Excellence In Design For Greater Efficiencies

EDGE Materials

Embodied Energy

Methodology & Results

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International Finance Corporation
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EDGE EMERGING ECONOMIES CONSTRUCTION DATASET METHODOLOGY REPORT

I. INTRODUCING THE EDGE EMERGING ECONOMIES CONSTRUCTION DATASET

A. About EDGE ("Excellence in Design for Greater Efficiencies")

EDGE is a building design tool, a certification system, and a global green standard available more than 150 countries. The platform is intended for anyone interested in the design of green buildings, whether architect, engineer, developer, or building owner.

EDGE empowers the discovery of technical solutions at the early design stage to reduce operational expenses and environmental impact. Based on the user's information inputs and selection of green measures, EDGE reveals projected operational savings and reduced carbon emissions. This overall picture of performance helps to articulate a compelling business case for building green.

The suite of EDGE tools includes homes, hospitals, offices, hotels, and retail supported by building-specific user guides.

EDGE is an innovation of IFC, a member of the World Bank Group.

B. EDGE Emerging Economies Construction Dataset

Embodied impacts are those impacts associated with construction products, for example due to their extraction, refining, processing, transportation, and fabrication. In determining the embodied environmental impacts of a given building, the EDGE software uses data on the embodied impact of construction materials from those specific economies.

This report describes the approach used to generate this embodied energy dataset, explaining the methodology, sources of data, and assumptions used.

The environmental impacts of materials vary according to where and how they are manufactured and used. Due to the global scope of EDGE, incorporating accurate impact data for materials in all locations is not yet possible. Instead, a targeted and phased approach is adopted that initially provides a single global Emerging Economies Construction Dataset (the "EDGE Dataset") for embodied energy of construction materials based on a life cycle assessment (LCA) model. Future phases will provide datasets for specific countries for use in national implementations of EDGE, which may consider other impact categories such as climate change.

II. CONSTRUCTION MATERIALS TO BE INCLUDED IN THE EDGE DATASET

The construction materials included within the EDGE Dataset are listed in Table 1.

To provide data for products such as ready-mix concrete and stabilized earth blocks, datasets have also been produced for intermediate products with high impacts, such as Ordinary Portland Cement, which are not used directly in a building but are incorporated within products. This methodology describes how the datasets for both intermediate and "final use" products are modeled.

Table 1: List of materials within the EDGE Dataset

Material type	Materials or products included	
Ceramic masonry	Facing brick and common brick	Honeycomb clay block
Ready mix concrete, etc.	Cement screed OPC concrete PFA concrete	GGBS concrete Cement-based plaster
Precast concrete elements	"Ferrocement" wall panel	Precast concrete panels/flooring
Masonry blocks	Autoclaved aerated concrete block (aircrete) Lightweight concrete block Medium weight hollow concrete block	Dense concrete block FaLG (fly ash/lime/gypsum) block Local limestone block
Roofing tiles	Clay roofing tile	Microconcrete roof tile
Earth-based products	Cement stabilized earth block Fly ash stabilized soil block GGBS stabilized soil block	Rammed earth blocks/walls Mud plaster
Flooring	Linoleum sheet Carpet Terrazzo tiles Vinyl flooring	Stone tiles/slabs Ceramic tile Terracotta tile Laminated wooden flooring
Gypsum products	Plasterboard Gypsum panel	Phosphogypsum panel Gypsum plaster
Insulation	Mineral wool Expanded polystyrene Straw bale	Jute Rigid polyurethane foam
Metal products	Reinforcing steel Structural steel section Aluminum profiled cladding	Corrugated galvanized steel (corrugated zinc) Coated steel profiled cladding
Timber products	Plywood sheathing	Structural timber
Glass and windows	Float glass PVC-u window frames Steel window frames	Aluminum window frames Timber window frames Wood/plastic composite window frames

III. APPROACH

The approach for developing a dataset for emerging economies involved adapting existing European LCA models, covering a range of technologies, to reflect the differences in the EDGE economies, including:

- the range of technologies available in emerging economies,
- the influence of regulation on environmental measures,
- the amount of imports to and from developed economies,
- the grid mix including use of mobile generators, and
- the variety of energy sources used for heat.

For the global dataset for emerging economies, EDGE only reports on the embodied energy indicator as this varies less between different countries than embodied carbon, which is strongly influenced by differences in national energy mixes. Embodied energy therefore provides a more representative indicator across emerging economies globally.

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 which are not intended to be used as an energy source, for example the timber in wooden products

The quantity of fuel energy directly used in the process gives the "delivered energy". However, all delivered energy requires indirect energy consumption and losses in the extraction, refining, supply and transmission of the energy to the customer. This total energy used is known as the "primary energy".

The EDGE Embodied Energy Indicator is based on primary energy, 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.

For processes that generate co-products, impacts associated with fuel energy have been allocated as described in EN 15804. Feedstock energy is a physical property of co-products and cannot be allocated.

A. Software and database

The LCA models for the EDGE emerging economies are created within the GaBi 6 Software and Databases. The GaBi databases are chosen as GaBi is the only life cycle inventory (LCI) database to have been independently audited to follow consistent modeling guidelines and is also the only database that is updated annually, which simplifies the process of accounting for changes in grid mixes and other changes in production of upstream energy and materials.

All of the models produced for EDGE, as well as the underlying data in GaBi, have been produced in accordance with ISO 14040 and ISO 14044 as well as the International Reference Life Cycle Data (ILCD) guidance. The ISO 14040 and 14044 standards define the basic framework of the LCA process and provide measures of quality control and transparency in conducting and reporting LCA. The ILCD system was developed by the European Commission to provide more precise guidance for LCI dataset development, beyond the ISO standards, to allow LCI datasets to be more comparable. LCI datasets that follow ILCD are composed using consistent rules for the boundaries of processes as well as the types and definitions of material and energy flows composing the inventory. These rules allow users to generate results that are meaningful, consistent, and more comparable across databases, studies, and practitioners.

In conducting an LCA, wherever possible, it is best to use representative data rather than proxy data. The breadth of materials available in an LCI database is therefore also a key metric. The GaBi databases represent the largest internally consistent collection of life cycle inventory data with over 7,200 profiles, allowing more representative data to be used specific to modeling the EDGE materials.

The use of GaBi data, as well as conformance to ISO 14040/44 and ILCD, provide assurance of the quality and comparability of the EDGE models, so that future versions of the EDGE software can be maintained and updated with suitably representative data.

B. System boundaries

The system boundary for the datasets is based on EN 15804:2012 covering Modules A1 to A3, cradle to gate. This includes:

- 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.

C. Declared unit and reference flow

The declared units used for the datasets relate to the product at the factory gate in an emerging economy, including manufacturing and transport in the supply chain. Installation material and off-cuts from the installation stage are excluded. All data are provided for a declared unit of one kilogram of product. In all instances, the declared unit can be related back to a volume unit using conversion information such as density.

D. Representativeness of data

Time reference

The LCA models used are adapted using the most recent, robust data available for emerging economies (based on information from 2014 where possible). The embodied energy dataset for emerging economies will be updated based on more recent data via the annual update of the underlying GaBi models.

Technology reference

Wherever possible, the approach represents the mix of technologies relevant to emerging economies. 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 countries considered within the EDGE Dataset are shown in Figure 1 and Table 2 and relate to IFC's program activity. The list aligns somewhat with the set of non-OECD countries although it excludes most wealthy or relatively wealthy non-OECD countries (e.g., Iran, Saudi Arabia, Luxembourg, Venezuela), and includes three countries that are members of the OECD (Mexico, Chile, Turkey).

The development of representative LCA models represented a particular challenge due to the diverse and numerous countries addressed by the EDGE software.

Figure 1: Map of countries included in the EDGE Dataset geographic boundaries

Table 2: Countries to be considered within the EDGE Dataset project

Angola	Georgia	Panama
Argentina	Ghana	Papua New Guinea
Armenia	Guatemala	Peru
Bangladesh	Guinea	Philippines
Benin	Guinea Bissau	Republic of Congo
Bhutan	Guyana	Romania
Bolivia	Haiti	Russia
Bosnia Herzegovina	Honduras	Rwanda
Brazil	India	Saint Lucia
Bulgaria	Indonesia	Samoa
Burkina Faso	Jordan	Sao Tome and Principe
Burundi	Kenya	Senegal
Cambodia	Kyrgyzstan	Sierra Leone
Cameroon	Laos	Solomon Islands
Cape Verde	Lebanon	South Africa
Central African Republic	Lesotho	Sri Lanka
Chad	Madagascar	Sudan
Chile	Malawi	Tajikistan
China	Maldives	Tanzania
Colombia	Mali	Thailand
Comoros	Mauritania	Togo
Costa Rica	Mexico	Tonga
Côte d'Ivoire	Moldova	Tunisia
Croatia	Mongolia	Turkey
Democratic Republic of Congo	Morocco	Uganda
Djibouti	Mozambique	Ukraine
Dominica	Myanmar	Uruguay
Dominican Republic	Nepal	Uzbekistan
Egypt	Nicaragua	Vanuatu
Eritrea	Niger	Vietnam
Ethiopia	Nigeria	Yemen
Gambia	Pakistan	Zimbabwe

IV. OVERVIEW OF THE ADAPTATION PROCESS

Data for the EDGE Dataset is based on European or other regional sources that has been adapted to represent the EDGE group of emerging economies. The types of adaptation used have provided data relevant for construction products across all emerging economies as listed in Table 2. The data is as representative as possible given the scope of the project and available information.

The data has been adapted to be more representative of the EDGE economies 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.)

In developing the approach to adapt European and other regional data to the EDGE economies, the construction materials are ranked according to their expected relative environmental influence within construction projects in order to consider how detailed the adaptation needed to be in each case. In the context of a building, it is considered that:

- Bulky, high-volume materials (such as concrete) will contribute more to impacts than materials used in smaller amounts.
- High impact materials, such as aluminum cladding, which do not comprise a large proportion of the mass of the building may also contribute significant impacts.

For example, brick has a much lower embodied energy per unit mass than steel. However in the context of the EDGE Dataset where brick is very widely used in construction, it has a similar influence on the building impact and is therefore considered a high priority material.

The highest priority materials are steel, cement, brick, and aluminum. These four materials are given the greatest focus and most detail in adaptation due to their high influence on construction impacts.

The following sections provide a detailed description of the approach taken to adapting energy and technology data for all the materials used in the EDGE Dataset.

A. Adaption of energy data

A two-step approach is adopted for modeling electricity and fuel:

- First, the mix of energy sources is assessed. For example, to determine the proportion of electricity sourced from coal, oil, hydro, etc.
- Second, for each fuel source specified in this mix, the impact of production by different emerging economies is considered. For example, the efficiency of electricity production from coal will vary from country to country depending upon the efficiency of the power stations and the technology used.

These steps are described in more detail in the following sections.

