UNIVERSITY OF BATH

INVENTORY OF CARBON & ENERGY (ICE)

Version 1.6a

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This project was joint funded under the Carbon Vision Buildings program by:

CARBON TRUST Making business sense of climate change

EPSRC

Available from: www.bath.ac.uk/mech-eng/sert/embodied/

Peer Review Source: Hammond, G.P. and C.I. Jones, 2008, 'Embodied energy and carbon in construction materials', *Proc. Instn Civil. Engrs: Energy*, in press.

Inventory of Carbon & Energy (ICE)

Welcome to the Inventory of Carbon & Energy (ICE) Version 1.6a. ICE is the University of Bath's embodied energy & embodied carbon database, and is the freely available summary of the larger ICE-Database. The aim of this work was to create an inventory of embodied energy and carbon coefficients for building materials. The data has been collected from secondary resources in the public domain, including journal articles, Life Cycle Assessments (LCA's), books, conference papers...etc. There has been no use of subscription based resources due to potential copyright issues. To aid in the selection of 'best' coefficients it was required to create a database (called the ICE-Database). This database stores relevant information from the literature (i.e. Country of data, year, boundaries, report specifics (Data source), notes...etc). At the time of writing the ICE-Database contained over 1,700 records on embodied energy. The work presented here is a summary of the information contained within the larger ICE-Database. This report has been structured into 34 main material groups (i.e. Aggregates, Aluminium...etc), a material profile was created for each main material. For an introduction to these profiles please see the 'Material Profiles Guide'.

<u>EMBODIED ENERGY (CARBON)</u>

"The embodied energy (carbon) of a building material can be taken as the total primary energy consumed (carbon released) over its life cycle. This would normally include (at least) extraction, manufacturing and transportation. Ideally the boundaries would be set from the extraction of raw materials (inc fuels) until the end of the products lifetime (including energy from manufacturing, transport, energy to manufacture capital equipment, heating & lighting of factory, maintenance, disposal...etc), known as 'Cradle-to-Grave'. It has become common practice to specify the embodied energy as 'Cradle-to-Gate', which includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is 'Cradle-to-Site', which includes all of the energy consumed until the product has reached the point of use (i.e. building site)."

Data on embodied energy & carbon data was not always determined to have complete boundary conditions (e.g. the energy not traced back to the earth, electricity not traced upstream…etc). However, incomplete data often contained enough substance to have a useful role when estimating embodied energy coefficients. Cradle-to-Gate was the most commonly specified boundary condition and was selected as the ideal scope of this study. This has been revised from the previous ideal of cradle to site. It is now encouraged for the user to consider the impacts of transportation for their specific case. It should be noted that the boundary conditions for each material are specified within the material profiles. Data intricacies and inconsistencies made it very difficult to maintain the same boundary conditions for the entire inventory. In a few cases Cradle-to-Grave has been specified due to the original data resources. In many cases, and certainly for materials with high embodied energy and high density, the difference between Cradle-to-Gate and Cradle-to-Site could be considered negligible. Although this will certainly not be true for materials with a very low embodied energy per kilogram, such as aggregates, sand…etc.

ICE contains both embodied energy and carbon data, but the embodied energy coefficients carry a higher accuracy. One of the reasons for this was that the majority of the collected data was for embodied energy, and not embodied carbon. It was therefore necessary to estimate the embodied carbon for many materials. Ideally the embodied carbon would be derived from an accurate Life Cycle Assessment; however this was not normally the case. Many of the embodied carbon coefficients within ICE were estimated by the authors of this report. In these cases the embodied carbon was estimated from the typical fuel mix in the relevant UK industries. This method is not perfect, but it must be remembered that neither are the results from Life Cycle Assessments (the preferred source). It remains vastly superior to applying a common conversion factor from embodied energy to embodied carbon across the whole dataset.

From analysing the ICE-Database it was estimated that approximately 40% of the collected data either specified the embodied carbon, a global warming potential (or similar method of greenhouse gas measurement) or a fuel mix (from which the carbon emissions could be estimated). Of this 40% around half were the less useful (to estimating embodied carbon (dioxide)) GWP or fuel mix, therefore only 20% of authors were specifying a useful embodied carbon. Consequently the author had less data to verify embodied carbon coefficients. Another reason for greater uncertainty in embodied carbon was a result of different fuel mixes and technologies (i.e. electricity generation). For example, two factories could manufacture the same product, resulting in the same embodied energy per kilogram of product produced, but the total carbon emitted by both could vary widely dependent upon the mix of fuels consumed by the factory.

The nature of this work and the problems outlined above made selection of a single value difficult and in fact a range of data would have been far simpler to select, but less useful to apply in calculations. There are several openly available inventories similar in nature to this one, and more subscription basis ones. Comparison of the selected values in these inventories would show many similarities but also many differences. It is rare that one single value could be universally agreed upon by researchers within this field of work. Uncertainty is unfortunately a part of embodied energy and carbon analysis and even the most reliable data carries a natural level of uncertainty. That said results from ICE have proved to be robust when compared to those of other databases.

Caution must be exerted when analysing materials that have feedstock energy. Feedstock energy is the energy that is used as a material rather than a fuel, e.g. oil and gas can be used as a material to manufacture products such as plastics and rubber instead of direct combustion. When collecting data it was not always apparent if feedstock energy was included or excluded from the data. For this reason the values in the ICE-Database are stored as reported in the literature, hence the records in the database needed to be manually examined. The database statistics may prove misleading in some instances (some records include feedstock energy, some exclude it and others were unknown). The feedstock energy in this inventory was identified and is included in the total embodied energy coefficients in this report.

The next page explains the criteria for selection, which was used when estimating embodied energy & embodied carbon.

For the authors' contact details or to download further copies of this report please visit:

www.bath.ac.uk/mech-eng/sert/embodied/

Selection Criteria

The criteria used to estimate the embodied energy & carbon are displayed below. Due to the difficulties experienced when selecting these values the criteria needed to be flexible but maintain an ideal set of conditions. One of the main difficulties was inconsistent & poor specification of data in the literature, i.e. different and incomplete boundary conditions and authors not reporting enough detail on the scope of their study.

Five criteria were applied for the selection of embodied energy and carbon values for the individual materials incorporated into the ICE database. This ensured consistency of data within the inventory. The criteria were:

1-Compliance with Approved Methodologies/Standards: Preference was given to data sources that complied with accepted methodologies. In the case of modern data an ideal study would be ISO 14040/44 compliant (the International standard on environmental life cycle assessment). However, even studies that comply with the ISO standards can have wide ranging and significant differences in methodology, as such further selection criteria were necessary, thus ensuring data consistency. A recycled content, or cut-off approach, was preferred for the handling of (metals) recycling.

2-System Boundaries: The system boundaries were adopted as appropriate for 'cradle-to-gate' embodiment. Feedstock energy was included only if it represented a permanent loss of valuable resources, such as fossil fuel use. For example, fossil fuels utilised as feedstocks, such as the petro-chemicals used in the production of plastics, were included (although identified separately). However, the calorific value of timber has been excluded. This approach is consistent with a number of published studies and methodologies. The effects of carbon sequestration (for example carbon that was sequestered during the growing of organic materials, i.e. timber) were considered but not integrated into the data. For justification of this decision please see the timber material profile. Non-fuel related carbon emissions have been accounted for (Process related emissions).

3-Origin (Country) of Data: Ideally the data incorporated into the ICE inventory would have been restricted to that emanating from the British Isles. But in the case of most materials this was not feasible, and the best available embodied energy data from foreign sources had to be adopted (using, for example, European and world-wide averages). A much stronger preference was given to embodied carbon data from UK sources, due to national differences in fuel mixes and electricity generation.

4-Age of the Data Sources: Preference was given to modern sources of data, this was especially the case with embodied carbon; historical changes in fuel mix and carbon coefficients associated with electricity generation give rise to greater uncertainty in the embodied carbon values.

5-Embodied Carbon: Ideally data would be obtained from a study that has considered the life cycle carbon emissions, for example via a detailed LCA, but there is often an absence of such data. In many cases substitute values therefore had to be estimated using the typical fuel split for the particular UK industrial sector. British emission factors were applied to estimate the fuel-related carbon. Additional carbon (non-energy related, i.e. process related carbon) carbon was included.

In addition to these selection criteria the data primarily focused on construction materials. The embodied energy and carbon coefficients selected for the ICE database were representative of typical materials employed in the British market. In the case of metals, the values for virgin and recycled materials were first estimated, and then a recycling rate (and recycled content) was assumed for the metals typically used in the marketplace. This enabled an approximate value for embodied energy in industrial components to be determined. In order to ensure that this data was representative of typical products (taking timber as an example), the UK consumption of various types of timber was applied to estimate a single 'representative' value that can be used in the absence of more detailed knowledge of the specific type of timber (i.e., plywood, chipboard, softwood, ...etc.). Finally it was aimed to select data that represented readily usable construction products, i.e., semi-fabricated components (sections, sheets, rods…etc. which are usable without further processing), rather than (immediately) unusable products such as steel billet or aluminium ingot.

Notes

Transport

In the previous versions of ICE the boundary conditions were ideally selected as cradle to site. This was based on the assumption that in many cases transport from factory gate to construction site would be negligible. Whilst this may be true for many materials, and normally true for high embodied energy and carbon materials, this is not exclusively the case. In the case of very low embodied energy and carbon materials, such as sand and aggregates, transport is likely to be significant. For these reasons the ideal boundaries have been modified to ***cradle to gate*** (from the previous cradle to site). This decision will also encourage the data users to estimate transport specific to their case in hand. This should act as a further check to ensure transporting the selected material many thousands of miles around the world does not create more energy and carbon than a local alternative.

To estimate the embodied energy and carbon of transport it is recommended that users start with the following resources (in no particular order):

- **DEFRA, 2007.** "Guidelines to Defra's GHG conversion factors for company reporting" http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf
- **European Commission's information hub on life cycle thinking based data, tools and services.** http://lca.jrc.ec.europa.eu/lcainfohub/index.vm
- Data in LCA software and databases such as **SimaPro, GaBi or Ecoinvent**.

Recycling Methodology (Particularly Metals)

When applying the ICE data it is important to ensure that the ICE recycling methodology is consistent with the scope and boundaries of your study, especially for metals. It is particularly important that recycling methodologies are not mixed. This could occur with the use of data from different resources. If this is the case then care must be exerted to ensure that all of the data is applied in a consistent manner. Some of the ICE data (especially if classified as a 'Typical' or 'General' metal) has a pre-selected recycled content and this conforms to the default ICE recycling methodology.

The default ICE recycling methodology is known as the **recycled content approach.** However, the metal industries endorse a methodology that is often known as the **substitution method**. Each method is fundamentally different. The recycled content approach is a method that credits ***recycling***, whereas the substitution method credits

recyclability. This may be considered in the context of a building. Using the recycled content approach the incoming metals to the building could be split between recycled and primary materials. If this gives 40% recycled metals then the recycled content is set at 40%. This is a start of life method (i.e. start of life of the building) for crediting recycling. Using this method the materials entering a building takes the recycling credit (thus upstream of the building/application).

The substitution method has the opposite school of thought. In this method it is the act of recyclability that is credited and therefore it is an end of life methodology. Using this methodology the recycled content of the materials entering the building is not considered in the analysis. Instead the ability for the materials to be recycled at the end of the products lifetime is considered. For example, in the case of metals this could feasibly be taken as, say, 85% recyclability. This implies that at the end of the buildings lifetime it is expected that 85% of the metals in the building will be recycled into new products. Therefore the building will be credited to the extent that 85% of the materials (metals) will be treated as recycled (and therefore it is a substitution of primary and recycled materials, hence the name). Such a methodology may be approximated by applying a recycled content of 85%.

It is clear that the application of each methodology will yield very different results; this is particularly true for aluminium. Recycled aluminium can have a saving of 85-90% in its embodied impacts over primary aluminium. It is therefore important that an appropriate methodology for the study in hand must be selected. The methodology must be consistent with the goal and scope of the study. The authors of this work remain convinced that for construction, where lifetimes are large (60-100 years in the residential sector), the recycled content approach is the most suitable method. The present authors consider that it reflects a truer picture of our current impacts and that the substitution method may run the risk of under accounting for the full impacts of primary metal production. They believe that the advantages of the recycled content methodology fit in more appropriately with the (normal) primary motivation for undertaking an embodied energy and carbon assessment. This is normally to estimate the current impacts of its production. However if the purpose of the study is different then it may be desirable to apply a different recycling methodology.

Essentially, each method suffers from its own pitfalls and neither may be applicable under all circumstances. The ICE data is structured to identify the difference between recycled and primary metals. The user is therefore free to apply any recycling methodology.

Things to Consider…

- **Functional units:** It is inappropriate to compare materials solely on a kilogram basis. Products must be compared on a functional unit basis, a comparative study should consider the quantity of materials required to provide a set function. It is only then that two materials can be compared for a set purpose. For example, what if the quantity of aluminium that is required to provide a square meter of façade versus the quantity of timber?
- **Lifetime:** Ideally the functional unit should consider the lifetime of the product. For example, what if product A lasts 40 years and product B only lasts 20 years? This may change the conclusion of the study.
- **Waste:** The manufacture of 1 kg of product requires more than this quantity of material. The quantity of waste must be considered. Additionally what happens to the wasted materials? Is it re-used, recycled, or disposed?
- **Maintenance:** What are the maintenance requirements and how does this impact on the energy and material consumption? Does the product require periodical attention, e.g. re-painting?
- **Further processing energy:** Highly fabricated and intricate items require manufacturing operations that are beyond the boundaries of this report. In the case of a whole building such a contribution could be assumed to be minimal, however the study of an individual product may require this energy to be investigated.

