any other comments?	None

PLASTICS

Consultee	Reliance Industries Mr. Sanjay Kesarwani Senior Manager- R&D
Are the plastic/polymer products listed relevant to the Indian construction industry? Are there any additional major plastic products that should be included?	Yes, these are relevant to Indian construction industry.
Geographical representativeness: Plastic/polymer-based products have been modelled as being produced in India. a. Is this a fair assumption for carpet tiles, PVC flooring and u-PVC window frames? b. If not, are the differences between the production methods for domestic and imported products likely to be significant?	Yes it's a fair assumption
Technological representativeness: For carpet tiles, a bitumen backed nylon carpet tile with mass 4.04 kg/m2 has been modeled as representative of commercial carpet. The energy and fuel consumption in manufacturing used is: electricity = 2.2 MJ/m2, fuel oil 3.5 MJ/m2, heating steam 2.4 MJ/m2. In addition to this, the water consumption is 0.93-0.96 kg/m2. Adhesive used for installation is 0.2 kg/m2. Are these values reasonable? If not what values should be used?	Don't know.
Technological representativeness: Vinyl flooring is modeled as a homogenous vinyl tile with mass 3.2 kg/m2. 0.3 kg adhesive is required per m2. Manufacturing is based on European conditions. Are there likely to be any significant differences between European and Indian vinyl flooring production methods and the quantities of energy/materials used? Are these assumptions reasonable?	The assumptions are fair. Energy/material used are generally a function of scale of operation.
Technological representativeness: The u-PVC window frame is modelled as having a mass of 2.8 kg/linear meter, including steel reinforcement which is just over 50% by mass. Production is based on a European production process with Indian electricity and fuels. a. Are there likely to be any significant differences between European and Indian u-PVC window frame production? b. Is the mass assumption per linear meter reasonable?	Significant difference in production is not expected. Mass/length assumption looks reasonable.
Any other comments?	From environmental study point of view, most of the assumptions looks reasonable in the absence of Indian production data. There may be a significant difference in cost of production.

No response received from:

Bayer Material Science, Mr. Srinivas Reddy, Senior Manager- Environment.

CIPET (Central Institute of Plastics Engineering & Technology), Prof. (Dr.) Sanjay K. Nayak, Director.

STEEL

Consultee	JSW Steel Limited Mr. SMR Prasad Head- Environment
Are the semi-finished and finished steel products and production routes listed relevant to the Indian construction industry? Are there any additional major finished products or production routes that should be included?	Yes, for the construction industry, this is representative
Geographical representativeness: Steel products are currently modelled as being produced in India. a. Is it a fair assumption that the majority of steel used in construction in India is produced domestically? b. If not, which are the major importing countries and what mix should be used?	Yes, this holds for the construction industry
Technological representativeness: The current model assumes a steel mix of 44% BF/BOF, 32% DRI in EAF and 24% scrap EAF (24%). This mix of production routes is assumed for all four finished products. a. Is this mix representative for the finished products used in construction in India? b. If not, what would be a more representative mix for each product and are you aware of any relevant references?	BF/BOF share of production will be on a higher side in India, however your data sources are credible and you can take the above ratios
Technological representativeness: The approach used to allocate impact to granulated slag makes very little difference to the impact of BOF steel. For allocating impacts between pig iron and blast furnace slag (to be used as a cement substitute), the following prices have been used – Pig iron = 23000 IRN/t, blast furnace slag = 660 IRN/t. a. Are these values reasonable for the products in question b. If not, which values should be used and can you provide references?	Yes, ok
Technological representativeness: It is assumed that the scrap-based EAF route uses grid electricity. DRI is produced using hard coal , with the linked EAF powered by electricity generated from a power plant fueled by hot process gases from DRI production. The BF/BOF is primarily fueled by hard coal/coke. a. Do these technological assumptions seem reasonable?	Yes
Any other comments?	None

No response received from :