Energy sources

The mix of energy sources for electricity and fuels are modeled based on energy statistics for the non-OECD countries, as provided by IEA (IEA, 2015) (IEA, 2012) and the resulting data used in the models are shown in Table 3 (EDGE Electricity) and Table 4 (EDGE Fuels).

As discussed earlier, the list of EDGE emerging economies aligns well with the set of non-OECD countries although it excludes some wealthy or relatively wealthy non-OECD countries and includes three members of the OECD.

The influence of the inclusion of Mexico and Turkey and the exclusion of Middle Eastern countries is found to be very small (the proportion of electricity sourced from different fuels does not change by more than 2%). Hence the energy sources for electricity and heat for non-OECD countries are considered to be representative of the energy mix used in the EDGE emerging economies. The resulting models for EDGE electricity (Table 3) and EDGE fuels (Table 4) reflect the mix of non-OECD energy sources used in electricity and industrial fuel consumption.

Table 3: EDGE electricity grid mix, from IEA statistics for non-OECD countries in 2011 (IEA, 2012)

Generation source	% Electricity
Hard coal	46.8%
Natural gas	21.0%
Hydro	20.7%
Heavy fuel oil	6.4%
Nuclear	4.4%
Solid biomass	0.5%
Geothermal	0.2%

Table 4: EDGE fuel heat mix, from IEA statistics for non-OECD countries in 2012 (IEA, 2015)

Fuel	% Energy value
Coal	52.2%
Natural gas	20.5%
Oil and oil products	17.4%
Biofuels and waste	9.9%

The IEA "biofuels and waste" category represents a mix of energy sources which, on a global basis, is dominantly composed of traditional biomass (wood, charcoal, agricultural residues, and animal dung), but also includes liquid biofuels (such as bioethanol) and smaller contributions from methane from anaerobic digestion and landfill gas (IEA, 2012). As traditional biomass is identified as the dominant fuel, this category is modeled based on wood and wood waste as fuel.

The EDGE fuel heat mix is suitable for processes where many different fuels are used across the EDGE economies and is used for many lower priority materials. However, in some cases a specific fuel type will be known to be predominantly used for a given manufacturing process. For example, coal (in the form of coke) is used as the main fuel source in blast furnace steel production because it is the only suitable major fuel for blast furnaces in terms of carbon content and energy density. Other fuels are not used in this process in any quantity. For many higher priority materials, rather than applying the EDGE fuel heat mix, a specific fuel mix for the particular fuel types is used.

Individual fuel models

For each of the energy sources specified in Table 3 and Table 4, an LCA model reflecting the extraction, processing, and combustion of the fuel is developed, and this model reflects a mix of geographies. For example, generation of electricity from hard coal is modeled to reflect a mix of several life cycle models of hard coal power plants (including all of the upstream extraction and processing of fuels), each reflecting the conditions of a given country.

When developing the EDGE fuel heat mix, the EDGE electricity mix and EDGE specific fuels it is impractical to develop LCA models for fuel combustion in every individual emerging economy; overall energy consumption in the EDGE emerging economies is dominated by relatively few large countries. As such, the sourcing, extraction, processing, and combustion of individual fuels are based only on those countries that, combined, account for at least 80% of the total industrial energy used within the EDGE emerging economies. Figure 2 gives the contribution to the total non-OECD industrial energy for the EDGE economies for each country. This shows how the 80% threshold requirement is met by modeling fuel production and use from just 10 countries: China, Russia, India, Brazil, Indonesia, Thailand, Mexico, South Africa, Ukraine, and Turkey, as shown in Table 5.

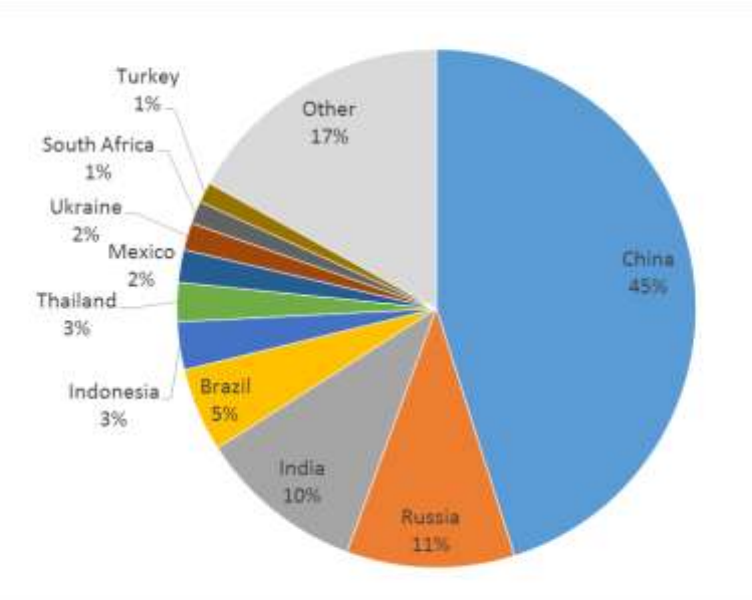

Figure 2: Contribution by country to industrial energy use in emerging economies (IEA, 2015)

Table 5: Geographical mix used in EDGE heat and electricity models

Country	**Contribution to energy mix in EDGE heat and electricity models**
China	54.4%
Russia	12.6%
India	12.5%
Brazil	6.3%
Indonesia	3.6%
Thailand	2.9%
Mexico	2.4%
Ukraine	2.1%
South Africa	1.7%
Turkey	1.5%

The resulting fuel-specific datasets are considered to be robust as the impacts of extracting, processing, and generating heat from these fuels does not vary significantly by location. For example, the energy released from the combustion of coal is broadly similar wherever it is sourced from, and this impact is much greater than the impacts of extraction and processing. Furthermore, extraction impacts will, in many cases, also be similar regardless of location (e.g. a coal mine in China would be expected to have similar impacts to a coal mine in Brazil since the technological processes for extracting is the same in both places).

Energy recovered from waste

Where process waste and scrap arise in the EDGE construction material production models, the type of waste treatment is not adapted, however, any energy generated during waste treatment is credited using the mix of energy and fuels representative of the EDGE emerging economies. As an example, if the regional conditions of a European cement process includes landfilling where landfill gas is recovered, the appropriate primary energy value for this recovered landfill gas is determined based on the EDGE fuel mix.

B. Adaption of technology data

The countries considered in the EDGE Dataset are highly diverse in their geography and in their levels of development, both across and within their economies. For example, some steel production in China is state of the art and on par with global best practice energy efficiency, while other steel producers in the same country rank among the lowest in energy efficiency globally. Given the diversity across the EDGE emerging economies, it is important to note that the average values are not likely to be fully representative of any individual country or producer.

Broadly speaking, the construction materials to be included in the EDGE Dataset fall into five main groups which are defined by those aspects of the global supply of materials that affect environmental impacts. These are described in Table 6. These groups are used to classify construction products according to their importance and so inform the approach taken for adapting the data in each case.

Table 7 shows the adaption group allocated to the different materials considered in the EDGE Dataset. The following sections of this report explain in detail what adaptions are made for each material type. The appendix provides links to online documentation for the aggregated datasets that are used or adapted to model the core production processes for these materials.

Table 6: Adaptation groups used for classification of construction products

Group 1	Energy-intensive, high-cost materials, such as aluminum, steel, and glass. Both electricity and fuel sources used have a significant influence on the impact, as do the efficiency of the process and the use of recycled content.
Group 2	Fuel-intensive, lower-cost materials, such as cement[1], bricks, and kiln-dried timber. Fuel source and technology significantly affect the impacts.
Group 3	Input-related products such as concrete blocks and gypsum-based products, where the input materials such as cement and gypsum have the greatest effect on impacts. Use of alternative raw materials such as ground granulated ballast furnace slag (GGBS), pulverized fuel ash (PFA) or flue gas desulfurized (FGD) gypsum has a strong influence over impacts.
Group 4	Electricity-intensive, high-cost goods such as flooring and board products. Electricity source and recycled content have the most influence on impacts.
Group 5	Low-cost, less-processed products such as aggregates, straw, etc. These materials are generally produced locally, with predictable production processes and lower impacts.

[1] Cement and gypsum anhydrite are intermediate products not listed directly within the EDGE Dataset, but cement has a major impact on concrete products, and gypsum anhydrite has a major impact on plaster and gypsum-based products, both of which fall into Group 3.

Table 7: EDGE construction materials classified by adaptation group

Material	Group 1	Group 2	Group 3	Group 4	Group 5
Masonry		Brick, common brick, honeycomb clay block	Autoclaved aerated concrete block (aircrete), lightweight concrete block, medium weight concrete block (hollow), dense concrete block, FaLG (fly ash/lime/gypsum) block, cement stabilized earth block	Local stone block	Fly ash stabilized soil block, GGBS stabilized soil block, rammed earth blocks/walls
Flooring	Linoleum sheet, carpet, vinyl flooring	Ceramic tiles, terracotta tile	Terrazzo tiles	Stone tiles/slabs, laminated wooden flooring	
Glass and windows	Float glass, steel window frames, aluminum window frames, PVC-u window frames, wood/plastic composite window frames.			Timber window frames	
Insulation	Expanded polystyrene, polyurethane			Mineral wool insulation	Straw bale, jute
Metal products	Reinforcing steel, structural steel section, aluminum profiled cladding, corrugated galvanized steel, coated steel profiled cladding				
Plaster products			Gypsum plaster, gypsum panel, plasterboard, phosphogypsum panel, cement based plaster		Mud plaster
Precast concrete			“Ferrocement” wall panel, precast reinforced concrete panels/flooring		
Ready mix concrete			Cement screed, OPC concrete, PFA concrete, GGBS concrete		
Roofing tiles		Clay roofing tile	Microconcrete roof tile		
Timber products		Kiln-dried timber		Plywood sheathing	Sawn timber

V. ADAPTION PROCESS: GROUP 1

Group 1: Energy-intensive, high value-to-weight ratio materials, such as aluminum, steel, glass, and polymers. These materials are not produced widely across all EDGE emerging economies, but tend to be imported from a narrower group of economies. Both electricity and fuel sources have significant effects on the material's impact, as do the efficiency of the production processes and in some cases the use of recycled content.

For these materials, data on the main producing countries and exports are used to provide specific information on the sources of the products used in the EDGE emerging economies. Due to the dominance of China as both a producer and consumer of aluminum and steel, a particular focus is placed on China in modeling these materials.

A. Steel

The major factors influencing the impact of steel products are:

- the production route;
- recycled content, and
- route-specific energy factors: the electricity mix used in electric arc furnace (EAF) production, efficiency in blast furnace and basic oxygen furnace (BF/BOF) production, or energy used for direct reduced iron (DRI) production routes.

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 the production of steel from scrap, and (3) production of primary steel from direct reduced iron via the electric arc furnace (DRI/EAF). An additional route, the open hearth furnace, is much less common. Values reported in an OECD meeting on the 2012 fractional world production via each route (Laplace Conseil, 2013) are confirmed by combining reported 2012 production values from the World Steel Association industry group (World Steel Association, 2013) and comparing them with a 2012 DRI industry report (Midrex, 2014). The fractions of 2012 steel production via the four production routes, BF/BOF, scrap EAF, open hearth, and DRI/EAF, are presented in

Figure 3 (Laplace Conseil, 2013). Where there is knowledge of the typical split of steel production routes used for particular products the global average is used. This is discussed in more detail in the product descriptions below.