The following pages contain the main ICE data…

The Inventory of Carbon & Energy (ICE) – Main Data Tables

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Aggregate			
General	0.1	0.005	
Aluminium			
General	155	8.24	13.8 MJ/kg Feedstock Energy (Included). Assumes UK ratio of 25.6% extrusions, 55.7% Rolled & 18.7% castings. Worldwide recycled content of 33%.
Virgin	218	11.46	20.7 MJ/kg Feedstock Energy (Included).
Recycled	28.8	1.69	
Cast Products	159	8.28	14.3 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	226	11.70	21.3 MJ/kg Feedstock Energy (Included).
Recycled	24.5	1.35	
Extruded	154	8.16	13.6 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	214	11.20	20.2 MJ/kg Feedstock Energy (Included).
Recycled	34.1	1.98	
Rolled	155	8.26	13.8 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	217	11.50	20.6 MJ/kg Feedstock Energy (Included).
Recycled	27.8	1.67	
Asphalt			
General	2.60	0.045	1.91 MJ/kg Feedstock Energy (Included)
Road & Pavement	2.41	0.14	0.82 MJ/kg Feedstock Energy (Included), reference 123
EXAMPLE: Road	2,672 MJ/Sqm	134 KgCO2/Sqm	906 MJ/Sqm Feedstock Energy (Included)
Bitumen			
General	47	0.48	37.7 (?) MJ/kg Feedstock Energy (Included). Feedstock taken as typical energy content of Bitumen, uncertain carbon dioxide emissions
Brass			
General	44.00	2.42 (?)	poor data availability, largely dependent upon ore grade. Very poor carbon data, uncertain of estimates, which were taken from average quoted emissions per MJ energy
Virgin	80.00	4.39 (?)	
Recycled	20.00	1.1 (?)	
Bricks			
General (Common Brick)	3.00	0.22	
EXAMPLE: Single Brick	8.4 MJ per brick	0.62 kgCO2 per brick	Assuming 2.8 kg per brick
Facing Bricks	8.20	0.52	Very small sample size
EXAMPLE: Single Facing Brick	23 MJ per brick	1.46 kgCO2 per brick	Assuming 2.8 kg per brick
Limestone	0.85	?	
Bronze			
General	77.00	4.1 (?)	Reference 155
Carpet			
General Carpet	74.40	3.89	For per square meter see material profile
Felt (Hair and Jute) Underlay	18.60	0.96	Reference 77
Nylon	67.9 to 149	3.55 to 7.31	Very difficult to select value, few sources, large range, value includes feedstock's
Polyethylterepthalate (PET)	106.50	5.55	includes feedstock's
Polypropylene	95.40	5.03	includes feedstock's, for per square meter see material profile
Polyurethane	72.10	3.76	includes feedstock's
Rubber	67.5 to 140	3.91 to 8.11	
Saturated Felt Underlay (impregnated with Asphalt or tar)	31.70	1.70	Reference 77
Wool	106.00	5.48	For per square meter see material profile, References 57,166 & 234
Cement			
General (Typical)	4.6	0.83	Portland Cement, CEM I
Fibre Cement	10.90	2.11	
Mortar (1:3 cement:sand mix)	1.40	0.213	Values estimated from the ICE Cement, Mortar & Concrete Model
Mortar (1:4)	1.21	0.177	
Mortar (1:6)	0.99	0.136	
Mortar (1:½:4½ Cement:Lime:Sand mix)	1.37	0.196	
Mortar (1:1:6 Cement:Lime:Sand mix)	1.18	0.163	
Mortar (1:2:9 Cement:Lime:Sand mix)	1.09	0.143	
Soil-Cement	0.85	0.14	

% Cementitious Replacement	0%	25%	50%	0%	25%	50%	Note 0% is a 'standard' CEM I cement
General (with Fly Ash Replacement)	4.6	3.52	2.43	0.83	0.62	0.42	Portland Cement
General (with Blast Furnace Slag Replacement)	4.6	3.81	3.01	0.83	0.64	0.45	Portland Cement

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Ceramics			
General	10.00	0.65	Very Large data range, difficult to select best value.
Fittings	20.00	1.05	Reference 1
Refractory products	5.50	0.51	
Sanitary Products	29.00	1.48	
Tile	9.00	0.59	Very large data range
Clay			
General (Simple Baked Products)	3.00	0.22	General simple baked clay products (inc. terracotta)
Tile	6.50	0.46	
Vitrified clay pipe DN 100 & DN 150	6.19	0.45	
Vitrified clay pipe DN 200 & DN 300	7.03	0.49	
Vitrified clay pipe DN 500	7.86	0.53	
Concrete			
General	0.95	0.130	Use of a specific concrete specification is preferred to gain greater accuracy.
NOMINAL PROPORTIONS METHOD (Volume), Proportions from BS 8500:2006 (ICE Cement, Mortar & Concrete Model Calculations)			
1:1:2 Cement:Sand:Aggregate	1.39	0.209	(High strength)
1:1.5:3	1.11	0.159	(used in floor slab, columns & load bearing structure)
1:2:4	0.95	0.129	(Typical in construction of buildings under 3 storeys)
1:2.5:5	0.84	0.109	
1:3:6	0.77	0.096	(non-structural mass concrete)
1:4:8	0.69	0.080	
REINFORCED CONCRETE			
For reinforcement add to selected coefficient for each 25kg rebar	0.26	0.018	Add for each 25 kg Steel per m3 concrete
EXAMPLE: Reinforced RC30 (below)	2.12 (1.08 + 0.26 * 4)	0.241 (0.153 + 0.018 * 4)	
CONCRETE BLOCKS (ICE CMC Model Values)			
Block - 8 MPa Compressive Strength	0.60	0.061	Estimated from concrete block mix proportions.
Block - 10 MPa	0.67	0.074	
Block -12 MPa	0.71	0.080	
Block -13 MPa	0.81	0.098	
Autoclaved Aerated Blocks (AAC's)	3.50	0.28 to 0.375	Not ICE CMC model results
MISCELLANEOUS VALUES			
Prefabricated Concrete	2.00	0.215	Literature resources suggest this value, unknown why so high!
Fibre-Reinforced	7.75	0.450	
Concrete Road & Pavement	1.24	0.127	
EXAMPLE Road	2,085 MJ/Sqm	187.7 KgCO2/Sqm	
Wood-Wool Reinforced	2.08	-	Reference 12

% Cement Replacement - Fly Ash	EE 0%	EE 25%	EE 50%	EC 0%	EC 25%	EC 50%	Note 0% is a standard concrete
GEN 0	**0.64**	0.57	0.50	**0.071**	0.058	0.046	Compressive Strength C6/8 MPa
GEN 1	**0.77**	0.66	0.56	**0.095**	0.077	0.058	C8/10; Mass Concrete, mass fill, mass foundations
GEN 2	**0.81**	0.70	0.58	**0.103**	0.083	0.062	C12/15
GEN 3	**0.85**	0.73	0.60	**0.112**	0.089	0.066	C16/20
RC20	**0.95**	0.80	0.65	**0.128**	0.102	0.075	C20/25
RC25	**0.99**	0.83	0.67	**0.136**	0.108	0.079	C25/30
RC30	**1.08**	0.90	0.72	**0.153**	0.120	0.087	C30/37; (Strong) foundations
RC35	**1.13**	0.94	0.74	**0.161**	0.126	0.091	C35/45; Ground floors
RC40	**1.17**	0.97	0.77	**0.169**	0.132	0.096	C40/50; Structural purposes, in situ floors, walls, superstructure
RC50	**1.41**	1.15	0.88	**0.212**	0.165	0.117	C50
PAV1	**1.04**	0.87	0.70	**0.145**	0.114	0.083	C25/30
PAV2	**1.08**	0.90	0.72	**0.153**	0.120	0.087	C28/35

% Cement Replacement - Blast Furnace Slag	EE 0%	EE 25%	EE 50%	EC 0%	EC 25%	EC 50%	Note 0% is a standard concrete
GEN 0	**0.64**	0.59	0.54	**0.071**	0.059	0.048	Compressive Strength C6/8 MPa
GEN 1	**0.77**	0.69	0.62	**0.095**	0.078	0.061	C8/10; Mass Concrete, mass fill, mass foundations
GEN 2	**0.81**	0.70	0.65	**0.103**	0.083	0.065	C12/15
GEN 3	**0.85**	0.76	0.67	**0.112**	0.091	0.070	C16/20
RC20	**0.95**	0.84	0.73	**0.128**	0.103	0.079	C20/25
RC25	**0.99**	0.88	0.76	**0.136**	0.110	0.083	C25/30
RC30	**1.08**	0.95	0.82	**0.153**	0.122	0.092	C30/37; (Strong) foundations
RC35	**1.13**	0.99	0.85	**0.161**	0.129	0.096	C35/45; Ground floors
RC40	**1.17**	1.03	0.88	**0.169**	0.135	0.101	C40/50; Structural purposes, in situ floors, walls, superstructure
RC50	**1.41**	1.22	1.03	**0.212**	0.168	0.124	C50
PAV1	**1.04**	0.91	0.79	**0.145**	0.116	0.088	C25/30
PAV2	**1.08**	0.95	0.82	**0.153**	0.122	0.092	C28/35

COMMENTS

The first column represents standard concrete, created with 100% Portland cement. The other columns are estimates based on a direct substitution of fly ash or blast furnace slag in place of the cement content. The ICE Cement, Mortar & Concrete Model was applied. It was assumed that there will be no changes in the quantities of water, aggregates or plasticiser/additives due to the use of cementitious replacement materials.

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Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Copper			
General	**40 to 55**	**2.19 to 3.83 (?)**	Conflicting data, possibly due to large variations in ore grade. Assumes recycled materials of 46%. See material profiles for further details
Virgin	70 (?)	3.83 (?)	Large data range, very difficult to select possibly due to large variations in ore grade and therefore embodied energy and carbon.
Recycled from high grade scrap	**17.5 (?)**	**0.96 (?)**	
Recycled from low grade scrap	**50 (?)**	**2.75 (?)**	
Glass			
General	**15.00**	**0.85**	Poor data availability on recycled glass. Virgin Glass releases 0.185 Kg CO2 during production processes (Additional to energy emissions) this has been factored in (Fact taken from British Glass). Recycling rate from British glass report towards sustainable development 2004, difficult to select embodied carbon
Fibreglass (Glasswool)	**28.00**	**1.53**	
Toughened	**23.50**	**1.27**	Only three data sources
Insulation			
General Insulation	**45.00**	**1.86**	Estimated from typical market shares, Feedstock Energy 16.5 MJ/kg (Included)
Cellular Glass	**27.00**	**-**	Reference 48
Cellulose	**0.94 to 3.3**	**-**	
Cork	**4.00**	**0.19**	Reference 49
Fibreglass (Glasswool)	**28.00**	**1.35**	Poor data difficult to select appropriate value
Flax (Insulation)	**39.50**	**1.70**	Reference 2, 5.97 MJ/kg Feedstock Energy (Included)
Mineral wool	**16.60**	**1.20**	
Rockwool (stonewool)	**16.80**	**1.05**	
Paper wool	**20.17**	**0.63**	Reference 2
Polystyrene	**See Plastics**	**See Plastics**	see plastics
Polyurethane	**See Plastics**	**See Plastics**	see plastics
Woodwool (loose)	**10.80**	**-**	Reference 168
Woodwool (Board)	**20.00**	**0.98**	Reference 49
Wool (Recycled)	**20.90**	**-**	References 57,166 & 234
Iron			
General	**25.00**	**1.91 (?)**	Uncertain
Lead			
General	**25.00**	**1.33**	Allocated (divided) on a mass basis, assumes recycling rate of 61.5%
Virgin	49.00	2.61	
Recycled	10.00	0.53	
Virgin If produced with zinc	**13.6 to 23.6**	**0.72 to 1.25**	Allocated by system expansion (i.e. energy contributable to zinc by other processes)
Lime			
General	**5.30**	**0.74**	Embodied carbon was difficult to estimate
Linoleum			
General	**25.00**	**1.21**	Data difficult to select, large data range.
Miscellaneous			
Asbestos	**7.40**	**-**	Reference 4
Calcium Silicate Sheet	**2.00**	**0.13**	Reference 49
Chromium	**83**	**5.39**	Reference 21
Cotton, Padding	**27.10**	**1.28**	Reference 34
Cotton, Fabric	**143**	**6.78**	Reference 34
Damp Proof Course/Membrane	**134**	**4.20**	
Felt General	**36**	**-**	
Flax	**33.50**	**1.70**	Reference 2
Fly Ash	**0.10**	**0.01**	
Grit	**0.12**	**0.01**	Reference 92
Carpet Grout	**30.80**	**-**	Reference 139
Glass Reinforced Plastic - GRP - Fibreglass	**100**	**8.10**	Reference 1
Lithium	**853**	**5.30**	Reference 92
Mandolite	**63**	**1.40**	Reference 1
Mineral Fibre Tile (Roofing)	**37**	**2.70**	Reference 1
Manganese	**52**	**3.50**	Reference 21
Mercury	**87**	**4.94**	Reference 21
Molybedenum	**378**	**30.30**	Reference 21
Nickel	**164**	**12.40**	Reference 92
Perlite - Expanded	**10.00**	**0.52**	Reference 92
Perlite - Natural	**0.66**	**0.03**	Reference 92
Quartz powder	**0.85**	**0.02**	Reference 92
Shingle	**11.30**	**0.30**	Reference 62
Silicon	**2355**	**-**	Reference 138
Slag (GGBS)	**1.33**	**0.07**	Ground Granulated Blast Furnace Slag (GGBS)
Silver	**128.20**	**6.31**	Reference 124
Straw	**0.24**	**0.01**	References 57,166 & 234
Terrazzo Tiles	**1.40**	**0.12**	Reference 1
Vanadium	**3710.00**	**228.00**	Reference 21
Vermiculite - Expanded	**7.20**	**0.52**	Reference 92
Vermiculite - Natural	**0.72**	**0.03**	Reference 92
Vicuclad	**70.00**	**-**	Reference 1

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Water	0.20	-	Reference 139
Wax	52.00	-	Reference 139
Wood stain/Varnish	50.00	5.35	Reference 1
General Wool	3.00	0.15	Reference 155
Yttrium	1470	84.00	Reference 21
Zirconium	1610	97.20	Reference 21
Paint			
General	68.00	3.56	Large variations in data, especially for carbon emissions.
EXAMPLE: Single Coat	10.2 MJ/Sqm	0.53 kgCO2/Sqm	Assuming 6.66 Sqm Coverage per kg
EXAMPLE: Double Coat	20.4 MJ/Sqm	1.06 kgCO2/Sqm	Assuming 3.33 Sqm Coverage per kg
EXAMPLE: Triple Coat	30.6 MJ/Sqm	1.60 kgCO2/Sqm	Assuming 2.22 Sqm Coverage per kg
Paper			
Paperboard (General for construction use)	24.80	1.32	Excluding CV of wood, excludes carbon sequestration
Fine Paper	28.20	1.50	Excluding CV of wood, excludes carbon sequestration
Wallpaper	36.40	1.93	
Plaster			
General (Gypsum)	1.80	0.12	Problems selecting good value, inconsistent figures, West et al believe this is because of past aggregation of EE with cement
Plasterboard	6.75	0.38	
Plastics			
General	80.50	2.53	35.6 MJ/kg Feedstock Energy (Included). Determined by the average use of each type of plastic used in the European construction industry
ABS	95.30	3.10	48.6 MJ/kg Feedstock Energy (Included)
General Polyethylene	83.10	1.94	54.4 MJ/kg Feedstock Energy (Included). Based on average use of types of PE in European construction
High Density Polyethylene (HDPE)	76.70	1.60	54.3 MJ/kg Feedstock Energy (Included)
HDPE Pipe	84.40	2.00	55.1 MJ/kg Feedstock Energy (Included)
Low Density Polyethylene (LDPE)	78.10	1.70	51.6 MJ/kg Feedstock Energy (Included)
LDPE Film	89.30	1.90	55.2 MJ/kg Feedstock Energy (Included)
Nylon 6	120.50	5.50	38.6 MJ/kg Feedstock Energy (Included)
Nylon 6,6	138.60	6.50	50.7 MJ/kg Feedstock Energy (Included)
Polycarbonate	112.90	6.00	36.7 MJ/kg Feedstock Energy (Included)
Polypropylene, Orientated Film	99.20	2.70	55.7 MJ/kg Feedstock Energy (Included)
Polypropylene, Injection Moulding	115.10	3.90	54 MJ/kg Feedstock Energy (Included)
Expanded Polystyrene	88.60	2.50	46.2 MJ/kg Feedstock Energy (Included)
General Purpose Polystyrene	86.40	2.70	46.3 MJ/kg Feedstock Energy (Included)
High Impact Polystyrene	87.40	2.80	46.4 MJ/kg Feedstock Energy (Included)
Thermoformed Expanded Polystyrene	109.20	3.40	49.7 MJ/kg Feedstock Energy (Included)
Polyurethane	72.10	3.00	34.67 MJ/kg Feedstock Energy (Included). Poor data availability of feedstock energy
PVC General	77.20	2.41	28.1 MJ/kg Feedstock Energy (Included). Assumed market average use of types of PVC in the European construction industry
PVC Pipe	67.50	2.50	24.4 MJ/kg Feedstock Energy (Included)
Calendered Sheet PVC	68.60	2.60	24.4 MJ/kg Feedstock Energy (Included)
PVC Injection Moulding	95.10	2.20	35.1 MJ/kg Feedstock Energy (Included)
UPVC Film	69.40	2.50	25.3 MJ/kg Feedstock Energy (Included)
Rubber			
General	101.70	3.18	41.1 MJ/kg Feedstock Energy (Included). Assumes that natural rubber accounts for 35% of market. Difficult to estimate carbon emissions.
Synthetic rubber	120.00	4.02	42 MJ/kg Feedstock Energy (Included). Difficult to estimate carbon emissions.
Natural latex rubber	67.60	1.63	39.43 MJ/kg Feedstock Energy (Included). Feedstock from the production of carbon black. Difficult to estimate carbon emissions.
Sand			
General	0.10	0.005	
Sealants and adhesives			
Epoxide Resin	139.30	5.91	42.6 MJ/kg Feedstock Energy (Included)
Mastic Sealant	62.3 to 200	-	
Melamine Resin	113.00	-	Reference 77
Phenol Formaldehyde	87 to 89.3	-	
Urea Formaldehyde	40 to 78.2	1.3 to 2.26	
Soil			
General (Rammed Soil)	0.45	0.023	