Steel Authority of India Limited, Mr. K Praveen, Senior Manager- Environment

Tata Steel Limited, Mr. Shibojyoti Dutta, Head- Environment

TIMBER

Consultee	Godrej Interio Ms Ashwini Deodeshmukh AGM - Good and Green
For the purposes of this project, untreated timber is considered as either air dried or kiln dried as the drying phase generally has the largest impacts for the impact categories considered. Is there any reason to expand the list of untreated timber products?	Not required, this is appropriate for the Indian construction materials
Geographical representativeness: This project models timber products produced in India. References state that around 20% of logs used to manufacture timber products in India are imported primarily from Malaysia and Myanmar. Imported logs have been modelled assuming Indian conditions, fuels and techniques. Are there likely to be significant differences between the impacts of Indian logs and imported logs?	Not much, we can take Indian conditions for fuel and techniques which is broadly in line with the importing countries practices
Technological representativeness: Teak has been selected as the representative wood species for both air dried and kiln dried timber. The density is assumed to be 600 kg/m3 with a moisture content of 15%. Are these assumptions reasonable? If not what alternative species or density assumptions should be used and why?	This is also fine, teak being a costly, other wood species are being used. In India, most of the good quality plywood available in the markets is made from 'Gurjan wood
Technological representativeness: The sawmill energy consumption is 0.161 kWh/kg of electricity and 0.327 MJ/kg of diesel. Are these values and the fuel assumption reasonable?	These values are ok
Technological representativeness: The energy consumption of the kiln for kiln dried timber is 0.33 kWh/kg of electricity and 5 MJ/kg from an equal mix of coal, light fuel oil and waste wood. Are these values and the assumed fuel mix reasonable?	Ok, normally it is coal, FO and waste wood only used for heating purpose
Any other comments?	None

No response received from IPIRTI, Dr. SK Nath, Director.

ANNEX F: SUMMARY OF RELEVANT VOLUME, AREA & LINEAR DENSITIES

The information provided in the India Construction Materials Database gives results for embodied energy and global warming potential per kg product. This annex provides information to assist the user of the database to convert this information to other units that may also be useful. For many materials, a range of values may be possible, the values listed in Table 18, Table 19 and Table 20 are those used in this study. The tables contain the following information:

Volume density (kg/m^3) is provided for bulk materials such as bricks and concrete

Area density (kg/m^2) is provided for products as flooring and tiles.

Linear density (kg/m) is provided for window frames

Table 18: Volume density for relevant materials in the India Construction Materials Database

Material Name	Volume density (kg/m^3)
Aircrete (autoclaved aerated concrete)	500
Air-dried sawn timber	655
Aluminum profiled cladding	2800
Brick (common/facing)	1760
Cellulose insulation	50
Cement based plaster	2200
Cement floor screed (concrete screed)	2200
Cement mortar	2200
Cement/lime render for external wall finishes	2200
Copper sheet	8940
Electrogalvanized steel sheet ("corrugated zinc")	7850
Expanded polystyrene insulation (EPS)	20
FaLG (fly ash/lime/gypsum) block	1760
Fiber cement board	1700
Float glass	2500
Galvanized steel stud	7850
Glass reinforced concrete	2550
Glass wool	16
Honeycomb brick	700

Material Name	Volume density (kg/m³)
Kiln-dried timber	655
Lightweight concrete block	1097
Lime mortar	2200
Medium density concrete block	1400
Mud plaster	1000
OPC stabilized soil block	2000
Particle board/chipboard	710
PFA stabilized soil block	2000
Plasterboard	700
Plywood	600
Polyurethane rigid insulation foam (HCFC blown)	32
Polyurethane rigid insulation foam (pentane blown)	32
Portland slag cement stabilized soil blocks	2000
Precast concrete panels/flooring	2200
Rammed earth	1900
Ready mix concrete with fly-ash (30% pozzolana)	2200
Ready mix concrete with ordinary Portland cement (OPC)	2200
Ready mix concrete with Portland slag cement (25% GGBS)	2200
Steel reinforcement (steel rebar)	7850
Steel section	7850
Stone wool	25
Straw bale	140
Cork insulation	80
Dense concrete block	2200

Table 19: Area density for relevant materials in the India Construction Materials Database

Material Name	Area density (kg/m²)
Aluminum thin composite cladding	6
Asphalt shingles	15
Bamboo flooring	5
Carpet (nylon)	2.2
Carpet (nylon) tile	4
Cement-based terrazzo (in-situ)	252
Cement-based terrazzo tile	50

Clay roof tile	54
Cork flooring tile	2
Ferrocement roof panel	86
Ferrocement wall panel	86
Glazed ceramic floor tiles	18
Gypsum panel	35
Gypsum plaster	4
Jute flooring	2
Linoleum flooring tile	3
Microconcrete roof tile	46
Phosphogypsum panel	35
Polished stone cladding	120
Polymeric render for external walls	3
Rubber flooring	3
Shotcrete walling	236
Stone floor tile	65
Vinyl (PVC) flooring	3
Vitrified ceramic floor tiles	24
Wood block flooring	14
Wood laminate/multi-layer parquet flooring	6
Woodwool board insulation	12

Table 20: Linear density for relevant materials in the India Construction Materials Database

Material Name	Linear density (kg/m)
Aluminum extruded profile (window frame)	2.0
Steel window frame	2.7
Timber window frame	3.2
u-PVC window frame	2.8

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