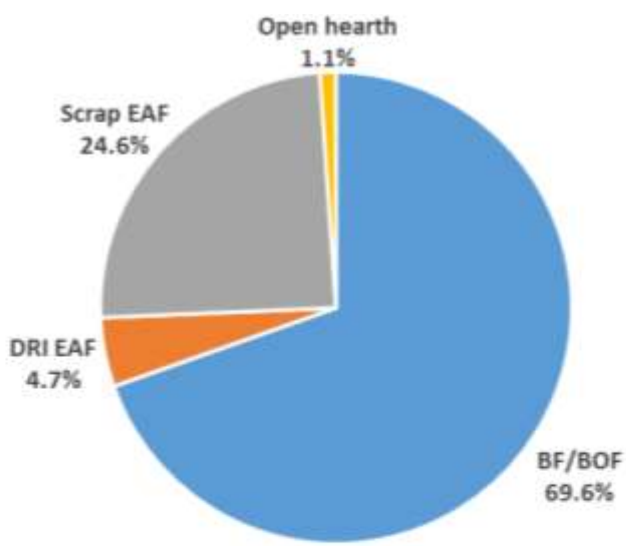

Figure 3: Steel production by production route

The embodied energy of steel produced via BF/BOF is highly variable globally. While equipment and process optimization improved substantially over the late 20th century, not all installed capacity reflects the latest and most efficient production technology. In particular, efficiency of the total installed capacity in China is reported to be lower than the global average

(Oda, et al., 2012) (Guo & Fu, 2010). Global production of crude steel is presented by country in Figure 4 and shows that China is the largest steel producer worldwide, by a considerable margin.

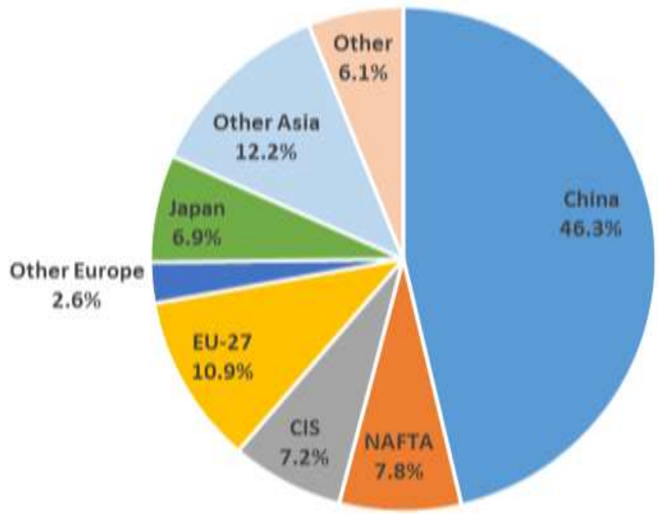

Figure 4: Worldwide steel production

The model in GaBi for blast furnace and basic oxygen furnace (BF/BOF) production represents a modern, highly efficient production process, with energy consumption representative of relatively high performance among the known range of efficiencies (Bettinger, 2012). When considering the range of plant efficiencies globally or across all EDGE steel producers, it can be seen that the model is not representative of average performance. Based on market analysis of steel production globally, roughly two thirds of 2009 steel production falls into lower efficiency performance groups (Bettinger, 2012). As steel production capacity has been continuously upgraded, notably at a fast pace in China (Oda, et al., 2012) (Guo & Fu, 2010), roughly half of BF/BOF production within the EDGE countries currently uses processes which are relatively inefficient. To account for this, the GaBi model is adjusted as described below.

BF/BOF steel is modeled based on a mix of production routes representing: 50% high efficiency BF/BOF, 50% low efficiency BF/BOF. For high efficiency BF/BOF, a model for a modern, high-efficiency integrated steel plant is used, while for the lower efficiency BF/BOF production, the individual process steps are adapted to reflect an efficiency reduction as outlined in the following table. The EDGE energy mixes for electricity and for each fuel used in production are applied.

Table 8: Efficiency reduction factors for lower efficiency BF/BOF steel

BF/BOF process step	Energy consumption relative to higher efficiency group
Coking	170%
Sintering	170%
BF iron making	130%
BOF steel making	250%

Steel production from the electric arc furnace (EAF) route is modeled based on European technology but adjusted to use the EDGE electricity mix. There is less variability in EAF production and the main difference in performance is due to the electricity mix used.

Galvanized steel sheet ("corrugated zinc")

The production of galvanized sheet is dominated by use of BF/BOF steel, though EAF and DRI steels can be used.

To model galvanized steel sheet, a mix of 95% BF/BOF steel and 5% EAF steel is processed through an integrated mill hot rolling process with electrogalvanizing. The EDGE energy mixes for electricity and for each fuel used in production are applied.

Profiled steel cladding and steel window frame

These products are typically organic coated galvanized steel using predominantly BF/BOF steel. To model coated steel sheet, a mix of 95% BF/BOF steel and 5% EAF steel is processed through an integrated mill hot rolling process with electrogalvanizing and organic coating. The EDGE energy mixes for electricity and for each fuel used in production are applied.

Structural steel section

Structural steel cross-sections are typically formed using hot rolling from a mix of BF/BOF, EAF, and DRI steels.

To model steel sections, the global average mix of 70% BF/BOF steel, 25% EAF steel, and 5% DRI steel is processed through an integrated mill hot rolling process. The EDGE energy mixes for electricity and for each fuel used in production are applied.

Steel reinforcement (rebar)

Steel reinforcement is predominantly produced using a hot rolling process from the EAF process. To model steel reinforcement a mix of 10% BF/BOF steel and 90% EAF steel is processed to produce rebar. The EDGE energy mixes for electricity and for each fuel used in production are applied.

B. Aluminum

Two factors have a large influence over the embodied energy of aluminum:

- The fraction of recycled aluminum in ingot production mix; and
- The electricity grid mix used in production of the ingot.

The average global fraction of recycled aluminum within finished products is 16% (IAI, 2014) (USGS, 2010). Data from World Aluminum (World Aluminum Association, 2014) shows that less than 25% of global production comes from countries outside of the EDGE emerging economies group (Australia, Canada, US, and Western Europe). Among the EDGE countries, China is the largest producer of aluminum. Secondary aluminum production in China during 2011 was 5.2 million metric tons (compared to 20.3 million metric tons primary production), representing a production mix of 20% secondary within China. Given the large representation of EDGE countries in global aluminum production, and the relative similarity of the global value to the EDGE countries' largest producer, the global fraction of secondary content is applied when modeling aluminum production. The EDGE aluminum ingot therefore represents a mix of 16% secondary ingot and 84% primary ingot.

Demand for aluminum ingot within the EDGE countries is largely met by production within the EDGE group. The EDGE emerging economies together represent over 75% of aluminum production (World Aluminum Association, 2014), and, in considering the largest EDGE economy, the IAI states that China's primary aluminum demand is balanced by domestic production (World Aluminum, 2014). Because consumption of aluminum ingot is largely met by production of ingot within the EDGE countries, EDGE primary and secondary aluminum ingot production is modeled using the EDGE fuel and electricity mixes.

Aluminum construction products

Modeling of aluminum for use in the EDGE construction products (cladding and window framing) is based on European Aluminium Association (EAA) unit processes with the EDGE ingot production process. The EDGE energy mixes for electricity and for each fuel used in the product fabrication process are applied.

Aluminum sheet

Aluminum rolling is an energy-intensive process, for example Europe's production requires nearly 2000 MJ natural gas and over 500 kWh electricity per metric ton of sheet (EAA, 2013). Aluminum sheet is modeled based on the EDGE aluminum ingot and the EAA unit process for sheet rolling. The EDGE energy mixes for electricity and for each fuel used in production are applied.

Aluminum extrusion

Aluminum extrusions are modeled using the EAA unit process for extrusion using the EDGE aluminum ingot. The EDGE energy mixes for electricity and for each fuel used in production are applied.

C. Float glass

Energy consumption and associated environmental impacts in glass production are most strongly influenced by production efficiency and recycled content.

Glass Alliance Europe states that European glass production currently uses around 8 GJ primary energy per metric ton and that energy intensity per metric ton of glass has been reduced by 77% (and CO_2 emissions reduced by 50%) since the 1960s (Glass Alliance Europe, 2014). However, European glass production is highly regulated in comparison to overseas production. A report from Lawrence Berkeley Laboratory states that the primary energy consumption per ton of flat glass for China in 2010 was 0.335 ton coal equivalent, or 9.82 GJ/ton (Berkeley National Laboratory, 2012), which is about 22% higher than that of European glass.

Several energy carriers are used in the glass production process: electricity, natural gas, and fuel oil. Natural gas and fuel oil are used for heating the furnace and are interchangeable for this purpose. However, according to the industry, using natural gas instead of fuel oil requires approximately 8% more energy (Centre for European Policy Studies, 2014). Electricity accounts for about 25% of the primary energy used in production, with heat from natural gas or fuel oil representing most of the rest (EIA, 2014) (CEPS 2014).

Figure 5: Countries exporting and importing glass (redrawn) (Savaete, The world flat glass industry, Focus on history and economy, 2014)

Figure 5 shows that China is a major exporter and India a major importer of flat glass. Only approximately 1.5% of Chinese float glass demand was imported during 2008, consisting primarily of specialized products that are not yet produced in

China, while 11% of the domestic float glass output, consisting primarily of standard glazing products, was exported (Pilkington NSG).

The dataset for float glass is based on a European float glass process that is adapted to take account of increased energy consumption. A 15% increase in electricity and fuel is applied, based on two thirds of glass being produced at Chinese efficiencies (having 22% higher energy use) and the remainder at European efficiencies. Energy inputs are modeled using the EDGE grid mix while for fuels the EDGE fuel mix for natural gas and fuel oil are modeled. Other fuels are not used for glass production. No post-consumer recycling input is assumed.

D. Plastic and polymer-based products and materials

This group includes nylon carpet, vinyl flooring, PVC-u window frames, expanded polystyrene, and polyurethane foam, as well as wood/plastic composite window frames and linoleum sheet.

Although polymer-based products differ from steel and aluminum in their lower relative contribution to overall building impacts, plastic construction materials are similar to metal and glass in that raw materials (polymers) are commodities sourced from a global supply chain. They are also similar in that their cradle-to-gate impacts are dominated by raw material processing rather than product fabrication and assembly. Among the polymers used in this group of products (polystyrene and polyurethane foams, PVC, nylon, and composites) none is widely recycled back to a virgin equivalent after use in the construction sector, nor typically expected to contain post-consumer recycled content. Therefore, recycled content does not have a significant influence on impacts for products in this category, in contrast to the other product types in Group 1.