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Steel			
General (average of all steels)	**24.40**	**1.77**	Estimated from UK mix of materials. Worldwide recycled content of 42.7%
Virgin	35.30	2.75	
Recycled	9.50	0.43	Could not collect strong statistics on mix of recycled steels
Bar & rod	**24.60**	**1.71**	Recycled content 42.7%
Virgin	36.40	2.68	
Recycled	8.80	0.42	
Engineering steel - Recycled	**13.10**	**0.68**	
Pipe - Virgin	**34.44**	**2.70**	
Recycled	Not Typical Production Route		
Plate - Virgin	**48.40**	**3.19**	
Recycled	Not Typical Production Route		
Section	**25.40**	**1.78**	Recycled content 42.7%
Virgin	36.80	2.78	
Recycled	10.00	0.44	
Sheet - Virgin	**31.50**	**2.51**	
Recycled	Not Typical Production Route		
Sheet - Galvanised - Virgin	**39.00**	**2.82**	
Wire - Virgin	**36.00**	**2.83**	
Stainless	**56.70**	**6.15**	4.3 MJ/kg Feedstock Energy (Included). This data has been difficult to select, there is highly conflicting data, finally selected world average data from institute of Stainless Steel Forum (ISSF) due to the large extent of the study. Values specified are for the most popular grade (304).
Stone	Data on stone was difficult to select, with high standard deviations and data ranges.		
General	**1.00**	**0.056**	
Stone Gravel/Chippings	**0.30**	**0.017**	
Granite	**0.1 to 13.9 !**	**0.006 to 0.781**	Reference 22
Limestone	**0.30**	**0.017**	
Marble	**2.00**	**0.112**	
Marble tile	**3.33**	**0.187**	
Shale	**0.03**	**0.002**	Reference 36
Slate	**0.1 to 1.0**	**0.006 to 0.056**	Large data range
Timber	All timber values exclude the Calorific Value (CV) of wood. Timber values were particularly difficult to select!		
General	**8.50**	**0.46**	Estimated from UK consumption of timber
Glue Laminated timber	**12.00**	**0.65 (?)**	
Hardboard	**16.00**	**0.86**	
Laminated Veneer Lumber	**9.50**	**0.51 (?)**	Ref 126
MDF	**11.00**	**0.59**	Only 4 data sources
Particle Board	**9.50**	**0.51**	Very large data range, difficult to select best value
Plywood	**15.00**	**0.81**	
Sawn Hardwood	**7.80**	**0.47**	
Sawn Softwood	**7.40**	**0.45**	
Veneer Particleboard (Furniture)	**23.00**	**1.24**	
Tin			
Tin Coated Plate (Steel)	**19.2 to 54.7**	**1.03 to 2.93**	
Tin	**250.00**	**13.70**	lack of modern data, large range of data
Titanium			
Virgin	**361 to 745**	**-**	lack of modern data, large range of data, small sample size
Recycled	**258.00**	**-**	lack of modern data, large range of data, small sample size
Vinyl Flooring			
General	**65.64**	**2.29**	23.58 MJ/kg Feedstock Energy (Included), Same value as PVC calendered sheet
Vinyl Composite Tiles (VCT)	**13.70**	**-**	Reference 77
Zinc			
General	**61.90**	**3.31**	uncertain carbon estimates, currently estimated from typical fuel mix
Virgin	72.00	3.86	
Recycled	9.00	0.48	

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon

Miscellaneous:

	Embodied Energy - MJ	Embodied Carbon - Kg CO2	
PV Modules	MJ/sqm	Kg CO2/sqm	
Monocrystalline	4750 (2590 to 8640)	242 (132 to 440)	Assumed typical industrial fuel mix to estimate CO2
Polycrystalline	4070 (1945 to 5660)	208 (99 to 289)	
ThinFilm	1305 (775 to 1805)	67 (40 to 92)	
Windows	MJ per Window		
1.2mx1.2m Single Glazed Timber Framed Unit	286 ?	14.60	Assumed typical UK industrial fuel mix to estimate CO2
1.2mx1.2m Double Glazed (Air or Argon Filled):	--	--	--
Aluminium Framed	5470	279	
PVC Framed	2150 to 2470	110 to 126	
Aluminium -Clad Timber Framed	950 to 1460	48 to 75	
Timber Framed	230 to 490	12 to 25	
Krypton Filled Add:	510	26	
Xenon Filled Add:	4500	229	

Guide to the Material Profiles

The following worksheets contain profiles of the main materials within this inventory. The inventory was created through manually analysing the separate ICE-Database, which stored data on each value of embodied energy/carbon (i.e. Data source and where possible a hyperlink to the report, year of data, boundary conditions, fuel mix, specific comments...etc). The full ICE database contains far more detail than available in this inventory. These profiles have been created to present a summary of the database and to present the embodied energy & carbon values. Below you will find an example of a profile (largely blank) which has been separated into smaller segments to allow a clearer annotation of each section.

Section 1: Database statistics

The materials were broken down into sub-categories, which reflected how the data is stored within the database. Most materials have a general category, and are possibly broken down into more specific forms i.e. Aluminium general, Aluminium extruded…etc. Each of the sub-categories are then broken down into further classifications according to the recycled/virgin content of the material. In many cases the authors of the data sources have not specified this data, hence it was required to create an unspecified classification.

Here are simple statistics from the main ICE-Database. They include the number of records within the database, which represents the sample size that was used to select this data. This may be used as a (simple) indicator of the quality and reliability of the selected values. Additional statistics include the average embodied energy (EE) from the literature; this should not be used in place of the selected values. The ICE database stored the data as published by the original author, hence each record had different boundary conditions or were for a very specific/rare form of the material. These facts can not be represented by statistics but only with manual examination of the ICE-Database records. However, in many cases these statistics are similar to the selected 'best' values. Finally, the standard deviation and a full data range are presented to maintain an openness to this inventory.

Material Profile: Example

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Material						
Sub-Material Category						
100% Recycled						
50% Recycled						
Other Specification						
Unspecified						
Virgin						

Section 2: Selected (or 'Best') values of embodied energy & carbon

The values of embodied energy are presented here; the example below is only for materials that can be recycled, i.e. metals. The format of presentation has minor variations according to the needs of the data being presented. The 'general' material classification is the value that should be used if unsure of which value to select. The primary material is for predominantly virgin materials and secondary for predominantly recycled materials i.e. many authors allow a slight fraction of recycled material under a primary classification, but these are not always stated. Alternatively a recycled content could be assumed and these values can be used to estimate the embodied energy for any given recycled content.

The embodied carbon has been presented separately. Again the values distinguish between primary (virgin) materials, secondary (recycled) materials and the average value typical of the UK market place.

The best range is what the author of this work believes to be a more appropriate range than the full range given in the database statistics (presented in section 1, above). The selection of the range and the 'best' values of embodied energy was not an easy task, especially with so many holes in data provided by authors, but they provide a useful insight into the potential variations of embodied energy within this material. The selected coefficient of embodied energy may not fall within the centre of the range for a number of reasons. The selected value of embodied energy tries to represent the average on the marketplace. However, variations in manufacturing methods or factory efficiency are inevitable.

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg			Embodied Carbon - Kg CO2/Kg			Boundaries	Best EE Range - MJ/Kg		Specific Comments
	UK Typical	Primary	Secondary	UK Typical	Primary	Secondary		Low EE	High EE	
General Material							Cradle to Gate	(+/-30%)		
Cast Products										
Extruded										
Rolled										
Comments										

Guide to the Material Profiles

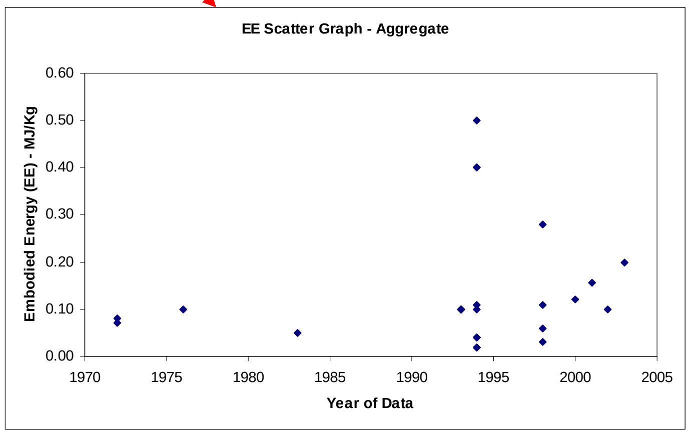
Section 3: Scatter Graph and Fuel split & embodied carbon split

There is a scatter graph for each material (Sometimes more than one scatter graph where it is beneficial). The scatter graph plots the year of data versus the value of embodied energy for each data point in the database. This maintains the transparency of this inventory and highlights any historical variations in data values, which may be a result of technological shifts. It could also be determined whether a small number of data points distort the above database statistics.

The fuel split is presented here along with the fraction of embodied carbon resulting from the energy source (or additional carbon released from non-energy sources). Ideally this data will be specified by authors completing a detailed study, but this was seldom the case and in many cases this data was estimated from the typical fuel mix within the relevant UK industry which was obtained from the Department of Trade and Industry (DTI). In several cases it was not possible to provide a fuel mix or carbon breakdown. Here the typical embodied carbon was estimated based on values specified by authors in the literature.

Where possible the historical embodied carbon per unit fuel (energy) use was calculated as an index of 1990 data. This data is general and was estimated from the typical fuel split in the most appropriate industry. It was not a detailed analysis, in that it is generalised for the entire industry and not for specific products. It illustrates any improvement in carbon emissions since 1990 and the variation in carbon contributions by (fuel) source. This section does not appear on all profiles

Material Scatter Graph

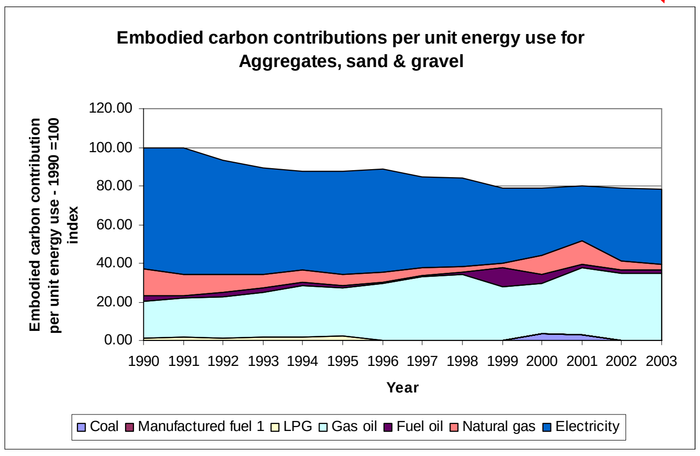


Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal		
LPG		
Oil		
Natural gas		
Electricity		
Other		
Total	0.0%	0.0%

Fuel Split & Embodied Carbon Comments:

Historical embodied carbon per unit fuel use



Section 4: Material Properties (CIBSE Data)

Data extracted from the most recent CIBSE guide (Volume A) is presented here for each material. The list of materials here was in many cases more specific than there is data available on embodied energy. But it may be possible to estimate the appropriate embodied energy from the most similar material in the inventory or to use the general category.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Material		230	2700	880	9.68013E-05
Material Galvanised		45	7680	420	1.39509E-05

Material Profile: Aggregate

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Aggregate	**36**	**0.11**	**0.12**	**0.01**	**0.50**	None
Aggregate, General	36	0.11	0.12	0.01	0.50	
Predominantly Recycled	3	0.25	0.21	0.10	0.40	
Unspecified	17	0.11	0.07	0.02	0.28	
Virgin	16	0.10	0.15	0.01	0.50	

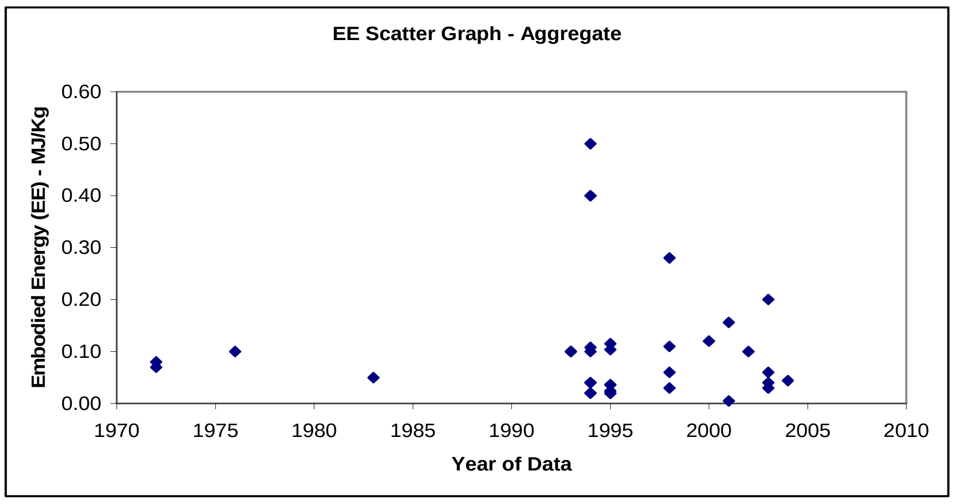
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Aggregate	0.1	0.005	Cradle to Gate	0.05	0.25	None

Comments

It should be noted that the scatter graph does not display all of the data that needs to be considered when selecting a best value, e.g. the boundary conditions (cradle to site, cradle to gate...etc), these are stored in the database but they are not represented in the scatter graph. Transport will likely be significant for aggregates.

Material Scatter Graph



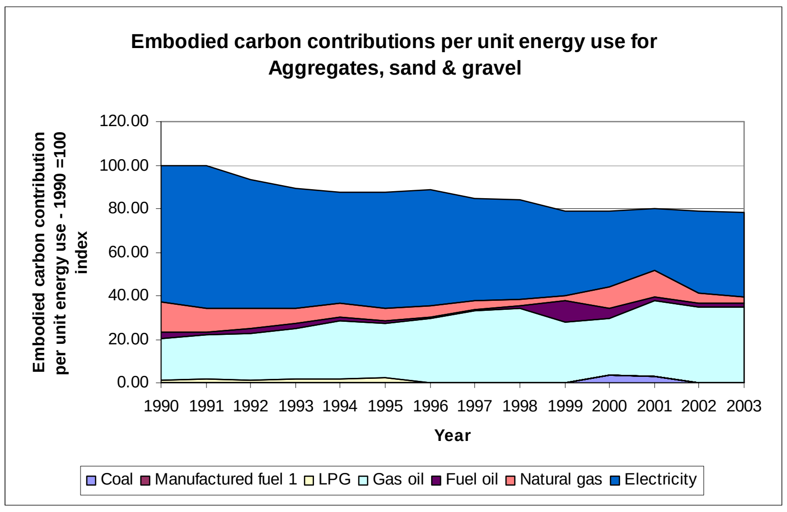
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	19.8%	22.7%
Natural gas	14.9%	12.6%
Electricity	65.3%	64.7%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry, the resulting value is in agreement with other results in the literature.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
aggregate	Undried	1.8	2240	840	9.5663E-07
aggregate (sand, gravel or stone)	Oven dried	1.3	2240	920	6.3082E-07

Material Profile: Aluminium

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	tandard Deviatio	Minimum EE	Maximum EE	Comments on the Database Statistics:
Aluminium	**111**	**157.1**	**104.7**	**8.0**	**382.7**	
Aluminium, General	111	157.1	104.7	8.0	382.7	
50% Recycled	4	108.6	53.4	58.0	184.0	
Other Specification	3	146.5	79.3	55.0	193.5	There was a large sample size, with many high quality data sources.
Predominantly Recycled	28	17.9	8.7	8.0	42.9	
Unspecified	14	169.1	67.0	68.0	249.9	
Virgin	62	224.1	68.5	39.2	382.7	

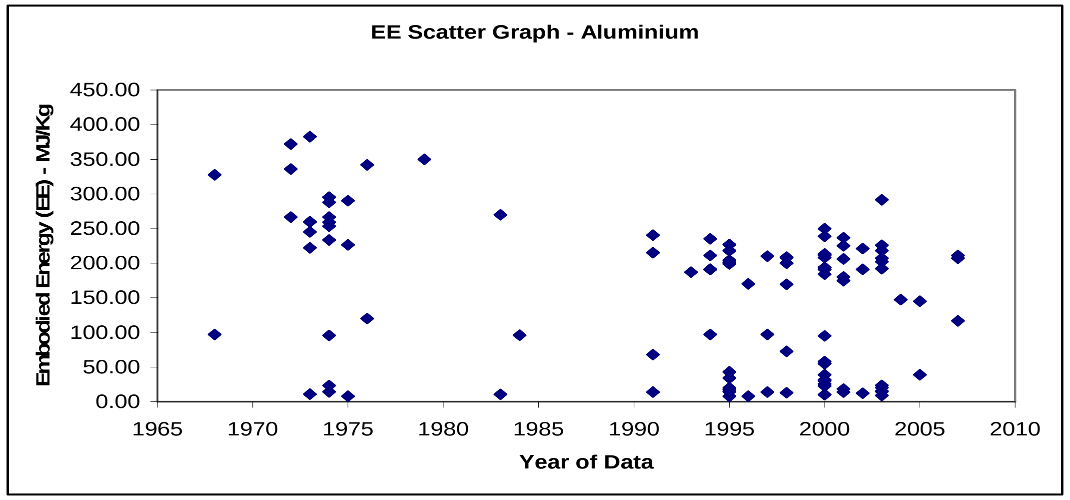
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg			Embodied Carbon - Kg CO2/Kg			Boundaries	Best EE Range - MJ/Kg		Specific Comments
	Typical	Primary	Secondary	UK Typical	Primary	Secondary		Low EE	High EE	
General Aluminium	155.00	218	28.8	8.24	11.5	1.69	Cradle to Gate	(+/-20%)		General aluminium assumes UK ratio of 25.6% extrusions, 55.7% Rolled & 18.7% castings. Worldwide recycled content of 33%. For feedstock energy please see the main ICE summary tables.
Cast Products	159.00	225.5	24.5	8.28	11.7	1.35				
Extruded	154.00	213.5	34.1	8.16	11.2	1.98				
Rolled	155.00	217	27.8	8.26	11.5	1.67				

Comments

Worldwide average data was selected and obtained from the International Aluminium Institute (IAI). The data is freely available from the IAI. The averages from the database statistics are in good agreement with the final selected values. The value for general aluminium was calculated assuming the UK split between the different forms of aluminium. The selected value for secondary aluminium is towards the top of the full data range in the database. This is because the value depends upon the level of material processing (i.e., ingot or (semi-) fabricated product). A 33% recycled content (worldwide average) was assumed for the typical market values statistic from the IAI, International Aluminium Institute). Primary aluminium production does have feedstock energy; this is because primary aluminium uses coke as a raw material in the production of carbon anodes. Please see note on recycling methodology at the front of the document.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Electricity	63.6%	57.2%
Other	36.4%	42.8%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fraction of energy and carbon from electricity was extracted from an IAI (International Aluminium Institute) report.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m 1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
aluminium		230	2700	880	9.68013E-05
aluminium cladding		45	7680	420	1.39509E-05

Material Profile: Asphalt

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Asphalt	**17**	**6.63**	**11.89**	**0.20**	**50.20**
Asphalt, General	17	6.63	11.89	0.20	50.20
Predominantly Recycled	2	7.32	0.28	7.12	7.52
Unspecified	13	7.46	13.47	0.23	50.20
Virgin	2	0.49	0.40	0.20	0.77

Comments on the Database Statistics:

There was a large data range, some values included the feedstock energy, but some excluded it. This was complicated by the fact that it was not always possible to determine if the feedstock energy was included or excluded! An additional indication of the difficulty in selecting the best value was that the standard deviation was much higher than the mean Value.

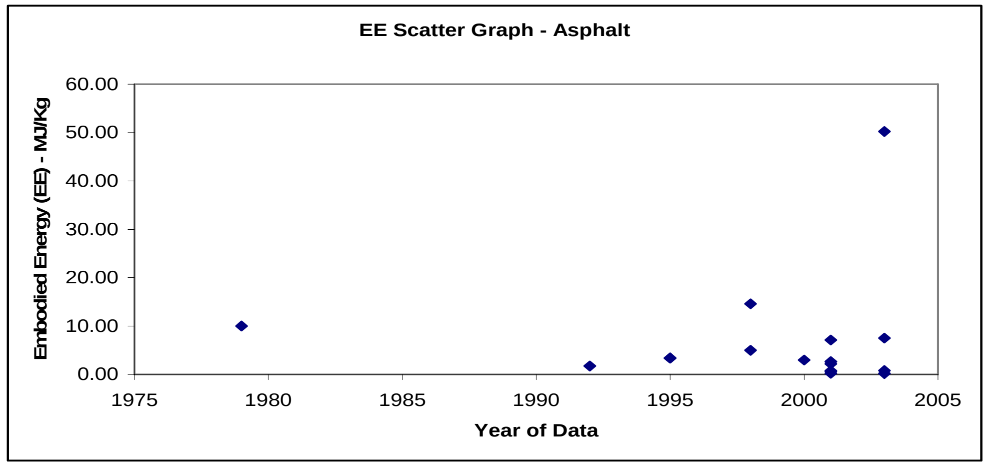
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
					Low EE	High EE	
General Asphalt	2.6	1.91	0.045	Cradle to Gate	0.23	4	See main comments
Roads & Pavements	2.41	0.82	0.14	40 year life time	Not enough data sources		Very limited data, see reference 123
Road Example	2,672 MJ/Sqm	906 MJ/Sqm	134 KgCo2/Sqm	40 year life time	Not enough data sources		limited data

Comments

Asphalt is a mixture of mineral aggregate with a bituminous binder, however in the US the term 'asphalt' is used as the term for 'bitumen' itself. This is obviosuly a cause of confusion, especially due to the large difference in embodied energy of these two distinct materials. Overall this data was difficult to select. The scatter graph below displays that the selected value is towards the lower end of the range. This is most likely because most of the resources did not specify if the data included feedstock energy (in fact most of them probably include them). There is a further problem from authors assuming that asphalt and bitumen have the same embodied energy (which is very inaccurate). Inappropriate use of the names asphalt and bitument and international differences between the use of these names cause additional confusion. Consequentially, the data was stored in its quoted form, as a result the data set (as seen in the scatter graph) has inconsistent boundaries and certain assumptions were required to be made when analysing the data.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

NO fuel split and embodied carbon breakdown data available. The values used were quoted in the main sources

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)	Comments
Asphalt A		0.5	1700	1000	2.94118E-07	The CIBSE guide provides two sets of values from different sources
Asphalt B		1.2	2300	1700	3.06905E-07	
poured		1.2	2100	920	6.21118E-07	
reflective coat		1.2	2300	1700	3.06905E-07	
roofing, mastic		1.15	2330	840	5.87574E-07	

Material Profile: Bitumen

Embodied Energy (EE) Database Statistics - MJ/Kg

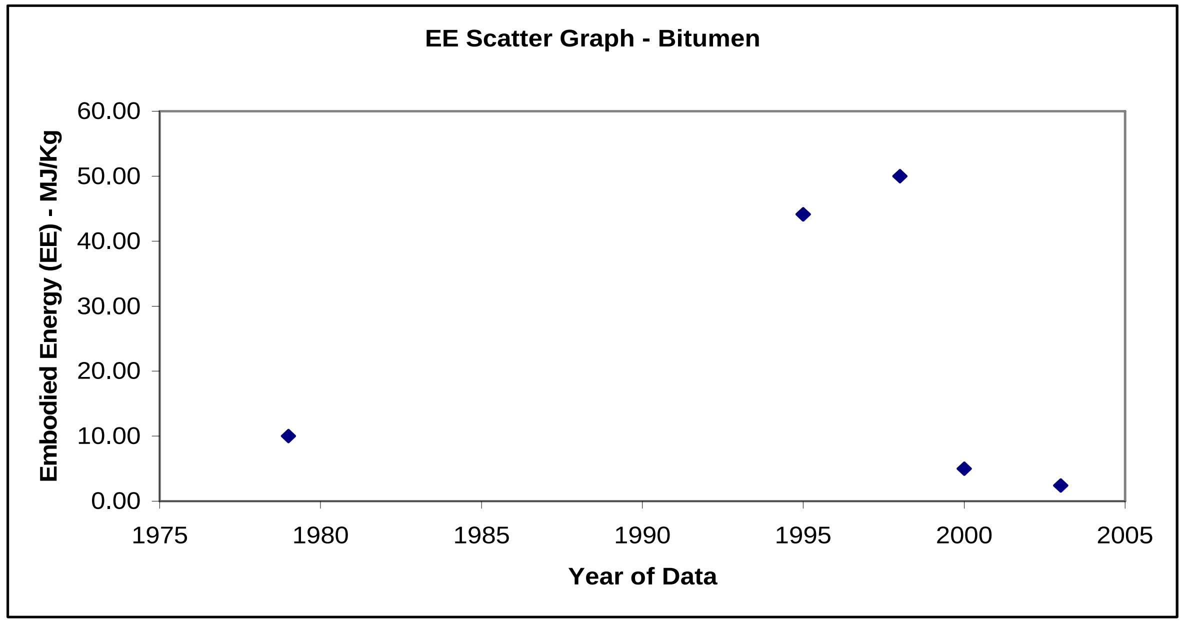
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Bitumen	**7**	**17.91**	**20.21**	**2.40**	**50.00**	Very poor data availability and very large data range.
Bitumen, General	7	17.91	20.21	2.40	50.00	
Unspecified	6	20.50	20.84	3.38	50.00	
Virgin	1	2.40	2.40	2.40	-	

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
					Low EE	High EE	
General Bitumen	47	37.7 (?)	0.48	Cradle to Gate	(+/- 30%)		Unknown embodied carbon

Comments	
Comments	Bitumen is a black/brown, sticky substance that is often used in paving roads or for waterproofing. Bitumen may be natural (crude bitumen) or synthetic (refined). Refined bitumen is the residual (bottom) fraction obtained by fractional distillation of crude oil. Naturally occurring crude bitumen is the prime feed stock for petroleum production from tar sands, of which the largest know reserves are in Canada. Bitumen must not be confused with asphalt, which is a mineral aggregate with a bituminous binder, however in the US the term 'asphalt' is used as the term for 'bitumen'. For selection of best values we experienced similar problems to asphalt (Bitumen is used to make asphalt), but with a smaller sample size. There was additional confusion as a result of the English speaking languages (British, American, Australian and Canadian) using the term 'Bitumen' in different ways. The author believes that the large data range can mainly be attributed to feedstocks. Bitumen is produced from oil, as such it has a high feedstock energy value. The inconsistencies among authors specifying embodied energy values made the data range appear larger than it should be.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

NO fuel split and embodied carbon breakdown data available.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Bitumen, composite, flooring		0.85	2400	1000	3.54167E-07
Bitumen, insulation, all types		0.2	1000	1700	1.17647E-07

Material Profile: Brass

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Brass	**9**	**80.70**	**71.87**	**16.81**	**239.00**	Poor data quantity
Brass, General	9	80.70	71.87	16.81	239.00	
Other Specification	1	39.00	39.00	39.00	-	
Predominantly Recycled	1	20.00	20.00	20.00	-	
Unspecified	5	113.95	72.67	62.00	239.00	
Virgin	2	16.81	16.81	16.81	-	

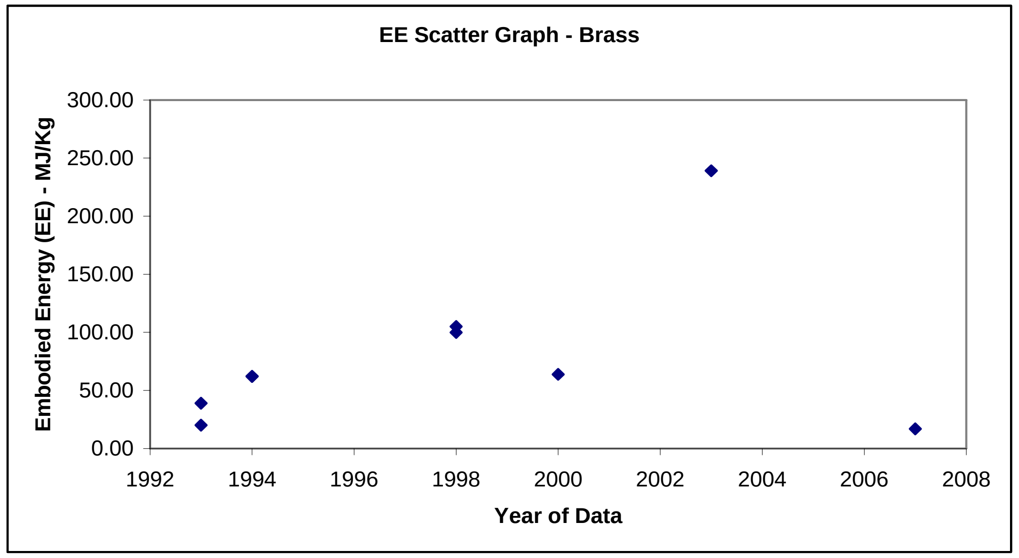
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Brass	44	2.42 (?)	Cradle to Gate	Wide Range		60% recycled material assumed
Primary Brass	80	4.39 (?)		60	100	
Secondary Brass	20	1.1 (?)		10 ?	30 ?	

Comments

largely dependent upon ore grade. Very poor carbon data, which made estimating the carbon emissions difficult. This was estimated based on the mix of fuels in the UK brass industry. This method was not ideal but was all that could be estimated in the time available. Assumed recycled content of 60%.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	4.0%	5.9%
LPG	0.0%	0.0%
Oil	10.8%	12.4%
Natural gas	19.0%	16.1%
Electricity	66.2%	65.6%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in the closest available industry (Copper).