The most influential factors determining the impacts of this set of products are the energy mix, refinery production efficiency, and the hydrocarbon source used in polymer production.

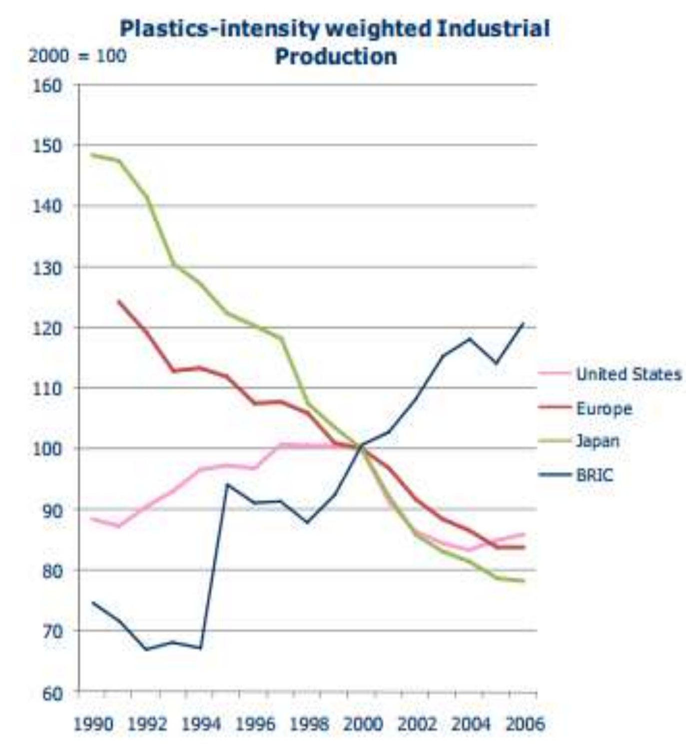

Figure 6: Plastics-intensity weighted industrial production (WRAP, 2014)

With the exception of linoleum and the wood content of composite products (such as window frames), plastic construction products are manufactured from petroleum and natural gas processed at refineries. The EDGE production route for plastic granulate is based on a refinery model and subsequent processing models that use petroleum as the starting feedstock. Subsequent fabrication steps are modeled using European unit processes powered by EDGE electricity and fuels.

A recent report on plastics production worldwide shows considerable growth in production capacity in the combined group of Brazil, Russia, India, and China (WRAP, 2014). Although the WRAP report covers a wide variety of polymers, the reported data includes the specific polymers relevant to the EDGE construction products. The report provides a strong indication that many of these raw materials are imported from major producers within the EDGE emerging economies group and that plastic production is best represented with an emerging economies mix than the global average mix for these plastics. Plastic production is therefore modeled using the EDGE emerging economies energy mixes in European production processes. For each final construction product (window frames, expanded polystyrene, polyurethane foam, etc.), the fabrication steps are also modeled using a European production technology with the EDGE emerging economies energy mixes for electricity and fuels.

For vinyl flooring and carpet, detailed process data which would allow remodeling using the EDGE energy models are not available at the time of writing this report. As such, embodied energy values for these resilient flooring and carpet materials are based on EPD which report European averages. The energy value for vinyl flooring represents homogenous PVC tiles.

Where necessary for determining the weight or thickness of flooring materials (e.g., carpet) the Floor Covering Standard Symbols (FCSS) class 32 and luxury class 2, which represent the typical specifications for commercial offices, are used.

VI. ADAPTATION PROCESS: GROUP 2

Group 2: Fuel-intensive, lower-cost materials, such as bricks, ceramic tiles, cement[2], and kiln-dried timber. These materials tend to be produced where resources such as limestone, clay, or timber are available. Their lower cost means that they are not likely to be transported long distances by road but may be imported by sea – this is particularly true for timber. Fuel source and technology have significant effects on their impacts.

A. Clay-based products

Clay-based products in the EDGE Dataset include several types of brick and tile. Production of bricks in emerging economies, notably in the largest brick producers, India and China, show a particularly wide variation in manufacturing energy demand.

Bricks (facing brick, common brick, honeycomb clay block)

Brick is an important material within the EDGE Dataset due to its widespread production and use in EDGE economies, as well as its large mass contribution as a bulk structural material. While brick does not have high specific embodied energy when compared with other construction materials such as metals, as a structural material it represents a large proportion of construction mass where it is used. Considering the high priority of brick among the construction materials in the EDGE Dataset a detailed modeling approach is required with regard to kilning technologies.

Kilning has the greatest influence over impacts in the brick cradle-to-gate life cycle, which includes clay extraction and processing, brick forming, drying, and firing. Energy consumption in brick firing is highly variable within the emerging economies due to the variety of kilns and fuel types used, and there are also variations from country to country, as shown in Table 9. In modeling brick production, a mix of kilning technologies is used covering both modern tunnel kilning and lower technology kilns, based on production in the top five producing countries as detailed in the following section. The energy used in firing is modeled based on the EDGE grid mix and EDGE fuel heat mix datasets.

Brick is widely employed in EDGE economies for construction and brick production accounts for considerable portions of industrial energy consumption, with notable examples of high energy use by the sector in India and China. The total energy consumption of the brick-making industry in China is estimated at 119 million tons of coal equivalent (tce), which is about 30% of the energy used in the entire informal/artisanal manufacturing sector (formally the "Town and Village Enterprise" industrial sector). In India, the conventional practice of firing clay bricks in rural country clamps and Bull's Trench kilns consumes enormous quantities of fuel in the form of coal as well as firewood and other biomass fuels. It is estimated that the Indian brick industry consumes more than 24 million tons of coal annually in addition to several million tons of biomass fuels (TERI, 2001) (Asian Institute of Technology, 2003).

Clamping, the most ancient method of brick firing, involves stacking green bricks over a fuel pile which is then ignited and manually managed. Scotch kilns and intermediate clamp kilns are variations on the clamp kiln where more permanent structures are built around the pile. Among all nations, India continues to maintain the largest capacity of brick production via clamp kilning. The Bull's Trench and Hoffman kiln (also known as an annular kiln) types are both continuous firing kiln structures and are the most widely used globally, with the Bull's Trench dominant in India and Hoffman most popular in China. Vertical shaft kilns, developed in the 1950s, are more efficient but represent less than 1% of global production (Swiss Agency for Development and Cooperation, 2014), finding most use in Vietnam. Tunnel kilning is a continuous, automated

[2] Cement is not a product used directly within the EDGE Dataset but has a major impact on concrete products, which are covered separately in Group 3.

process and is the most modern production approach. Modern tunnel kilning is present in many EDGE emerging economy countries and is the kilning technology used most widely in developed economies.

Table 9: Specific energy consumption of various brick kilning technologies (Asian Institute of Technology, 2003)

Country	**Technology**	**MJ/kg product**
China	Intermittent kiln	2.47
	Natural drying & Hoffmann kiln	1.16- 1.46
	Artificial drying & Hoffmann kiln	1.39- 1.56
	Tunnel kiln	1.29- 1.52
India	Intermediate clamp kiln	3-11
	Scotch kiln	1.5-7
	Bull's Trench kiln	1.8-4.2
	Hoffmann kiln	1.5-4.3
	Tunnel kiln	1.5-2
Sri Lanka	Down draft batch kiln	5.83
Vietnam	Vertical kiln	6.15-9.23
	Beastly kiln	4.11-6.37
	Hoffmann kiln	2.9-3.08
	Tunnel kiln	2.42

Asia is the largest global producer of bricks. Chinese production is estimated at 900 billion bricks/year for 2004, with 90% produced in Hoffman kilns and by open air drying (Baum, Presentation Black Carbon from Brick Kilns, 2010). India is estimated to produce around 260 billion bricks/year with over 70% production from Bull's Trench kilns (UNEP, 2014) (Swiss Agency for Development and Cooperation, 2014). In contrast, the brick-producing EDGE economies in the Americas (Argentina, Bolivia, Brazil, Colombia, Ecuador, Honduras, Mexico, Nicaragua, and Peru) together produce less than 0.1 billion bricks per year (Climate and Clean Air Coalition, 2014), accounting for less than 0.1% of world production.

Global brick production is illustrated in Figure 7, highlighting the five largest brick producers among the EDGE emerging economies: China, India, Pakistan, Vietnam, and Bangladesh.

To model brick making, a mix of modern and traditional kilning technologies is used. Modern kilning is modeled based on a continuous tunnel kilning process using European technology with energy adapted using the EDGE energy mixes.

China, India, Pakistan, Vietnam, and Bangladesh represent over 80% of EDGE emerging economies brick production (Figure 7). The kilning types in these countries are used to define the kiln technology mix used to model lower technology brick production. A new unit process is developed with energy consumption based on an average of reported energy consumption per unit mass for this kiln mix.

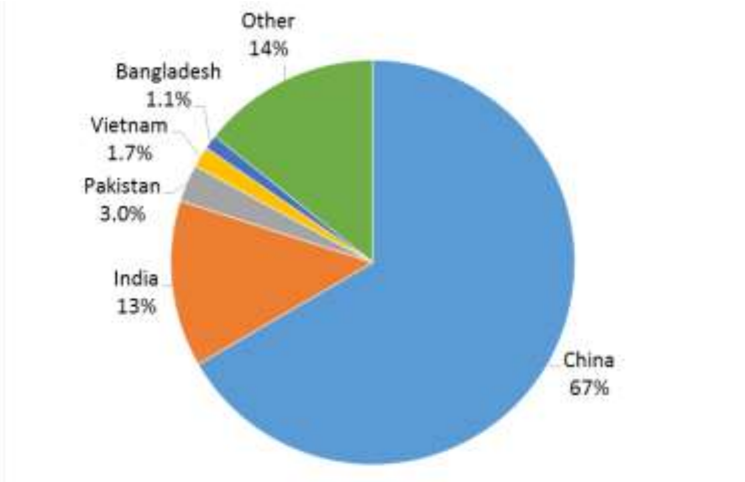

Figure 7: Global brick production by percentage volume (Baum, 2012)

For each of the five top brick producers among the EDGE emerging economy list (China, India, Pakistan, Bangladesh, and Vietnam) the production capacity by kiln type is reported in Table 10. Brick production capacity in EDGE economies includes large contributions from rural, remote, or small-scale sources which could be under-represented in industry production statistics. Total production capacity for each of the top brick producing nations is based on 2012 annual production values from a research report which captures this small-scale and rural production (Baum, 2012). The mix of kiln technologies for India, Pakistan, Bangladesh, and Vietnam are based on recent UNEP research reports (UNEP, 2014) which detail production capacity for each kiln technology. Kiln technologies for China are based on a reported 90% Hoffman kiln penetration (Baum, 2010), with a split of the remaining capacity among the two most disparate kiln types which are known to be used in China: modern tunnel kilning and clamp kilning.

Table 10: Production capacity by kiln type for top EDGE brick producers (billion bricks per year) (UNEP, 2014) (Baum, 2012)

Technology	China	India	Pakistan	Bangladesh	Vietnam	Sum capacity
Modern continuous tunnel	50	0.08			10.5	60.58
Hoffman, hybrid Hoffman	900	2		0.12		902.12
Bull's Trench, Fixed Chimney Bull's Trench Kiln (FCBTK)		185	56	17.4		258
Vertical or vertical shaft brick kiln (VSBK)		0.3			1.8	2.1
High-draught zigzag, natural zigzag, down draught kiln		10.49		0.75	0	11.24
Clamp kiln, intermediate clamp kiln, Scotch kiln	50	50				100

From this information the percentage capacity of each kilning technology is calculated. The resulting mix is presented in Table 11.

Table 11: Kiln technology mix for EDGE emerging countries

Kiln type	% total
Hoffman and hybrid Hoffman	67.6%
Modern continuous	4.5%
Bull's Trench, Fixed Chimney Bulls Trench Kiln (FCBTK)	19.4%
Clamp kiln, intermediate clamp kiln, Scotch kiln	7.5%
Vertical or vertical shaft brick kiln technology (VSBK)	0.2%
High-draught zigzag, natural zigzag and down draught	0.8%

Modeling for the modern tunnel kiln is based on a European process model fueled by the EDGE energy mixes. For all other kiln types, the specific energy consumption for each kiln type is based on reported values (Asian Institute of Technology, 2003). Where multiple regional reported data points are available, the value from the dominant brick producing country is used. For the Hoffman kiln, the dominant Hoffman producer is China; for Bull's Trench, India. For clamp kilns, an average of the intermediate and Scotch kilning values from India is used. The group of remaining kiln types (high-draught zigzag, natural zigzag, and down draught) are represented by the Sri Lankan down draught as there are no reported values for high-draught zigzag or natural zigzag kilning.

The resulting energy consumption per kg brick produced by the mix of the technologies, excluding the modern tunnel kiln, is calculated from the weighted average for each technology as reported in Table 12. Energy inputs to this kilning process technology mix are the EDGE emerging economies fuels mix.

Table 12: Kilns and associated specific energy consumption values composing the EDGE brick kilning technology mix

Kiln type	MJ/kg brick
Hoffman and hybrid Hoffman	1.3
Bull's Trench, Fixed Chimney Bulls Trench Kiln (FCBTK)	3.0
Clamp kiln, intermediate clamp kiln, Scotch kiln	5.6
Vertical or vertical shaft brick kiln technology (VSBK)	7.7
High-draught zigzag, natural zigzag and down draught	5.8

Ceramic tiles, terracotta tiles, clay roofing tiles

Energy consumption from the production of ceramic tiles, terracotta tiles, and clay roofing tiles is driven by kiln efficiency and the energy mix used in firing, as in brick production. Energy consumption for clay, ceramic, and terracotta tile production is not reported widely in the literature, though process descriptions indicate that terracotta and ceramic tiles are fired at higher temperatures than clay brick.

The available data for manufacturing non-glazed stoneware tiles and clay roofing tiles, reflecting European technologies, are used in combination with the EDGE energy mixes to represent terracotta floor tile and clay roof tile production for the EDGE Dataset. The European glazed stoneware tile process data is modeled with an additional firing process to represent ceramic floor tiles.

B. Kiln-dried timber

The factors having the greatest influence over the energy and climate change impacts of kiln-dried construction wood are:

- Energy mix in kiln drying;
- Moisture content of green logs (wood before kilning); and
- Density of wood.

Energy-related impacts in the cradle-to-gate production of timber are dominated by kiln drying, while energy used in felling, hauling, and sawing contribute to a much lower extent. Kilning, which involves drying green logs to a moisture content below 19%, is very much dependent on the original moisture content of the green log. The density of the final wood log is an additional factor that affects impacts per unit mass of wood. While other construction materials have a specified or very narrow range of densities, construction timber can meet strength requirements at a relatively wide range of densities. Therefore, the density of the final timber is important in determining the energy-related impacts per unit mass of the product in this category.

China, Brazil, Chile, and Russia are all major producers of sawn timber for construction, together producing 66% of all sawn logs, veneer logs, and sawn wood for construction in the EDGE emerging economies by volume in 2013 (FAO, 2014). Exports from China, Brazil, Chile, and Russia for sawn logs, veneer logs, and sawn wood for construction far outweighed imports in 2013. Based on FAO reported production and trade figures, EDGE emerging economies are not highly dependent on construction timber imports from the largest timber producers among the non-EDGE economies (the US, Canada, Sweden, Germany and Finland) (FAO, 2014). The mix of construction timber consumption among the EDGE economies is thus found to be represented well by the mix of production within the EDGE emerging economies, as expected for a product in Group 2.

To obtain values for average green moisture content and density of timber in the EDGE economies, the literature has been reviewed and best estimates selected to account for the larger fraction of hardwood found in the EDGE economies versus developed countries. While Russia and China are large timber producers and span more temperate regions where there are larger fractions of softwood (coniferous, evergreen) timber, when looking at the global distribution of the EDGE economies, tropical latitudes are disproportionately represented.

The moisture content of green wood varies widely. Climate (tropical, temperate, etc.) provides very little indication of average moisture content of timber as the ranges of moisture content in hardwoods (deciduous) and softwoods (evergreen or coniferous) overlap. Within a given species, moisture content will vary by about 10% based on climate and the time of year at which it is felled. However, given the very large number of timber species produced in the EDGE economies, a truly representative average based on species produced would be limited by lack of detailed production data.

Given the variability in wood moisture content, an average value of 95% (dry basis) for green wood is calculated based on a review of softwood and hardwood literature values, accounting for moisture content differences in heartwood versus sapwood in softwood timber (Shmulsky & Jones, 2011). The density of wood is represented by an average value of 580 kg/m^3.

In the models for timber products it is assumed that timber is kiln dried, with no fraction of air drying. The energy required in kilning is calculated from the wood density and moisture content of the green logs using an existing process model for kilned wood. The fuel mix used in kiln drying is based on the EDGE emerging economies heat fuel mix.

The eco-system value of tropical hardwood

Brazil is one of the largest construction timber producers and exporters among the EDGE economies. As it is located largely within tropical latitudes it is important to consider the special case of tropical wood as well as the state of logging in Brazil. Tropical hardwood is exceptional in its physical properties, and therefore may have special kilning requirements.

In some cases, it may not be necessary to kiln dry tropical timber for construction purposes. Many tropical species suitable for general construction possess good air drying characteristics, and it is possible to reduce moisture content to below 20% by air drying, even in tropical climates, to render it safe from rot (Falconer, 1971). The main problem with air drying is the space and time consumed. It takes up to four times as long to air dry as it does to kiln dry, and therefore air drying is not necessarily an economic production choice in all cases, even when achievable. However, where air drying is possible it will result in lower environmental impacts than kiln drying.

Trees serve an important ecological role, particularly in old growth or ancient forests. Current on-the-ground research in Brazil by Greenpeace has provided insight into illegal logging and laundering practices to give a more detailed understanding of how illegal logging bypasses regulation and oversight through subterfuge and laundering (Greenpeace, 2014). Due to the unlawful and undocumented nature of predatory logging, estimates vary for the quantities of timber that are illegally logged in Brazil. While the Forest Trust reports that "*over 95% of sawnwood exports from Brazil are still hardwood, mainly from Amazonia*" (TFT, 2013), the International Tropical Timber Organization found in 2011 that illegal harvesting represented 35–72% of logging in the Brazilian Amazon (ITTO, 2011). Providing a more definitive perspective, the Brazilian space agency (INPE) determines, through satellite mapping, the area of Amazonian forest lost each year. In 2013, the total area of forest lost in Amazonia was 5,891 square kilometers (INPE, 2014). Forest loss at this scale supports estimated figures for volumes of illegal logging which could represent over 75% of Brazilian timber production. By any estimate, logging of virgin forest represents a serious issue for timber products in the EDGE economies, with deforestation in Brazil being a primary example.

The ecosystem value of tropical hardwood species in many countries in South America, Africa and Asia is very high, and tropical regions are composed predominantly of EDGE emerging economy nations. Additionally, due to the potentially lower energy consumption of air dried wood compared to kiln dried wood, there is a danger that decision-making based only on the embodied energy may result in perverse incentives for illegally logged tropical wood. As such, we note that embodied energy alone can provide an incomplete picture of environmental impacts associated with timber.

C. Ordinary Portland cement

The principal drivers of impacts in Ordinary Portland Cement production are:

- Efficiency of cement kilning
- Fuel mix used in kilning

Energy consumption data from the World Business Council for Sustainable Development Cement Sustainability Initiative (WBCSD CSI) is used, except in China and the Middle East, where an energy intensity for clinker of 3.94 GJ/ton data (WWF, 2008) is used. The WBCSD CSI reports audited data for the energy, fuel, and alternative cementitious material use of their members globally (WBCSD, 2014), and represents the best available energy consumption data for these producers. China dominates production of clinker, the main ingredient of cement, producing 61% of the clinker produced in the EDGE regions. However, WBCSD members only account for 4% of Chinese cement production so there is insufficient coverage for the WBCSD energy consumption data to be representative for this study. The situation is similar for the Middle East, which produces 9% clinker in the EDGE regions but where WBSCD members only account for 12% coverage. For the other regions WBCSD data are representative for EDGE economies. Information on production, coverage, and energy consumption per ton of clinker for the EDGE regions is provided in Table 13 below.

Table 13: Percentage (%) production of clinker and energy used for emerging economy regions

Country/region	**Total Production, million metric tons**	**Production, %**	**WBCSD member coverage**	**Weighted average thermal energy consumption, MJ/t**
China	1.70	61%	4%	Insufficient coverage
Asia (excl. China, India, CIS) + Oceania	340	12%	36%	3320
Middle East	240	9%	12%	Insufficient coverage
India	190	7%	47%	3120
Africa	120	4%	44%	3700
Brazil	45	2%	78%	3610
CIS	69	2%	20%	5610
Central America	40	1%	77%	3510
South America ex. Brazil	38	1%	54%	3760

In addition to the energy use per metric ton of clinker, WBCSD also provides the fuel mix used for clinker production in each region, as shown in Table 14 for the regions with sufficient data coverage. The fuel mix for the relevant WBCSD regions are used to generate the overall cement fuel mix where WBCSD has sufficient coverage. For the remaining regions the emerging economies fuel mix is used.

Table 14: Percentage (%) fuel use for cement in emerging economy regions, sourced from WBCSD CSI

% fuel use for cement in emerging economy regions with sufficient data coverage (WBCSD)	Africa	Brazil	Central America	CIS	India
Coal and anthracite and waste coal	8.9	2.7	8.1	47.4	72.6
Petroleum coke	19	96.8	88	0.4	27.1
Ultra heavy fuel oil	19.1	0.3	[3]0.7	0	0
Diesel	0.4	0.3	0.2	0.3	0.1
Natural gas	52.5		3.1	51.8	0
Shale	0			0.1	0
Lignite	0				0.1

The emerging economies Ordinary Portland Cement dataset is based on 95% clinker (modeled as described above) with 5% natural gypsum. Electricity consumption for cement production is modeled using the EDGE electricity mix.