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
brass		110	8500	390	3.31825E-05

NOTE: Bronze only had two data sources, hence a material profile could not be produced

Embodied Energy (EE) Database Statistics - MJ/Kg						
Main Material	**No. Records**	**Average**	**Standard Deviation**	**Minimum**	**Maximum**	
Bronze	**2**	**69.34**	**10.37**	**62.00**	**76.67**	
Bronze, general	2	69.34	10.37	62.00	76.67	
Unspecified	1	76.67	76.67	76.67	-	
Virgin	1	62.00	62.00	62.00	-	

Material Properties (CIBSE Data)					
Material	**Condition**	**Thermal conductivity (W m-1 K-1)**	**Density (kg m -3)**	**Specific heat (J kg-1 K-1)**	**Thermal Diffusivity (M^2 S-1)**
Bronze		64	8150	-	-

Material Profile: Carpets

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Carpet	**20**	**99.41**	**83.90**	**3.00**	**390.00**	None
Carpet	20	99.41	83.9	3	390	
Unspecified	20	99.41	83.9	3	390	

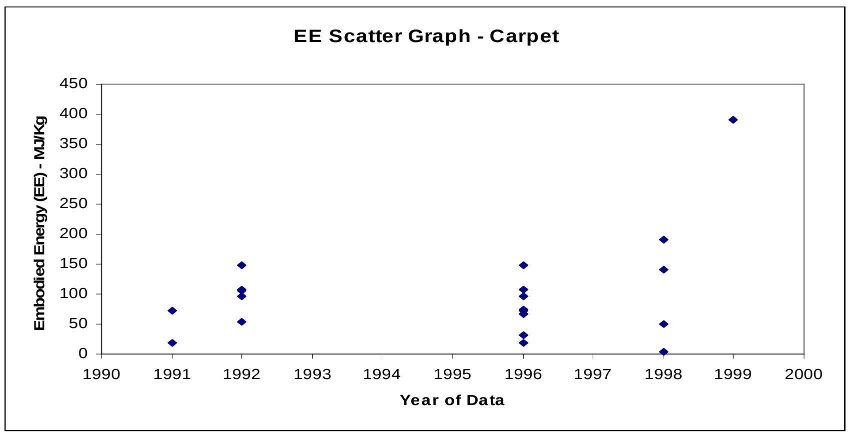
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Carpet	74.4 (186.7 per sqm)	3.89 (9.76 per sqm)	Cradle to Grave	44.4	104.4	
Felt (Hair and Jute) Underlay	18.6	0.96		(+/- 30%)		Reference 77
Nylon	67.9 to 149	3.55 to 7.31		-	-	Very difficult to select value, few sources, large data range, value includes feedstocks
Polyethylterepthalate (PET)	106.5	5.55		(+/- 30%)		includes feedstocks
Polypropylene	95.4 (120 MJ/sqm)	5.03				includes feedstocks
Polyurethane	72.1	3.76				includes feedstocks
Rubber	67.5 to 140	3.91 to 8.11		-	-	
Saturated Felt Underlay (impregnated with Asphalt or tar)	31.7	1.7		(+/- 30%)		Reference 77
Wool	106 (84 MJ/sqm)	5.48				References 57,166 & 234

Comments

The majority of the above data was selected from the American institute of Architects Environmental Resource Guide (Reference 77). There was a shortage of quality data on carpets.

Material Scatter Graph



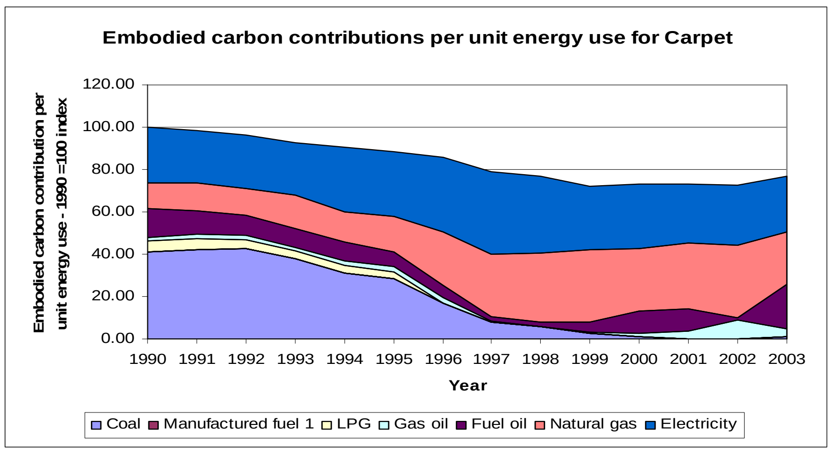
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	8.0%	9.7%
Natural gas	36.3%	32.3%
Electricity	55.7%	58.0%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
with cellular rubber underlay		0.1	400	1360	1.83824E-07
synthetic		0.06	160	2500	0.00000015
polyurethane board, cellular		0.023	24	1590	6.02725E-07
polyisocyanurate board		0.02	32	920	6.79348E-07
foil-faced, glass-fibre reinforced		0.019	32	920	6.4538E-07
polystyrene, expanded (EPS)		0.035	23	1470	1.0352E-06
polystyrene, extruded (EPS)		0.027	35	1470	5.24781E-07
polyvinylchloride (PVC), expanded		0.04	100	750	5.33333E-07
vermiculite, expanded, panels		0.082	350	840	2.78912E-07
vermiculite, expanded, pure		0.058	350	840	1.97279E-07
silicon		0.18	700	1000	2.57143E-07

Material Profile: Cement

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Cement	**112**	**5.08**	**2.54**	**0.10**	**11.73**	There was an excellent sample size of data for cement.
Cement Mortar	11	1.54	0.91	0.10	3.49	
Unspecified	9	1.30	0.70	0.10	2.10	
Virgin	2	2.63	1.22	1.77	3.49	
Cement, Fibre Cement	1	4.60	4.60	4.60	-	
Virgin	1	4.60	4.60	4.60	-	
Cement, Fibre Cement	6	9.57	1.22	7.60	10.90	
Unspecified	4	9.71	1.55	7.60	10.90	
Virgin	2	9.28	0.17	9.16	9.40	
Cement, General	92	5.32	2.05	1.42	11.73	
Market Average	7	5.02	0.66	4.29	6.20	
Unspecified	65	5.46	2.27	1.42	11.73	
Virgin	20	4.82	1.07	3.00	6.50	
Cement, Soil-Cement	2	0.85	0.21	0.70	1.00	
Unspecified	2	0.85	0.21	0.70	1.00	

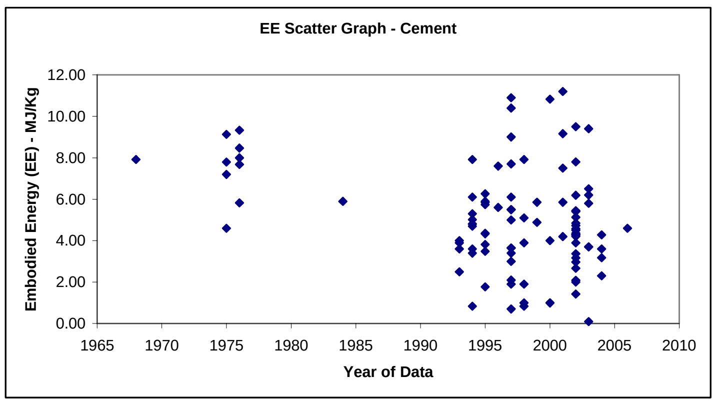
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General	4.6	0.83	Cradle to Gate	2.8	6.8	The high range is due to the fact that the embodied energy is highly dependent upon the clinker content of cement (i.e. if additions have been added, i.e. fly ash, slag...etc) and the method of manufacture.
General - 25% Fly Ash	3.52	0.62		(+/- 30%)		Fly ash does have a lower embodied carbon than blast furnace slag, however the upper threshold of fly ash content is lower than for blast furnace slag.
General - 50% Fly Ash	2.43	0.42				
General - 25% Blast Furnace Slag	3.81	0.64				Blast furnace slag does have a higher embodied carbon than fly ash, however the upper threshold of blast furnace slag content is higher than for fly ash.
General - 50% Blast Furnace Slag	3.01	0.45				
Fibre Cement	10.9	2.11		Estimated range +/- 40%		This value was selected form the top end of the range of data. This was justified because two of the three references quoted a figure around this value. Additionally, the data point at the low end of the range did not have full boundary conditions.
Mortar (1:3 cement:sand mix)	1.55	0.213		(+/- 30%)		Estimated from the ICE Cement, Mortar & Concrete Model.
Mortar (1:4)	1.34	0.177				
Mortar (1:6)	0.99	0.136				
Mortar (1:½:4½ Cement:Lime:Sand mix)	1.48	0.196				
Mortar (1:1:6 Cement:Lime:Sand mix)	1.27	0.163				
Mortar (1:2:9 Cement:Lime:Sand mix)	1.16	0.143				
Soil-Cement	0.85	0.14		0.7	1	Only two data points, this value is the average of the two sources.

Comments

Cement is an important building material due to its use in the manufacture of concrete. There are a wide range of cement types with a large variation in the embodied energy and carbon, but the typical cement (general category above) provides a good value to use in the absence of knowing which type of cement has been used in construction. This typical value is consistent with the database statistics and modern sources of data. The scatter graph shows a large amount of modern data.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	70.9%	31.1%
LPG	0.0%	0.0%
Oil	1.2%	0.4%
Natural gas	0.0%	0.0%
Electricity	27.9%	7.5%
Other	0.0%	61% (Non-fuel emission)
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

0.51 KgCO2/Kg is released by de-carbonation in manufacture of clinker, which is the main constituent of cement. This has been represented in the row labelled 'other' above.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
cement		0.72	1860	840	4.60829E-07
cement blocks, cellular		0.33	520	2040	3.11086E-07
cement fibreboard, magnesium oxysulphide binder		0.082	350	1300	1.8022E-07
Cement mortar		0.72	1650	920	4.74308E-07
cement mortar	Dry	0.93	1900	840	5.82707E-07
cement mortar	Moist	1.5	1900	840	9.3985E-07
cement/lime plaster		0.8	1600	840	5.95238E-07
cement panels, wood fibres A	Dry	0.08	350	1890	1.20937E-07
cement panels, wood fibres B	Moist	0.12	350	3040	1.12782E-07
cement panels, wood fibres C		0.12	400	1470	2.04082E-07
cement panels, wood fibres D	Dry	0.35	1650	840	2.52525E-07
Cement Screed		1.4	2100	650	1.02564E-06

Material Profile: Ceramics

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Ceramic	**17**	**10.01**	**8.27**	**2.50**	**29.07**	None
Ceramic, General	17	10.01	8.27	2.50	29.07	
Unspecified	15	10.96	8.36	2.50	29.07	
Virgin	2	2.90	0.57	2.50	3.30	

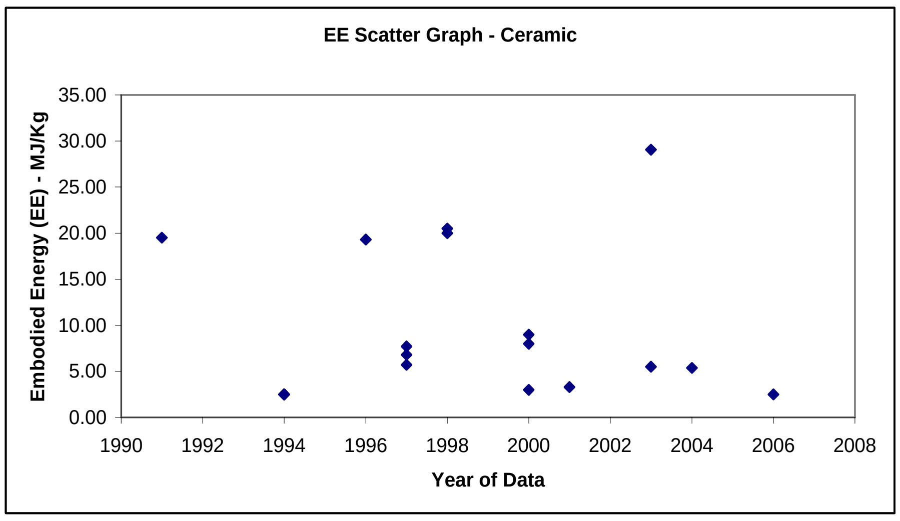
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Ceramics	10	0.65	Cradle to Gate	2.5	29.1	There was an incredible data range, which made selection of a single value difficult.
Fittings	20	1.05	Cradle to Gate			Reference 1
Refractory products	5.5	0.51	Cradle to Gate	Estimated Range (+/- 30%)		
Sanitary Products	29	1.48	Cradle to Gate	Estimated Range (+/- 30%)		
Tile	9	0.59	Cradle to Gate	2.5	19.5	

Comments

The scatter graph displays a large data range, which made selection of a best value difficult. The large range may be attributed to different types of ceramic products.

Material Scatter Graph



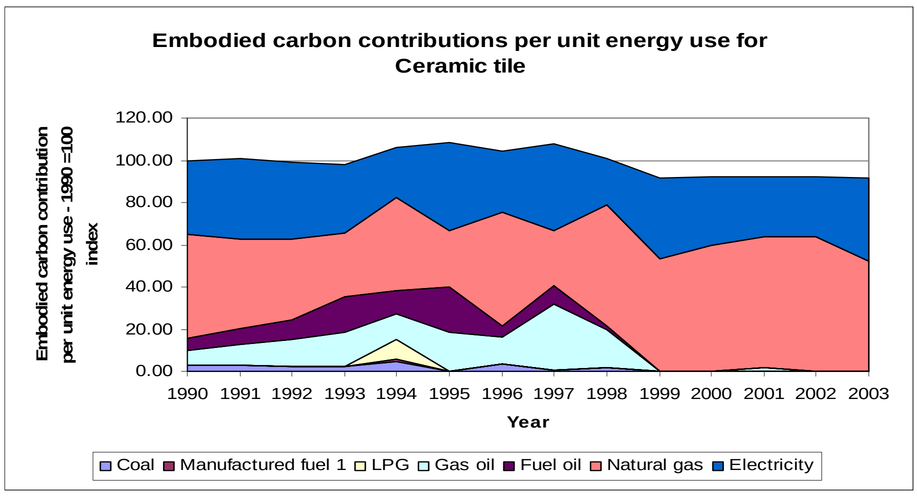
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	0.0%	0.0%
Natural gas	40.2%	28.7%
Electricity	59.8%	49.9%
Other	0.0%	21.4%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry. The fuel split is for general ceramics.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Ceramic tiles	Dry	1.2	2000	850	7.05882E-07
ceramic floor tiles	Dry	0.8	1700	850	5.53633E-07
clay tiles		0.85	1900	840	5.32581E-07
clay tiles, burnt		1.3	2000	840	7.7381E-07
clay tile, hollow, 10.2mm. 1 cell		0.52	1120	840	5.52721E-07
Clay tile, hollow, 20.3mm, 2 cells		0.623	1120	840	6.62202E-07
Clay tile, hollow, 32.5mm, 3 cells		0.693	1120	840	7.36607E-07
clay tile, pavior		1.803	1920	840	1.11793E-06

Material Profile: Clay (including Bricks)

Embodied Energy (EE) Database Statistics - MJ/Kg

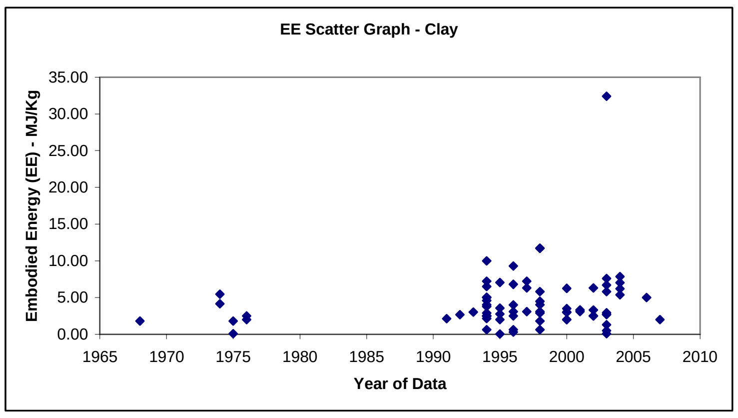
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Clay	**79**	**4.30**	**4.12**	**0.02**	**32.40**	There was a good sample size
Clay, General	79	4.30	4.12	0.02	32.40	
Unspecified	58	4.53	4.57	0.07	32.40	
Virgin	21	3.59	2.22	0.02	7.60	

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General simple baked clay products	3	0.22	Cradle to Gate	1	5	None
Tile	6.5	0.46		2.88	11.7	
Vitrified clay pipe DN 100 & DN 150	6.2	0.45		Estimated range +/- 30%		
Vitrified clay pipe DN 200 & DN 300	7	0.49				
Vitrified clay pipe DN 500	7.9	0.53				
General Clay Bricks	3 +/-1	0.22		0.63	6	
EXAMPLE: Single Brick	8.4 per brick	0.62 per brick		-	-	Assuming 2.8 kg per brick
Facing Bricks	8.2	0.52		4.5	11.7	Very small sample size
EXAMPLE: Single Facing Brick	23 per brick	1.46 per brick		-	-	Assuming 2.8 kg per brick
Limestone Bricks	0.85	?	Cradle to Gate	0.7	1.01	

Comments: Clay products experience process related carbon dioxide emissions. There was a large data range associated with all ceramic and brick products.