VII. ADAPTATION PROCESS: GROUP 3

Group 3: Concrete and gypsum products, such as concrete blocks and plasterboard, where the input materials of cement and gypsum have a large effect on impact. Use of alternative raw materials such as ground granulated blast furnace slag (GGBS), pulverized fuel ash (PFA), or flue gas desulfurization (FGD) gypsum also has a large influence on impacts.

A. Concrete products

The concrete products provided in the EDGE Dataset are lightweight concrete block, medium weight concrete block (hollow), dense concrete block, autoclaved aerated concrete block (aircrete), FaLG (fly ash/lime/gypsum) block, cement based plaster, "ferrocement" wall panel, precast reinforced concrete panels/flooring, cement screed, Ordinary Portland Cement (OPC) ready-mix concrete, PFA ready-mix concrete, GGBS ready-mix concrete, and micro-concrete roof tiles.

Manufacturing impacts for these concrete products generally account for a very small proportion of cradle-to-gate or life-cycle impacts. Overall impacts are dominated by the production of the "mix" ingredients, particularly the amount of cement and the use of alternative cementitious products such as PFA and GGBS. The impact of the Ordinary Portland Cement is therefore highly influential and the EDGE OPC dataset is used as described in chapter VI, above.

The WWF estimates that the use of cementitious alternatives, such as slag and PFA, already accounts for around 25% of all cement use in China and 30% in Brazil, but suggests that across developing countries in general a much lower figure is

[3] Commonwealth of Independent States

currently achieved (WWF, 2008). For ready mix concrete, this variation is considered by providing datasets for three concrete options – one using OPC, one using OPC with 25% GGBS clinker replacement (GGBS ready-mix concrete), and one using OPC with 30% PFA clinker replacement (PFA ready-mix concrete). For the precast and masonry products, a clinker replacement of 5% GGBS and 5% PFA is assumed. For precast concrete, 4.8% steel reinforcement (or 120 kg/m^3) has been assumed within the modeled product but results for different levels of steel reinforcement content can to be calculated using the EDGE steel reinforcement dataset. Other production data and inputs are based on European production, but with electricity use adapted to represent the grid mix of emerging economies.

For lightweight concrete products a broad range of aggregate sources is available, including pumice, waste aircrete, expanded clay or shale, PFA, furnace bottom ash (FBA), and slags. The choice of aggregate will depend on local availability. Only the expanded clay or shale has significant impacts from the use of thermal energy. Products such as pumice have minimal extraction impacts and the other materials are by-products or wastes with minimal impact. For the EDGE Dataset it is assumed that pumice is the lightweight aggregate used.

FaLG (fly ash/lime/gypsum) block is modeled with a constituent ratio by mass of PFA (23%), lime (18%), gypsum (5%), dust (45%), water (9%), and a density of 1760 kg/m^3. These products are modeled as hand mixed and molded[4].

Ferro-cement is modeled with a constituent ratio by mass of sand (23%), OPC (45%), and water (32%) (1:2:1.4) formed into 1m^2 25mm thick panels with 16m x 3mm reinforcing steel bar and 1m^2 chicken wire[5]. Fabrication is assumed to be hand mixed and molded.

B. Gypsum products

These products include gypsum plaster, gypsum panels, plasterboard, and phosphogypsum panels.

The source of gypsum, the calcining of gypsum, and the production process for plasterboard and gypsum panels are the processes that most affect energy consumption and associated environmental impacts for gypsum products.

Gypsum products were traditionally made with natural gypsum, but synthetic gypsum can also be used, such as flue gas desulfurization (FGD) gypsum, titanogypsum, or phosphogypsum. FGD gypsum is a by-product of emissions control technology used to remove SO_2 from combustion gases in coal and oil power stations. Titanogypsum is produced from the treatment of sulfuric acid generated from the production of titanium dioxide. Phosphogypsum is produced when phosphate ores[6] are treated with sulfuric acid to produce phosphates for fertilizer. Synthetic gypsums are low-value by-products from other processes. Allocating impacts between co-products based on economic value means that these products generally have lower environmental impacts than natural gypsum. However calcining of gypsum, which is required whether natural or synthetic gypsum is used, is still significant for gypsum products. Other steps in the production process (predominantly requiring electricity) are responsible for around 50% of the impacts of panel and board products.

Potential world production of synthetic gypsum almost certainly exceeds the current output of natural gypsum, but the amount used commercially is much smaller and synthetic gypsum does not yet appear to be widely used in the emerging economies. The majority of synthetic gypsum production is phosphogypsum (up to 100 million metric tons per year), followed by FGD gypsum (40-50 million metric tons per year), titanogypsum (6-7 million metric tons per year), and other sources (1-3 million metric tons per year) (PR Newswire, 2014). Due to the large amounts of phosphogypsum which could be used, specific phosphogypsum products are modeled using this resource. The increasing use of FGD technology for coal-fired power stations should increase the availability of FGD gypsum in China. It is suggested that currently around half of all global installed FGD capacity is in China, and this is expected to double the amount of FGD there by 2020 (McIlvaine Company, 2014). It is estimated that 8.5 million metric tons per year are currently produced in China. As such, the EGDE gypsum dataset is modeled based on a mix of 10% FGD gypsum and 90% natural gypsum.

For plaster, plasterboard and gypsum panel production modeling is based on European datasets with the EDGE emerging economies electricity mix. Compared to cement, less information is available on gypsum calcining globally. As such, the

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[4] see http://fal-g.com/aboutus.php and http://ijret.org/Volumes/V02/I13/IJRET_110213072.pdf

[5] http://www.ruralhousingnetwork.in/technical/ferrocement-wall-panels/Design
http://www.ruralhousingnetwork.in/technical/ferrocement-wall-panels/Design

[6] Where phosphate ores are radioactive, this will result in radioactive phosphogypsum. The IAEA has produced a guide to the safe use of phosphogypsum (IAEA, 2013).

energy mix generated for EDGE clinker kilns (see chapter VI) is used as the basis of the gypsum dataset, as these are both heat-intensive processes and likely to use the same types of fuels, based on economics and availability. As in the approach for glass (see section V), a 15% increase in energy intensity is modeled to account for lower expected process efficiency in EDGE countries.

VIII. ADAPTATION PROCESS: GROUP 4

Group 4: electricity-intensive, high-value goods such as stone, insulation, and timber board products. The electricity source and, in some cases, recycled content generally have the greatest influence on the impacts.

A. Stone (local stone blocks, stone tiles/slabs)

A life cycle assessment for Scottish stone shows that the major impact is due to the use of electricity for stone processing (Historic Scotland). This report also suggests that processing of stone in countries such as India and China would have lower impact as more processes would be undertaken manually. Other factors that influence the impact are:

- The type of stone (granite being much harder than sandstone for example).
- The size of quarry – Spanish stone is expected to have lower impact than Scottish stone due to the economies of scale of the much larger Spanish quarries. This argument applies to quarries in India and China which are also generally much larger than those in the UK.
- The degree of finishing – a polished granite slab will inevitably have a higher impact than split block.
- The transport of stone by road – unless the product value is high it is assumed that stone will only be used relatively locally (within 200 km).

Stone blocks for construction are produced from quarried rock primarily using electrical cutting processes. Although manual stone cutting also exists, very little information is available on the extent of hand cut stone production so this has not been modeled.

Natural stone block cutting processes are modeled based on European production using the EDGE emerging economies electricity mix.

B. Mineral wool insulation (glass wool, stone wool)

The major production impact of mineral wool insulation is due to the energy required to melt and extrude the mineral wools. The replacement of primary input with recycled glass cullet (glass wool) and blast furnace slag (stone wool) has some environmental benefits but is not yet prevalent in emerging economies. A 71:29 ratio of stone wool to glass wool by mass is assumed.

Mineral wool is modeled based on European production processes using the EDGE energy mixes.

C. Wood products (laminated wooden flooring, plywood sheathing, timber window frames)

For most timber products, the major impact is the energy required to reduce the moisture content of the timber from the high values found in the forest to the low values (5-15%) required for use in products, as described in section B. Additionally for laminated wooden flooring and plywood a significant amount of electricity is required for processing.

Among the group of EDGE emerging economies, Malaysia, Brazil, and India are all major producers of plywood while China and Brazil are major producers of particleboard (FAO, 2014). As large production sources exist within the emerging economies for wood-based construction products, consumption is not dominated by imports from outside of the EDGE group of countries.

To model processed wood products, the EDGE kiln-dried timber dataset (see section VI) is further processed in steps for laminated flooring, plywood, and window frame production, based on European or German datasets for these processes. The EDGE grid mix and EDGE fuel heat mix datasets are applied.

IX. ADAPTATION PROCESS: GROUP 5

Group 5: Natural raw material-based products, such as stabilized soil blocks, rammed earth, straw bale, and jute. These materials are generally produced and used locally, with similar processes and low impact.

A. Earth products: stabilized soil blocks, rammed earth, and mud plaster

The use of cementitious material to stabilize the soil is the main impact. As for concrete products, the use of alternative cementitious materials such as GGBS or PFA has much lower impacts than Ordinary Portland Cement (OPC) or lime.

Stabilized soil blocks, rammed earth, and mud plaster all have impacts associated with soil extraction – these are minimal if manual labor is used, but are low even if mechanical extraction is used. As a conservative approach, German data for excavated soil (using a mechanical digger for the earth elements of these products) is used.

For rammed earth, the "ramming" process can be manual or mechanical as modeled, but in either case the impact remains minimal. Three types of stabilized earth blocks are modeled based on the rammed earth dataset with additions of 8% OPC, 8% GGBS, and 10% PFA respectively.

Mud plaster is modeled based on a European clay plaster, with EDGE electricity grid mix and EDGE fuel heat mix datasets applied.

B. Bio-based products: jute, sawn timber, straw bale

Jute

Jute is a natural fiber grown with minimal use of fertilizers in areas of significant rainfall – predominantly in India and Bangladesh. India is the major user of jute, importing as well as using its own production. Bangladesh is the major exporter, with Brazil and Côte d'Ivoire also being importers. Jute production involves soaking the stems of the jute plant in water and further processing including a drying process to produce fibers.

EDGE data for jute is representative of Indian jute agricultural production and processing.

Air-dried sawn timber

Air-dried sawn timber (not kiln-dried) requires minimal agricultural and processing impacts. Timber needs to be seasoned for use in a building but air drying takes time and can result in uncontrolled shrinkage. Its use is therefore only likely in areas where kiln drying is not locally available. An existing Brazilian model for kiln-dried teak is adapted for this dataset, removing the modeled kiln drying to represent air drying.

Please also refer to the discussion on air-dried vs. kiln-dried timber reported in section VI.

Straw bale

Straw bale is a low value by-product of agricultural production of grain crops and has minimal impact, based on the relative economic value of straw to grain. The European wheat straw dataset from GaBi is used to model this dataset.

X. DATA QUALITY

Software models for the EDGE construction materials are generated using the GaBi software which cover the significant input and output flows of material and energy for each underlying unit process.

Data quality and uncertainty are mutually dependent. The precision of LCI data depends on measuring tolerance, assumptions, completeness, and comprehensiveness of the considered system and on the representativeness of underlying data.

Uncertainty of +/- 10% is considered to be the best achievable, even if a model is set up with high quality data. For the EDGE Dataset the uncertainty is likely to be higher due to the assumptions that are necessary when adjusting existing models to fit data for the EDGE emerging economies.

The EDGE Dataset is comprised of average values that are not intended to be representative of any individual producer's product nor production within a specific country.

XI. 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 15804:2012-04: Sustainability of construction works - Environmental Product Declarations - Core rules for the product category of construction products
EN ISO 14025	EN ISO 14025:2011-10 Environmental labels and declarations - Type III environmental declarations - Principles and procedures
EN ISO 14040	EN ISO 14040:2009-11 Environmental management - Life cycle assessment - Principles and framework
EN ISO 14044	EN ISO 14044:2006-10 Environmental management - Life cycle assessment - Requirements and guidelines
GaBi 6	GaBi 6.3 dataset documentation for the software-system and databases, LBP, University of Stuttgart and PE INTERNATIONAL AG, Leinfelden-Echterdingen, 2014 (http://documentation.gabi-software.com/)
EC JRC-IES 2010	European Commission Joint Research Centre Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - Specific guide for Life Cycle Inventory data sets. First edition March 2010. EUR 24709 EN. Luxembourg. Publications Office of the European Union; 2010
IBU 2013 PART A	PCR - Part A: Calculation rules for the Life Cycle Assessment and Requirements on the Background Report, Version 1.2, Institut Bauen und Umwelt e.V., www.bau-umwelt.com, 2013

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XIII. Appendix: Methodology Summary Table

The following table summarizes the modeling approach and the GaBi datasets that are used to generate datasets for the EDGE construction materials database. The underlying models for these datasets are sourced from the GaBi Master Database. In some cases, unit processes for a single process step are used directly, while in other cases the system model is adapted to use an energy source or mix as appropriate to achieve the highest level of representativeness possible within the project scope. In a few instances, an original GaBi dataset or literature source is used directly to represent the EDGE product, as in the cases of carpet, straw and jute.

Material	Primary energy demand (MJ/kg)	Modelling Approach and assumptions
EDGE fuels	Intermediate product	Geographic mix for each fuel/energy type: China 54%, Russia 13%, India 12%, Brazil 6.3%, Indonesia 3.6%, Thailand 2.9%, Mexico 2.4%, Ukraine 2.1%, South Africa 1.7%, Turkey 1.5%
EDGE electricity grid mix	Intermediate product	IEA primary energy input: coal 55%, natural gas 23%, hydro 7%, oil products 7%, nuclear 5%, biomass 2%, geothermal 1.0%
EDGE heat mix	Intermediate product	Geographic mix for each fuel thermal energy type: China 54%, Russia 13%, India 12%, Brazil 6.3%, Indonesia 3.6%, Thailand 2.9%, Mexico 2.4%, Ukraine 2.1%, South Africa 1.7%, Turkey 1.5%
High efficiency BF/BOF steel	Intermediate product	Base dataset: IN: BF Steel billet / slab/ bloom http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d6cbbc25-5c86-4a93-8b5e-bb97955f3414.xml Electricity modelled as EDGE grid mix Coke from EDGE coal used as the BF fuel Recycled content 15.5%
Lower efficiency BF/BOF steel	Intermediate product	Base dataset: IN: BF Steel billet / slab/ bloom http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d6cbbc25-5c86-4a93-8b5e-bb97955f3414.xml Electricity modelled as EDGE grid mix Coke from EDGE coal used as the BF fuel Recycled content 15.5% 170% increase in energy consumption for coking and sintering 130% increase in energy consumption for BF 250% increase in energy consumption for BOF
Scrap EAF	Intermediate product	Base dataset: confidential Electricity modelled as EDGE grid mix 100% recycled content
DRI/EAF	Intermediate product	Base dataset: confidential Electricity modelled as EDGE grid mix Recycled content 0% recycled content
Steel section 7850 kg/m^3	29.5 MJ/kg	Base dataset: DE: Steel section http://gabi-documentation-2014.gabi-software.com/xml-data/processes/8a8ca733-29ab-4141-85da-51a2d10baefe.xml Production mix: 35% high efficiency BF/BOF, 35% low efficiency BF/BOF, 25% scrap EAF and 5% DRI/EAF Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Steel sheet Electrogalvanized (hot rolled) "corrugated zinc" 7850 kg/m^3	19.2 MJ/kg	Base dataset: DE: Steel sheet parts (galvanized) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/8bacf381-345b-487f-a970-eb6f406171f9.xml Production mix: 47.5% high efficiency BF/BOF, 47.5% low efficiency BF/BOF, 5% scrap EAF Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Steel – organic coated profiled steel Steel window frame 7850 kg/m^3	34.2 MJ/kg	Base dataset: CN: BF Steel billet / slab / bloom, and DE: EAF Steel billet / slab / bloom Production mix: 0,475% high efficiency BF/BOF, 0,475% low efficiency BF/BOF, 0.05% scrap EAF Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Steel reinforcement 7850 kg/m^3	12.7 MJ/kg	Base dataset: DE: Steel wire http://gabi-documentation-2014.gabi-software.com/xml-data/processes/c7049ac3-9e4a-47a1-a8b7-0f5b93e2d7af.xml Production mix: 5% high efficiency BF/BOF, 5% low efficiency BF/BOF and 90% scrap EAF Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
EDGE Aluminum primary ingot mix	Intermediate product	Base dataset: DE: Aluminium ingot mix (consumption mix) EAA update 2010 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/05f94d68-6435-4312-9ae2-091abadc5b24.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix

EDGE Aluminum secondary ingot mix	Intermediate product	Base dataset: EU-27: Aluminium recycling including scrap preparation EAA 2009 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/ee5c6b93-b51f-4257-80b5-e51da2b226f3.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
EDGE Aluminum ingot production mix	Intermediate product	84% EDGE primary ingot 16% EDGE secondary ingot
Aluminum profiled cladding 2712 kg/m^3	137 MJ/kg	Base dataset EU27: Aluminium sheet http://gabi-documentation-2014.gabi-software.com/xml-data/processes/963676c0-a8da-42f3-8a88-779cdf6c5c2c.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Aluminum extrusion profile (window frame) 2712 kg/m^3	188 MJ/kg	Base dataset: DE: Aluminium casement frame section, powder coated http://gabi-documentation-2014.gabi-software.com/xml-data/processes/e9915c3a-d77b-4a7b-884b-fc171fd1ef76.xml Input: EDGE aluminum ingot production mix Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Float glass 2500 kg/m^3	17.9 MJ/kg	Base dataset: EU-27: Float flat glass http://gabi-documentation-2014.gabi-software.com/xml-data/processes/641ca70f-fca3-4f27-bac0-b8ad236efaff.xml No post-consumer recycled content 15% increase over Europe for all energy consumption Electricity modelled as EDGE grid mix Fuels: 81% EDGE natural gas fuel, 19% EDGE oil fuel
Carpet 2.11 kg/m^2	83.5 MJ/kg	Base dataset: EU-27: Carpet (GK 31 32, LC 2-3) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/6d1a21e3-edfc-4b92-800a-3c91cd540abf.xml No further adaptation
Linoleum 2.9 kg/m^2	43.0 MJ/kg	Base dataset: EU-27 Resilient flooring, Linoleum, EN ISO 24011, 1m^2 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/5dab6612-6b15-4d2e-b1e2-dd9a5422e8d0.xml No further adaptation
EDGE Plastic polymers (PVC, PS, PU, etc.)	Intermediate product	European production for each polymer plus Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Vinyl (PVC) flooring 3.2 kg/m^2	51.8 MJ/kg	Base dataset: EU-27 Resilient flooring, homogenous PVC, EN 649/ISO 10581, 1m2 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d503dc0d-4fab-441b-b29d-924097222a47.xml
PVC-u window frame 1.3-1.7 kg/linear meter	49.2 MJ/kg	Base dataset: DE: Window frame PVC-U (EN15804 A1-A3) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/698961dd-bab1-4c06-847c-4218e8fc2c82.xml EDGE Plastic polymer input (PVC) Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Expanded polystyrene insulation (EPS) 20 kg/m^3	82.6 MJ/kg	Base dataset: EU-27: EPS-Foam (expanded polystyrene foam (PS 20)) no flame retardant http://gabi-documentation-2014.gabi-software.com/xml-data/processes/9f091455-46c3-4a6f-9e76-cd92cb7d865a.xml EDGE Plastic polymer input Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Polyurethane rigid insulation foam 32 kg/m^3	123 MJ/kg	Base dataset: DE: Polyurethane (PUR high-density foam) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/8c8047b4-de6f-496e-86a4-224defb1b5ec.xml EDGE Plastic polymer input Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Wood plastic composite 990 kg/m^3	79.9 MJ/kg	New model. Only components considered Composition: 30% wood chips, 70% thermoplastic polyurethane Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix

Common brick and facing brick 1800 kg/m³	4.95 MJ/kg	Base dataset: CN: Brick; technology mix; production mix http://gabi-documentation-2014.gabi-software.com/xml-data/processes/266c5da8-55bc-4d58-a4af-cbf7724f7939.xml Kiln types and fuel consumption: Hoffman and hybrid Hoffman 67.6% Bull's Trench, Fixed Chimney Bulls Trench Kiln (FCBTK) 19.4% Clamp kiln, intermediate clamp kiln, Scotch kiln 7.49% Modern continuous 4.5% High-draught zigzag, natural zigzag and down draught 0.84% Vertical or Vertical Shaft Brick Kiln (VSBK) 0.16% Resulting fuel consumption: 3707.9 MJ/ton Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Honeycomb brick 815 kg/m³	2.02 MJ/kg	Base dataset: DE: Bricks vertically perforated; technology mix; production mix http://gabi-documentation-2014.gabi-software.com/xml-data/processes/23a8f311-c760-418c-af95-2cc4ec730895.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Terracotta tiles 2000 kg/m³	5.26 MJ/kg	Base dataset: BR: 1.3.07 Stoneware tiles unglazed 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/67639b48-b669-43f2-91d1-9492dee027c9.xml EDGE clay production Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Ceramic tiles 2000 kg/m³	7.96 MJ/kg	Base dataset: BR: 1.3.07 Stoneware tiles glazed 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/3ea2d263-5aa8-4bbc-b35b-008794487cd3.xml Firing process doubled to represent second firing. EDGE clay production Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Clay roof tiles 1800 kg/m³	6.94 MJ/kg	Base dataset: BR: 1.3.10 Roof tile 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/0a8ee061-3155-4e25-ab4b-fb4d8d20e01f.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Kiln-dried sawn timber 580 kg/m³	7.1 MJ/kg	Base dataset: Forest: BR: CULTIVATION TEAK LOG (estimated with Pacific Northwest) (low intensity) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/46d8534b-32da-468f-acf6-28d25edd145f.xml Sawmill: new model The thermal energy to dry the Wood was calculated. Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Plywood 491 kg/m³	14.2 MJ/kg	Base dataset: DE: plywood board (5% moisture) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/afd3614e-3233-4185-bf09-6d78314e4ec4.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Laminated wooden flooring 6.5 kg/m²	36.4 MJ/kg	Base dataset: DE: 3.3.2 Multi-layer parquet 1sqm http://gabi-documentation-2014.gabi-software.com/xml-data/processes/587e7b6f-5f77-4d80-9aa8-bb6232b26468.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Timber window frame 3.18 kg/linear meter	49.5 MJ/kg	Base dataset: DE: Window (IV 68 spruce) frame [p-agg] (wooden frame) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/b18f4d5d-a488-4f4c-8630-32f7fbccf480.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix Typical frame size: 5.093 m length of frame for a 1.23 m x 1.48 m window