Material Scatter Graph



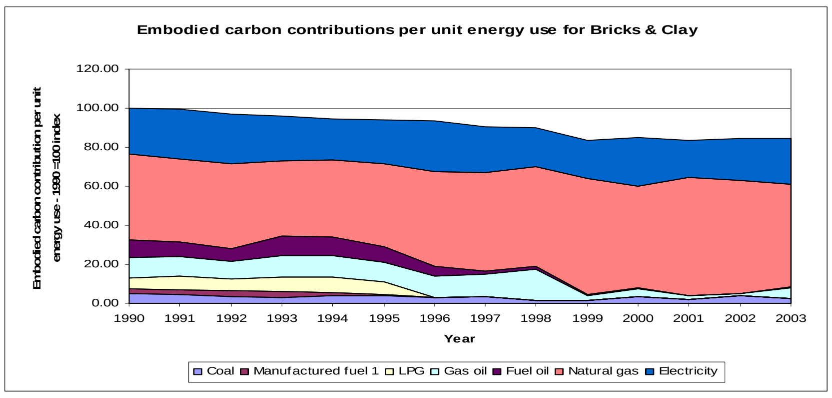
Fuel Split & Embodied Carbon Data (Bricks)

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	1.9%	0.2%
Natural gas	72.1%	49.5%
Electricity	26.0%	17.3%
Other	0.0%	33.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K 1)	Thermal Diffusivity (M^2 S-1)	Comments
clay tiles	0.85	1900	840	5.32581E-07	
clay tiles, burnt	1.3	2000	840	7.7381E-07	
clay tile, hollow, 10.2mm. 1 cell	0.52	1120	840	5.52721E-07	
Clay tile, hollow, 20.3mm, 2 cells	0.623	1120	840	6.62202E-07	
Clay tile, hollow, 32.5mm, 3 cells	0.693	1120	840	7.36607E-07	
clay tile, pavior	1.803	1920	840	1.11793E-06	
BRICKS					
Brick A	0.72	1920	840	4.46429E-07	The CISBE guide presented multiple values for brick
Brick B	1.31	2080	921	6.8383E-07	
aerated	0.3	1000	840	3.57143E-07	
brickwork, inner leaf	0.62	1700	800	4.55882E-07	
brickwork, outer leaf	0.84	1700	800	6.17647E-07	
burned A	0.75	1300	840	6.86813E-07	
burned B	0.85	1500	840	6.74603E-07	
burned C	1	1700	840	7.0028E-07	
mud	0.75	1730	880	4.92643E-07	
paviour	0.96	2000	840	5.71429E-07	
reinforced	1.1	1920	840	6.82044E-07	
tile	0.8	1890	880	4.81E-07	

Material Profile: Concrete

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Concrete	**122**	**2.91**	**8.68**	**0.07**	**92.50**	None
Concrete, General	112	3.01	9.07	0.07	92.50	
Unspecified	85	2.12	2.85	0.07	23.90	
Virgin	27	6.02	18.24	0.59	92.50	
Concrete, Pre-Cast	10	1.89	0.43	1.20	2.72	
Unspecified	6	2.01	0.43	1.36	2.72	
Virgin	4	1.72	0.42	1.20	2.19	

Selected Embodied Energy & Carbon Values and Associated Data

Boundaries	Cradle to Gate	Data Range	(+/- 30%)	Specific Comments
Material	**Embodied Energy - MJ/Kg**	**Embodied Carbon - Kg CO2/Kg**		
General Concrete	**0.95**	**0.130**		Selection of a specific concrete type will give grater accuracy, please see comments
1:1:2 Cement:Sand:Aggregate	**1.39**	**0.209**		(High strength)
1:1.5:3	**1.11**	**0.159**		(used in floor slab, columns & load bearing structure)
1:2:4	**0.95**	**0.129**		(Typical in construction of buildings under 3 storeys)
1:2.5:5	**0.84**	**0.109**		
1:3:6	**0.77**	**0.096**		(non-structural mass concrete)
1:4:8	**0.69**	**0.080**		
REINFORCED CONCRETE (ICE CMC Model Values)				
For reinforcement add to selected coefficient for each 25kg steel reinforcement	**0.26**	**0.018**		For each 25 kg Steel per m3 concrete
EXAMPLE: Reinforced RC30 (See Below) with 100kg Rebar	**2.12 (1.08 + 0.26 * 4)**	**0.241 (0.153 + 0.018 *4)**		
CONCRETE BLOCKS (ICE CMC Model Values)				
Block - 8 MPa Compressive Strength	**s**	**0.061**		Estimated from the concrete block mix proportions with a small allowance added for concrete block curing.
Block - 10 MPa	**0.67**	**0.074**		
Block -12 MPa	**0.71**	**0.080**		
Block -13 MPa	**0.81**	**0.098**		
Autoclaved Aerated Blocks (AAC's)	**3.50**	**0.28 to 0.375**		Not ICE CMC model results
MISCELLANEOUS VALUES				
Prefabricated Concrete	**2.00**	**0.215**		
Fibre-Reinforced	**7.75**	**0.450**		
Concrete Road & Pavement	**1.24**	**0.127**		
EXAMPLE Road	**2,085 MJ/Sqm**	**187.7 KgCO2/Sqm**		
Wood-Wool Reinforced	**2.08**	**-**		Reference 12

ALTERNATIVE CONCRETE MIXES (ICE Cement, Mortar & Concrete Model Results)

BS 8500:2006 SPECIFICATIONS

Material	Embodied Energy - MJ/kg			Embodied Carbon - kgCO2/kg			NOTE: Cradle to Gate
FLY ASH							
% Cement Replacement - Fly Ash	**0%**	**25%**	**50%**	**0%**	**25%**	**50%**	**Note 0% is a standard concrete**
GEN 0	**0.64**	0.57	0.50	**0.071**	0.058	0.046	Compressive Strength C6/8 MPa
GEN 1	**0.77**	0.66	0.56	**0.095**	0.077	0.058	C8/10; Possible uses: mass Concrete, mass fill, mass foundations
GEN 2	**0.81**	0.70	0.58	**0.103**	0.083	0.062	C12/15
GEN 3	**0.85**	0.73	0.60	**0.112**	0.089	0.066	C16/20
RC20	**0.95**	0.80	0.65	**0.128**	0.102	0.075	C20/25
RC25	**0.99**	0.83	0.67	**0.136**	0.108	0.079	C25/30
RC30	**1.08**	0.90	0.72	**0.153**	0.120	0.087	C30/37; Possible uses: foundations
RC35	**1.13**	0.94	0.74	**0.161**	0.126	0.091	C35/45; Possible uses: ground floors
RC40	**1.17**	0.97	0.77	**0.169**	0.132	0.096	C40/50; Possible uses: structural purposes, in situ floors, walls, superstructure
RC50	**1.41**	1.15	0.88	**0.212**	0.165	0.117	C50
PAV1	**1.04**	0.87	0.70	**0.145**	0.114	0.083	C25/30
PAV2	**1.08**	0.90	0.72	**0.153**	0.120	0.087	C28/35

GROUND GRANULATED BLAST FURNACE SLAG							
% Cement Replacement - Blast Furnace Slag	**0%**	**25%**	**50%**	**0%**	**25%**	**50%**	**Note 0% is a standard concrete**
GEN 0	**0.64**	0.59	0.54	**0.071**	0.059	0.048	Compressive Strength C6/8 MPa
GEN 1	**0.77**	0.69	0.62	**0.095**	0.078	0.061	C8/10; Possible uses: mass Concrete, mass fill, mass foundations
GEN 2	**0.81**	0.70	0.65	**0.103**	0.083	0.065	C12/15
GEN 3	**0.85**	0.76	0.67	**0.112**	0.091	0.070	C16/20
RC20	**0.95**	0.84	0.73	**0.128**	0.103	0.079	C20/25
RC25	**0.99**	0.88	0.76	**0.136**	0.110	0.083	C25/30
RC30	**1.08**	0.95	0.82	**0.153**	0.122	0.092	C30/37; Possible uses: foundations
RC35	**1.13**	0.99	0.85	**0.161**	0.129	0.096	C35/45; Possible uses: ground floors
RC40	**1.17**	1.03	0.88	**0.169**	0.135	0.101	C40/50; Possible uses: structural purposes, in situ floors, walls, superstructure
RC50	**1.41**	1.22	1.03	**0.212**	0.168	0.124	C50
PAV1	**1.04**	0.91	0.79	**0.145**	0.116	0.088	C25/30
PAV2	**1.08**	0.95	0.82	**0.153**	0.122	0.092	C28/35

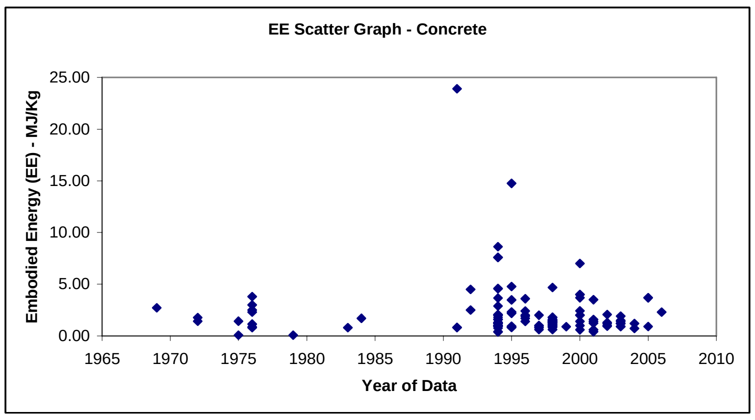
COMMENT ON ABOVE DATA STRUCTURE

The first column represents standard concrete created with 100% Portland cement. The other columns are based on a direct substitution of fly ash or blast furnace slag in place of cement. **They have been modelled on the fraction of cement replacement material (fly ash or slag). However there are thresholds on the upper limit that each of these replacement materials can contribute. This threshold is thought to be linked to the strength class of the concrete. It is understood that fly ash, which has a lower embodied energy and carbon, has a lower threshold than for blast furnace slag. This implies that less fly ash can be used for a particular concrete mix. In certain circumstances blast furnace slag could reach 70-80% replacement, this is much higher than the upper limits of fly ash.** The ICE Cement, Mortar & Concrete Model was used to estimate these values. It was assumed that there will be no changes in the quantities of water, aggregates or plasticiser/additives due to the use of cementitious replacement materials. **The above data is offered as a what if guideline only. The data user must ensure that any quantity of cement substitution is suitable for the specific application.**

Comments

The values of embodied carbon all exclude re-carbonation of concrete in use, which is application dependent. The majority of these concrete values were taken from the University of Bath's ICE Cement, Mortar and Concrete Model. It operates using the quantities of constituent material inputs. As a result these values are dependent upon the selected coefficients of embodied energy and carbon of cement, sand and aggregates, which are the main constituent materials for concrete. The values of embodied energy and carbon produced by this model are in good agreement with values quoted in the literature. It may appear that concrete has a confusing array of options but it is worth determining the strength class or preferably mix of concrete (particularly cement content) used in a project. **If none of the descriptions or comments above help then you may wish to apply the above general value, which is for a typical concrete mix. But in doing so (and in an extreme case) you may inadvertently add up to +/-50% additional error bars to your concrete results. Please note the suggested possible uses of each strength class of concrete is a rough guide only, this does depend upon the building type and height.**

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	47.1%	26.1%
LPG	0.0%	0.0%
Oil	15.4%	8.0%
Natural gas	3.1%	1.2%
Electricity	34.4%	12.9%
Other	0.0%	51.8% (Non-fuel emission)
Total	**0.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

This fuel mix was estimated based on the fuel mix of the constituent materials for concrete, including aggregates, sand and cement. The non-fuel related emissions are from the manufacture of cement and constitute a large proportion of the carbon emissions.

Material Properties (CIBSE Data) for Concrete

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Concrete blocks/tiles					
block, aerated		0.24	750	1000	0.00000032
block, heavyweight, 300mm		1.31	2240	840	6.96216E-07
block, lightweight, 150mm		0.66	1760	840	4.46429E-07
block, lightweight, 300mm		0.73	1800	840	4.82804E-07
	Dry	0.24	620	840	4.60829E-07
	Dry	0.25	670	840	4.44208E-07
	Dry	0.26	720	840	4.29894E-07
	Dry	0.3	750	840	4.7619E-07
	Dry	0.28	770	840	4.329E-07
	Dry	0.29	820	840	4.21022E-07
	Dry	0.3	870	840	4.10509E-07
block, medium weight, 150mm		0.77	1900	840	4.82456E-07
block, medium weight, 300mm		0.83	1940	840	5.09327E-07
	Dry	0.31	920	840	4.01139E-07
	Dry	0.32	970	840	3.92734E-07
	Dry	0.35	1050	840	3.96825E-07
	Dry	0.4	1150	840	4.14079E-07
block, hollow, heavyweight, 300mm		1.35	1220	840	1.31733E-06
block, hollow, lightweight, 150mm		0.48	880	840	6.49351E-07
block, hollow, lightweight, 300mm		0.76	780	840	1.15995E-06
block, hollow, medium weight, 150mm		0.62	1040	840	7.09707E-07
block, hollow, medium weight, 300mm		0.86	930	840	1.10087E-06
block, partially filled, heavyweight, 300mm		1.35	1570	840	1.02366E-06
block, partially filled, lightweight, 150mm		0.55	1170	840	5.59626E-07
block, partially filled, lightweight, 300mm		0.74	1120	840	7.86565E-07
block, partially filled, medium weight, 150 mm		0.64	1330	840	5.72861E-07
block, partially filled, mediumweight,300 mm		0.85	1260	840	8.03099E-07
block, perlite-filled, lightweight, 150mm		0.17	910	840	2.22397E-07
block, perlite-filled, mediumweight,150mm		0.2	1070	840	2.22519E-07
block, with perlite, lightweight, 150mm		0.33	1180	840	3.3293E-07
block, with perlite, medium weight, 150 mm		0.39	1340	840	3.46482E-07
tiles		1.1	2100	840	6.23583E-07
Concrete, cast:					
aerated		0.16	500	840	3.80952E-07
		0.29	850	840	4.06162E-07
		0.42	1200	840	4.16667E-07
aerated, cellular		0.15	400	840	4.46429E-07
		0.23	700	840	3.91156E-07
		0.7	1000	840	8.33333E-07
		1.2	1300	840	1.0989E-06
aerated, cement/lime based		0.21	580	840	4.31034E-07