EDGE Ordinary Portland Cement (EDGE OPC)	Intermediate product	Base dataset: CN: 1.1.01 Cement (average) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d57bd7db-cf9b-4327-ac67-392a885161f6.xml 95% clinker, 5% natural gypsum Electricity modelled as EDGE grid mix EDGE fuel consumption per ton clinker: 3709 MJ/kg EDGE clinker fuel modelled as: EDGE natural gas mix 3%, EDGE heavy fuel oil mix 1%, EDGE hard coal mix 90%, EDGE coke mix 5%
EDGE sand	Intermediate product	Base dataset: DE: Crushed sand grain http://gabi-documentation-2014.gabi-software.com/xml-data/processes/71d9b834-5be8-4ca4-8f1d-4b7e68e16810.xml Electricity modelled as EDGE grid mix Fuel modelled as EDGE OPC cement fuel mix
Aircrete (Autoclaved Aerated Concrete) 471 kg/m^3	3.54 MJ/kg	Base dataset: DE: 1.3.03 aerated concrete P4 05 not reinforced http://gabi-documentation-2014.gabi-software.com/xml-data/processes/6b3968d1-ca77-4940-91af-9ba89a0d1cd1.xml EDGE OPC and EDGE sand used Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Lightweight block 800 kg/m^3	1.30 MJ/kg	Base dataset: DE: 1.3.04 Pumice LB precision building block inner wall 1m^3 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/3f44f682-c5d1-4d11-bc44-60496b739a7e.xml EDGE OPC Pumice as lightweight aggregate Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Medium density block 1606 kg/m^3	0.66 MJ/kg	Base dataset: DE: 1.3.04 Pumice LB hollow block partition wall 1m3 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d309dee5-a08e-42d3-aab3-7eb82d6b4012.xml EDGE OPC Pumice as lightweight aggregate Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Dense concrete block 2000 kg/m^3	1.02 MJ/kg	Base dataset: DE: 1.3.05 Concrete masonry bricks, 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d4b01bd8-6c45-466f-a64c-a093ec81643a.xml EDGE ready mix concrete Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Cement floor screed 1590 kg/m^3	1.26 MJ/kg	Base dataset: DE: 1.4.3 Cement screed 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/e909f5ab-91db-424f-9a39-a187679923c1.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Lime: cement plaster 1174 kg/m^3	2.43 MJ/kg	Base dataset: DE: 1.4.4 Light plaster 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/0aefe389-3eb5-41c8-9b68-40ea674a46a4.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
OPC Ready mix concrete C30/C37 mix 2365 kg/m^3	0.82 MJ/kg	Base dataset: DE: Concrete C30/37 (Ready-mix concrete) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/94cd68ce-24da-4bea-87ca-5c751094de8b.xml EDGE OPC, EDGE gravel, EDGE sand Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
25% GGBS Ready mix concrete 2365 kg/m^3	0.72 MJ/kg	As OPC Ready mix concrete C30/C37 mix with 25% replacement with GGBS
30%% PFA Ready mix concrete 2365 kg/m^3	0.69 MJ/kg	As OPC Ready mix concrete C30/C37 mix with 30% OPC replacement with PFA

Precast concrete panels/flooring 2365 kg/m^3	1.45 MJ/kg	Base dataset: DE: 1.3.05 Prefabricated concrete part slab, 20cm, 1m3 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/7fdbb15f-ac34-48e6-b91c-bd8ff88aae4f.xml 95.2% EDGE: ready mix C30/37 concrete, 4.8% EDGE steel reinforcement. Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Microconcrete roof tile 1534 kg/m^3	2.41 MJ/kg	Base dataset: DE: 1.3.11 Concrete roof tile http://gabi-documentation-2014.gabi-software.com/xml-data/processes/d0678044-e370-4357-aa01-167b1fc91a0c.xml EDGE OPC, EDGE sand Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Cement-based terrazzo 1580 kg/m^3	1.88 MJ/kg	MIX DESIGN: 1: 2.5 cement sand by mass EDGE OPC, EDGE sand Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Ferrocement panel 50 kg/m^2	3.23 MJ/kg	Constituent ratio by mass: Sand (23%), EDGE OPC (45%) and water (32%) formed into 1m2 25mm thick panels with 16m x 3mm steel rebar and 1m2 chicken wire giving panel 50 kg/m2 EDGE sand, EDGE OPC, EDGE steel sheet parts
EDGE Calcined gypsum	Intermediate product	Base dataset: DE: 1.1.3 Gypsum (CaSO4-Beta-hemihydrate) 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/2abe6224-3a58-4804-b6de-c1f249d0621a.xml 10% FGD gypsum 90% Natural gypsum stone 15% increase over Europe for energy consumption Electricity modelled as EDGE grid mix Fuel is modelled as EDGE cement fuel mix
Gypsum plaster 1000 kg/m^3	1.99 MJ/kg	Base dataset: DE: 1.4.4 Gypsum interior plaster (gypsum) 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/b17878d7-c065-4a64-9a99-c33ef0772568.xml EDGE gypsum Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Plasterboard 800 kg/m^3	3.36 MJ/kg	Base Dataset:EU27 1.3.13 Gypsum plaster board (fire protection) 1sqm http://gabi-documentation-2014.gabi-software.com/xml-data/processes/cc39e70e-4a40-42b6-89e3-7305f0b95dc4.xml EDGE Calcined Gypsum as input Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Gypsum panel 840 kg/m^3	4.10 MJ/kg	Base dataset: DE: 1.3.13 Gypsum wallboard 1sqm http://gabi-documentation-2014.gabi-software.com/xml-data/processes/03d1c759-d8fd-4744-b2aa-2b94f148db3a.xml EDGE Calcined gypsum as input Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
EDGE Phosphogypsum	Intermediate product	Base dataset: DE: Phosphoric acid (100%) (wet process) http://gabi-documentation-2014.gabi-software.com/xml-data/processes/573e8ce0-499d-4c53-bd2f-aeb02ea534ae.xml Modelled as by-product from European Phosphoric Acid production using economic allocation
Phosphogypsum panel 840 kg/m^3	6.80 MJ/kg	Base dataset: DE: 1.3.13 Gypsum wallboard 1sqm http://gabi-documentation-2014.gabi-software.com/xml-data/processes/03d1c759-d8fd-4744-b2aa-2b94f148db3a.xml EDGE Phosphogypsum as input Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
FaLG (fly ash/lime/gypsum) block 1760 kg/m^3	1.35 MJ/kg	Constituent ratio by mass: PFA (23%), EDGE lime (18%), EDGE gypsum (5%), dust (45%), water (9%). These products are modelled as hand mixed and molded.
Cut stone for walls 2600 kg/m^3	4.62 MJ/kg	Base dataset: CN: 1.3.08 Natural stone slab, flexible, facade, 1m2 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/71fd8f14-d4d4-4cb1-9230-40295d3db2c1.xml Electricity modelled as EDGE grid mix

Stone floor tiles 2600 kg/m^3	8.60 MJ/kg	Base dataset: CN: 1.3.08 Natural stone slab, rigid, facade, 1m2 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/9e877fa1-0bc2-44cf-8a08-769260e22463.xml Electricity modelled as EDGE grid mix
Mineral wool 31 kg/m^3	19.1 MJ/kg	Base dataset: DE: 2.01 Mineral wool (partition walls insulation) 1m3 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/ed241209-07c7-4169-b45c-765bbbe62c8b.xml 29% glass wool at 15 kg/m3, 71% stone wool at 37 kg/m3 Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Excavated earth	Intermediate dataset	Base dataset: DE: Excavated soil with digger http://gabi-documentation-2014.gabi-software.com/xml-data/processes/322f857e-b6d0-4266-9df6-4312b14a63b9.xml Based on German excavated earth. No further adaptation.
Rammed earth 2000 kg/m^3	0.05 MJ/kg	Base dataset: DE: 1.3.17 Rammed earth wall 1 m3 http://gabi-documentation-2014.gabi-software.com/xml-data/processes/75a6e37d-a6a1-459d-af78-cc97d6709527.xml Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
OPC Stabilized soil 2000 kg/m^3	0.51 MJ/kg	EDGE Rammed Earth with 8% OPC
GGBS Stabilized soil 2000 kg/m^3	0.20 MJ/kg	EDGE Rammed Earth 8% GGBS
PFA Stabilized soil 2000 kg/m^3	0.24 MJ/kg	EDGE Rammed Earth with 10% PFA
Mud plaster 1600 kg/m^3	1.00 MJ/kg	Base dataset: DE: 1.4.4 Clay plaster 1kg http://gabi-documentation-2014.gabi-software.com/xml-data/processes/de3c3314-6e6f-44ac-b9a3-5fe34f990c02.xml Based on German clay plaster Electricity modelled as EDGE grid mix Fuel is modelled as EDGE fuel mix
Jute 120 kg/m^3	0.5 MJ/kg	Based on literature data from: Life Cycle analysis study of Synthetic, Jute and Paper Woven Sacks, Indian Centre for Plastics in the Environment (ICPE), New Delhi, 2002 Jan E.G. van Dam and Harriëtte L. Bos, The Environmental Impact of Fibre Crops in Industrial Applications, Agrotechnology and Food Innovations, (A&F) Wageningen, Netherlands Density from: Final progress report: Development of sound proofing composite materials using jute products, Indian Institute of Technology, Kharagpur & National Jute Board, Kolkata, India, 2013
Air-dried sawn timber 580 kg/m^3	3.6 MJ/kg	Base dataset: modified from EDGE kiln-dried timber, with removal of kiln drying
Straw bale 120 kg/m^3	1.3 MJ/kg	Base dataset: DE Winter wheat straw (price) http://gabi-6-lci-documentation.gabi-software.com/xml-data/processes/5e3002da-5e82-4538-88ac-2588b4957dcf.xml Based on German wheat straw (by-product from wheat production). No further adaptation.