Material Properties (CIBSE Data) for Concrete					
Material	**Condition**	**Thermal conductivity (W-m-1 K-1)**	**Density (kg m -3)**	**Specific heat (J kg-1 K-1)**	**Thermal Diffusivity (M^2 S-1)**
cellular		0.16	480	840	3.96825E-07
	At 50°C	0.19	700	1050	2.58503E-07
cellular bonded		0.3	520	2040	2.82805E-07
dense		**1.7**	**2200**	**840**	**9.19913E-07**
compacted,		**2.2**	**2400**	**840**	**1.09127E-06**
dense, reinforced		**1.9**	**2300**	**840**	**9.83437E-07**
compacted		**2.3**	**2500**	**840**	**1.09524E-06**
expanded clay filling		0.26	780	840	3.96825E-07
		0.6	1400	840	5.10204E-07
foamed	At 50°C	0.07	320	920	2.37772E-07
	At 50°C	0.08	400	920	2.17391E-07
	At 50'C	0.15	700	920	2.32919E-07
foam slag		0.25	1040	960	2.50401E-07
glass reinforced		0.9	1950	840	5.49451E-07
heavyweight	Dry	1.3	2000	840	7.7381E-07
	Moist	1.7	2000	840	1.0119E-06
lightweight	Dry	0.2	620	840	3.84025E-07
	Dry	0.25	750	840	3.96825E-07
	Dry	0.21	670	840	3.73134E-07
	Dry	0.22	720	840	3.63757E-07
	Dry	0.23	770	840	3.55597E-07
	Dry	0.24	820	840	3.48432E-07
	Dry	0.25	870	840	3.42091E-07
	Moist	0.43	750	840	6.8254E-07
	Moist	0.38	770	840	5.87508E-07
	Moist	0.4	820	840	5.8072E-07
	Moist	0.43	870	840	5.88396E-07
		0.08	200	840	4.7619E-07
		0.12	300	840	4.7619E-07
		0.17	500	840	4.04762E-07
		0.23	700	840	3.91156E-07
medium weight	Dry	0.32	1050	840	3.62812E-07
	Dry	0.37	1150	840	3.83023E-07
	Dry	0.59	1350	840	5.20282E-07
	Dry	0.84	1650	840	6.06061E-07
	Dry	0.37	1050	840	4.19501E-07
	Dry	0.27	920	840	3.49379E-07
	Dry	0.29	980	840	3.52284E-07
	Moist	0.59	1050	840	6.68934E-07
		0.5	1000	840	5.95238E-07
		0.8	1300	840	7.32601E-07
		1.2	1600	840	8.92857E-07
		1.4	1900	840	8.77193E-07
medium weight, with lime	At 50°C	0.73	1650	880	5.02755E-07
no fines		0.96	1800	840	6.34921E-07
residuals of iron works		0.35	1000	840	4.16667E-07
		0.45	1300	840	4.12088E-07
		0.7	1600	840	5.20833E-07
		1	1900	840	6.26566E-07
roofing slab, aerated		0.16	500	840	3.80952E-07
vermiculite aggregate		0.17	450	840	4.49735E-07
very lightweight		0.14	370	840	4.5045E-07
		0.15	420	840	4.2517E-07
		0.16	470	840	4.05268E-07
		0.17	520	840	3.89194E-07
		0.18	570	840	3.7594E-07
		0.12	350	840	4.08163E-07
		0.18	600	840	3.57143E-07
Masonry:		0.19	470	840	4.81256E-07
block, lightweight					
		0.2	520	840	4.57875E-07
		0.22	570	840	4.59482E-07
		0.22	600	840	4.36508E-07
block, medium weight	Dry	0.6	1350	840	5.29101E-07
	Dry	0.85	1650	840	6.13276E-07
	Dry	1.3	1800	840	8.59788E-07
heavyweight	Dry	0.9	1850	840	5.79151E-07
	Dry	0.73	1850	840	4.69755E-07
	Dry	0.79	1950	840	4.82295E-07
	Dry	0.9	2050	840	5.22648E-07
	Moist	0.81	1650	840	5.84416E-07
lightweight	Dry	0.22	750	840	3.49206E-07
	Dry	0.27	850	840	3.78151E-07
	Dry	0.24	850	840	3.36134E-07
	Dry	0.27	950	840	3.38346E-07
medium weight	Dry	0.32	1050	840	3.62812E-07
	Dry	0.54	1300	840	4.94505E-07
	Dry	0.37	1150	840	3.83023E-07
	Dry	0.42	1250	840	0.0000004
	Dry	0.45	1350	840	3.96825E-07
	Dry	0.49	1450	840	4.02299E-07
	Dry	0.54	1550	840	4.14747E-07

Material Profile: Copper

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Copper	**58**	**69.02**	**37.52**	**2.40**	**152.71**	None
Copper, General	58	69.02	37.52	2.40	152.71	
50% Recycled	1	55.00	55.00	55.00	-	
Market Average	1	41.90	41.90	41.90	-	
Predominantly Recycled	11	32.68	32.66	2.40	120.00	
Unspecified	20	67.54	31.04	32.95	152.00	
Virgin	25	88.62	33.06	33.00	152.71	

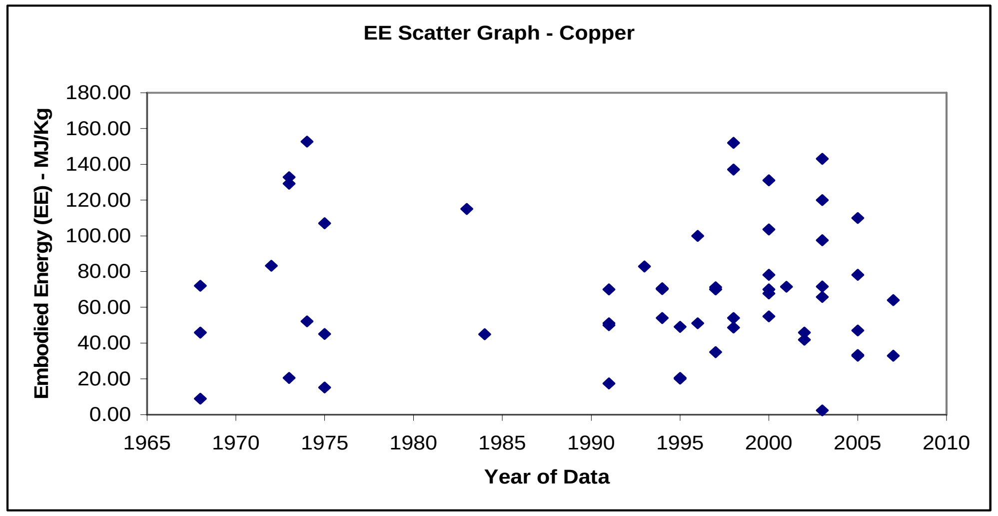
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Copper	40 to 55	2.19 to 3.83 (?)	Cradle to Gate	-	-	Assumes recycled materials of 46% (source: The environment agency).
Primary Copper	70 (?)	3.83 (?)		45	153	Large data range because the embodied energy is dependent upon ore grade
Secondary from low grade scrap	50 (?)	2.75 (?)	Cradle to Grave	40	60	
Secondary from high grade scrap	17.5 (?)	0.96 (?)		10	25	

Comments

The embodied energy of copper displays a very large data range. This is possibly due to variations in the grade of copper ore and copper scrap. There was poor data on the typical embodied carbon of copper, consequentially the embodied carbon data is uncertain.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	4.0%	5.9%
LPG	0.0%	0.0%
Oil	10.8%	12.4%
Natural gas	19.0%	16.1%
Electricity	66.2%	65.6%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in the copper industry.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
copper		384	8600	390	0.00011449

Material Profile: Glass

Embodied Energy (EE) Database Statistics - MJ/Kg

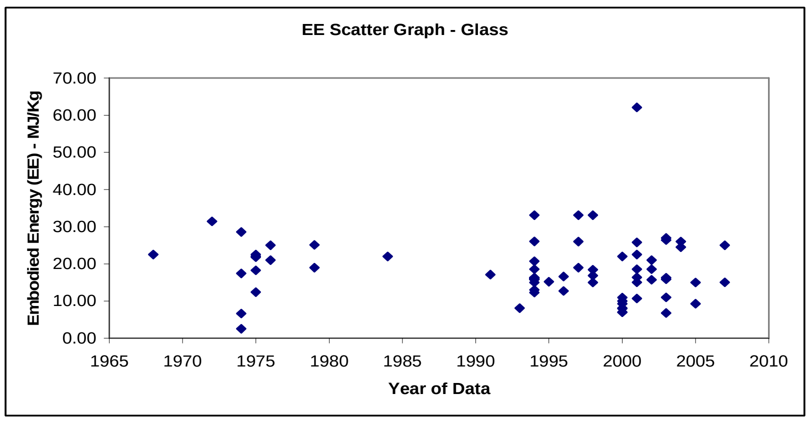
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Glass	**95**	**20.08**	**9.13**	**2.56**	**62.10**	None
Glass, Fibreglass	22	25.58	8.53	11.00	41.81	
Market Average	1	30.00		30.00	30.00	-
Predominantly Recycled	2	11.90		11.90	11.90	-
Unspecified	16	26.24	8.41	11.00	41.81	
Virgin	3	24.85	10.25	17.60	32.10	
Glass, General	73	18.50	8.73	2.56	62.10	
50% Recycled	1	7.00		7.00	7.00	-
Market Average	4	16.81	5.87	12.30	25.09	
Other Specification	1	8.10		8.10	8.10	-
Predominantly Recycled	4	6.63	4.07	2.56	10.70	
Unspecified	34	20.82	9.96	6.80	62.10	
Virgin	29	17.98	6.15	8.10	31.42	

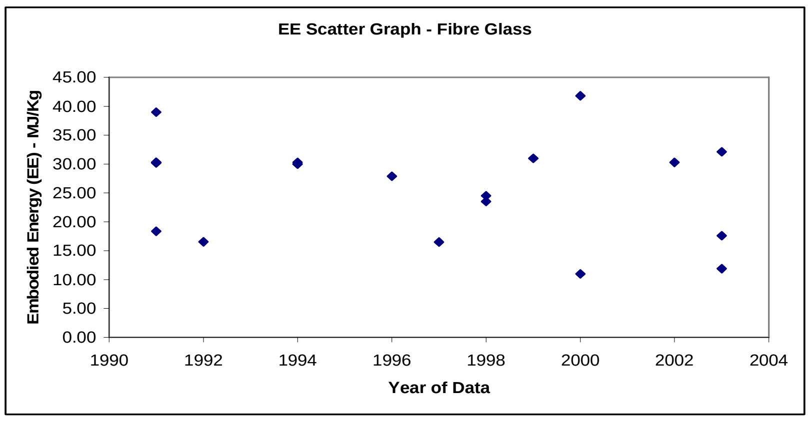
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Glass	15	0.85	Cradle to Gate	(+/- 30%)		38% recycling rate (British Glass). Recycling rate was taken from British glass report 'towards sustainable development 2004'
Fibreglass	28	1.53		16.5	42	Large data range, but the selected value is inside a small band of frequently quoted values.
Toughened Glass	23.5	1.27	Cradle to Gate	-	-	Only three data sources

Comments: Poor data availability on recycled glass.

Material Scatter Graph





Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	0.2%	0.2%
Natural gas	72.8%	60.0%
Electricity	27.0%	26.1%
Other	0.0%	13.7% (Non-energy related)
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

Primary Glass releases 0.185 Kg CO2 during production processes (Additional to energy emissions) this has been considered in the calculations (Fact from British Glass). The fuel mix was estimated from the UK glass industry typical fuel mix. Note that the carbon split is for general glass at 15 MJ/Kg embodied energy.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
cellular sheet		0.048	140	840	4.08163E-07
foam	At 50°C	0.056	130	750	5.74359E-07
		0.052	140	840	4.42177E-07
solid (soda-lime)	At 10°C	1.05	2500	840	0.0000005
Glass fibre/wool:					
fibre quilt		0.04	12	840	3.96825E-06
fibre slab		0.035	25	1000	0.0000014
fibre, strawboard-like		0.085	300	2100	1.34921E-07
wool	At 10°C	0.04	10	840	4.7619E-06
	At 10°C	0.04	12	840	3.96825E-06
	At 10°C	0.037	16	840	2.75298E-06
	At 10°C	0.033	24	840	1.6369E-06
	At 10°C	0.032	32	840	1.19048E-06
	At 10°C	0.03	48	840	7.44048E-07
	At 10°C	0.031	80	840	4.6131E-07
wool, resin bonded	At 50°C	0.036	24	1000	0.0000015

Material Profile: Insulation

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Insulation	**38**	**43.23**	**40.27**	**0.94**	**151.00**	None
Insulation (All)	38	43.23	40.27	0.94	151.00	
Unspecified	38	43.23	40.27	0.94	151.00	

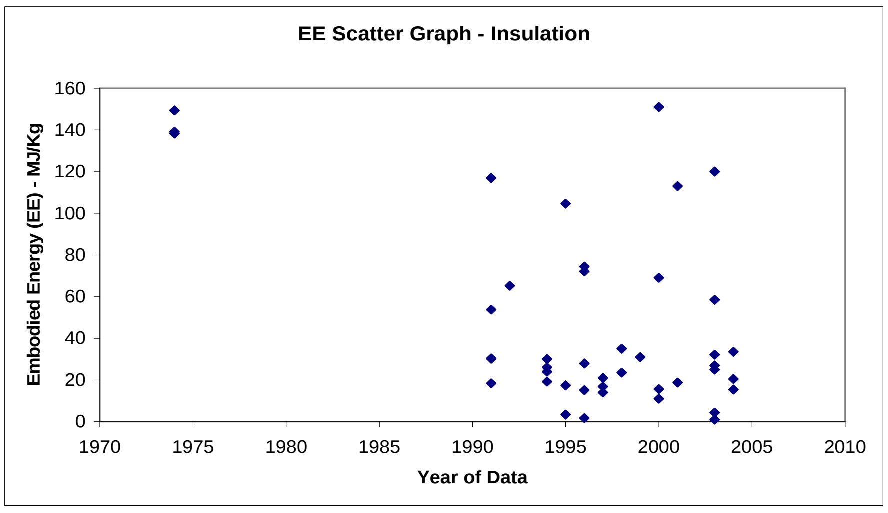
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
					Low EE	High EE	
General Insulation	45	16.5	1.86	Cradle to Gate	(+/- 40%)		Estimated from typical consumption mix of insulation materials in the UK
Cellular Glass	27	-	-	Unknown			Reference 48
Cellulose	0.94 to 3.3	-	-	Cradle to Gate			
Cork	4	-	0.19	Cradle to Gate			Reference 49
Fibreglass (Glasswool)	28	-	1.35	Cradle to Site			
Flax (Insulation)	39.5	5.97	1.7	Cradle to Grave			Reference 2
Mineral wool	16.6	-	1.2	Cradle to Gate			
Rockwool (stonewool)	16.8	-	1.05	Cradle to Site			Rockwool is a type of mineral wool (Brand)
Paper wool	20.2	-	0.63	Cradle to Grave			Reference 2
Polystyrene	See Plastics for a range of polystyrene data						
Polyurethane	See Plastics for a range of polyurethane data						
Woodwool (loose)	10.8	-	-	Cradle to Gate	(+/- 40%)		Reference 168
Woodwool (Board)	20	-	0.98				Reference 49
Recycled Wool	20.9	-	-				References 57,166 & 234

Comments

Embodied energy and carbon data for insulation materials was relatively poor. This may be a result of the fact that insulation materials save energy and will almost always payback the embodied energy during the lifetime of the insulation. But by comparing the embodied energy of insulation materials and considering U-values energy & carbon savings could still be made. It is important to consider space constraints in an embodied energy and carbon analysis of insulation. It there is only a fixed space, say 50mm, available then U-Value **must** be considered alongside embodied energy and carbon.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split, embodied carbon was estimated from the data available in the database

Material Properties (CIBSE Data) for Insulation

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Foam:					
phenol		0.04	30	1400	9.52381E-07
phenol, rigid		0.035	110	1470	2.1645E-07
polyisocyanate		0.03	45	1470	4.53515E-07
polyurethane		0.028	30	1470	6.34921E-07
polyurethane, freon-filled		0.03	45	1470	4.53515E-07
polyvinylchloride		0.035	37	1470	6.43501E-07
urea formaldehyde		0.04	10	1400	2.85714E-06
urea formaldehyde resin		0.054	14	1470	2.62391E-06
Mineral fibre/wool:					
fibre blanket, bonded	At 10°C	0.042	12	710	4.92958E-06
	At 10°C	0.036	24	710	2.11268E-06
	At 10°C	0.032	48	710	9.38967E-07
fibre blanket, metal	At 37.7°C	0.038	140	710	3.82294E-07
reinforced	At 93.3`C	0.046	140	710	4.62777E-07
fibre board, preformed		0.042	240	760	2.30263E-07
fibre board, wet felted		0.051	290	800	2.19828E-07
fibre board, wet moulded		0.061	370	590	2.79432E-07
fibre board, resin bonded		0.042	240	710	2.46479E-07
fibre, textile, organic bonded	At 10`C	0.043	10	710	6.05634E-06
fibre slag, pipe insulation	At 23.8°C	0.036	100	710	5.07042E-07

Material Properties (CIBSE Data) for Insulation					
Material	**Condition**	**Thermal conductivity (W-m-1 K-1)**	**Density (kg m -3)**	**Specific heat (J kg-1 K-1)**	**Thermal Diffusivity (M^2 S-1)**
	At23.8°C	0.048	200	710	3.38028E-07
	At 93.3°C	0.048	100	710	6.76056E-07
	At 93.3˚C	0.065	200	710	4.57746E-07
wool		0.038	140	840	3.23129E-07
wool, fibrous		0.043	96	840	5.33234E-07
wool, resin bonded		0.036	99	1000	3.63636E-07
Rock wool	At 10'C	0.037	23	710	2.26577E-06
	At 10'C	0.033	60	710	7.74648E-07
	At 10°C	0.033	100	710	4.64789E-07
	At 10˚C	0.034	200	710	2.39437E-07
unbonded		0.047	92	840	6.08178E-07
		0.043	150	840	3.4127E-07
Cork:		0.04	110	1800	2.0202E-07
board		0.04	160	1890	1.32275E-07
expanded		0.044	150	1760	1.66667E-07
expanded, impregnated		0.043	150	1760	1.62879E-07
slab		0.043	160	960	2.79948E-07
		0.055	300	960	1.90972E-07
tiles	Conditioned	0.08	530	1800	8.38574E-08

Material Profile: Iron

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Iron	**21**	**24.62**	**7.50**	**11.70**	**36.30**	The collected data was not sufficient to estimate coefficients for a broad range of iron products.
Iron, General	21	24.62	7.50	11.70	36.30	
Other Specification	1	20.50	20.50	20.50	-	
Unspecified	8	29.80	5.18	23.80	35.00	
Virgin	12	21.50	7.32	11.70	36.30	

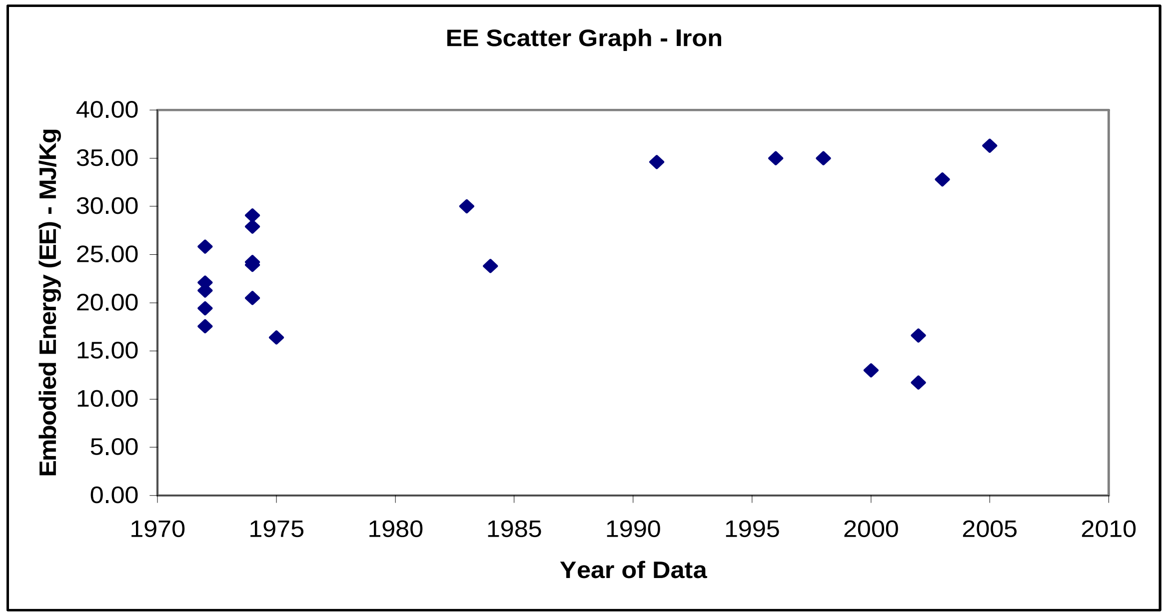
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
(Virgin) Iron - Statistical Average	25	1.91 (?)	Cradle to Gate	11.7	36.3	See comments below. This is a statistical average, which is NOT normally employed within the ICE database.

Comments

It is important to note that data for Iron is not of high enough quality to accurately estimate the embodied energy and carbon coefficients for a broad range of iron products. Iron shares the same ore as steel but the latter normally undergoes an extra processing operation, as such it would be expected to have a lower embodied energy and carbon than steel. Unfortunately and as a consequence of their similarities many people confuse the two materials. It was considered a possibility that some of the embodied energy data collected and categorised as Iron where in fact steel. Nevertheless the data available was insufficient to accurately determine the embodied energy and carbon of Iron. In the absence of improved data the selected embodied energy coefficient represents the average of the data within the database. Although it can't be stated with absolute certainty (because of ICE's reliance on secondary data resources) it was estimated that the selected value represents virgin iron. This would appear to be in line with the expectation that steel requires more processing energy than iron.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Iron			7870		

Material Profile: Lead

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Lead	**33**	**45.17**	**43.72**	**7.20**	**190.00**	None
Lead, General	33	45.17	43.72	7.20	190.00	
Predominantly Recycled	6	14.29	10.93	7.20	35.53	
Unspecified	9	41.83	35.63	20.00	134.00	
Virgin	18	57.14	49.72	22.00	190.00	

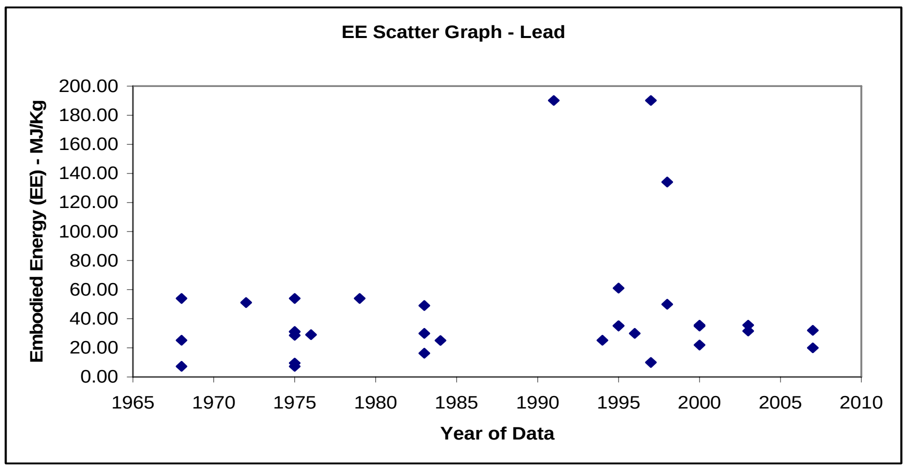
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Lead	25	1.33	Cradle to Gate	16	33	Assumes recycling rate of 61.5%
Primary Lead	49	2.61		30	60	Selected value is representative of a small band of frequently quoted values.
Secondary Lead	10	0.53		7	16	
Primary Lead Produced with Zinc	13.6 to 23.6	0.72 to 1.25		-	-	These values assumed that the energy allocated to the lead and zinc was divided assuming that the energy attributable to zinc was equal to that from other methods of producing zinc. The other values (above) assumed a mass based allocation.

Comments

Due to one of the methods of producing lead (lead can be produced in a process that also produces zinc) there is difficulty defining the energy attributable to the lead and the zinc. Some authors will assume that the energy is divided equally between the masses of each metal (or even on an economic basis). Others will assume that the zinc has the same energy as would be required to produce the zinc by other processes. The values above have assumed that the energy was divided upon a mass basis unless otherwise stated.

Material Scatter Graph



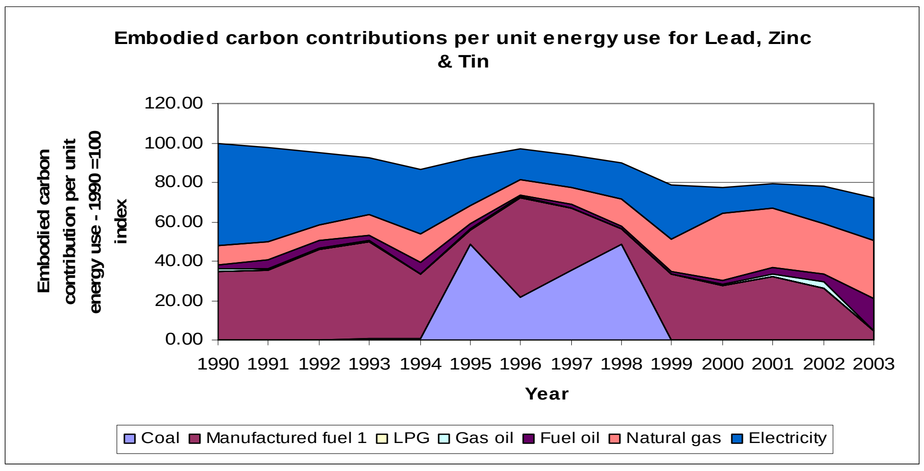
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	7.6%	11.7%
LPG	0.0%	0.0%
Oil	4.5%	5.3%
Natural gas	44.3%	38.5%
Electricity	43.6%	44.5%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK lead industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
lead		35	11340	130	2.37417E-05

Material Profile: Lime

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Lime	**39**	**4.57**	**2.79**	**0.04**	**10.24**	None
Lime, General	39	4.57	2.79	0.04	10.24	
Unspecified	4	6.51	4.36	0.20	10.24	
Virgin	35	4.24	2.40	0.04	9.10	

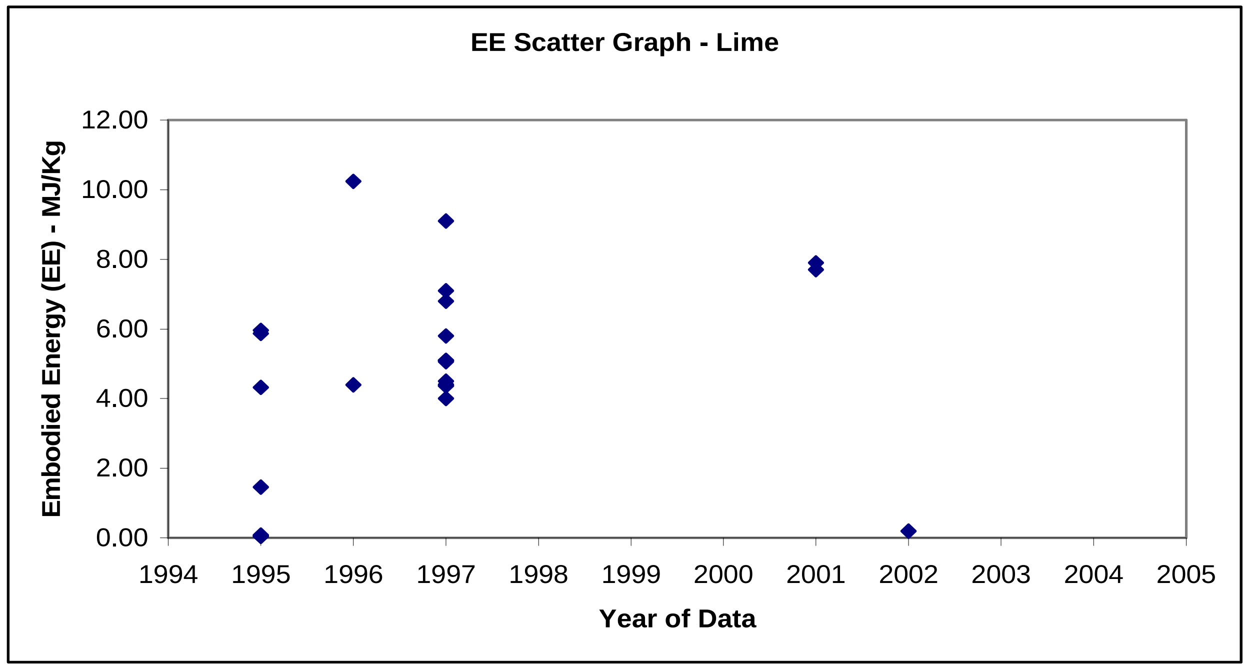
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Lime	5.3	0.74	Cradle to Gate	4	9.1	Wide range, dependent upon manufacturing technology. Although the embodied energy was higher than for cement the mix of fuels were cleaner in the UK, as such its embodied carbon was lower.

Comments

Lime is often chosen as an environmentally friendly material. It was therefore surprising to learn that the embodied energy of lime was slightly higher than for cement. This was observed from the respectable sample size of 39 data records. Lime is fired in the kiln to a lower temperature than cement, which is often misconceived as proof for a lower embodied energy. Yield, density, and time in the kiln are all vital parameters to total energy consumption. This is presented as a possibility for the higher embodied energy. It should be noted that embodied energy is, in itself, is not evidence to discredit limes environmental claims. Due to a more favourable fuel mix and slightly lower process related carbon dioxide emissions lime has a lower embodied carbon than cement. Additional benefits of using lime based mortar would include the increased ability for deconstruction, rather than demolition. The re-carbonation that occurs over the lifetimes of both cement and lime based mortars (when exposed to air) will reduce the embodied carbon impact of the materials. Examination of lime's full carbon cycle may be necessary.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	2.2%	2.9%
Natural gas	78.6%	75.4%
Electricity	19.3%	21.7%
Other	0.0%	0.0%
Total	**100.1%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK lime industry. Lime releases approximately 0.48 kg CO2/kg lime produced. This is a process related emission and is additional to the fuel related CO2.

Material Profile: Linoleum

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Linoleum	**9**	**30.49**	**34.38**	**1.00**	**116.00**	There is a very large data range due to one record which is much higher than other sources of data, see scatter graph.
Linoleum, General	9	30.49	34.38	1.00	116.00	
Unspecified	8	30.07	36.73	1.00	116.00	
Virgin	1	33.84	33.84	33.84	-	

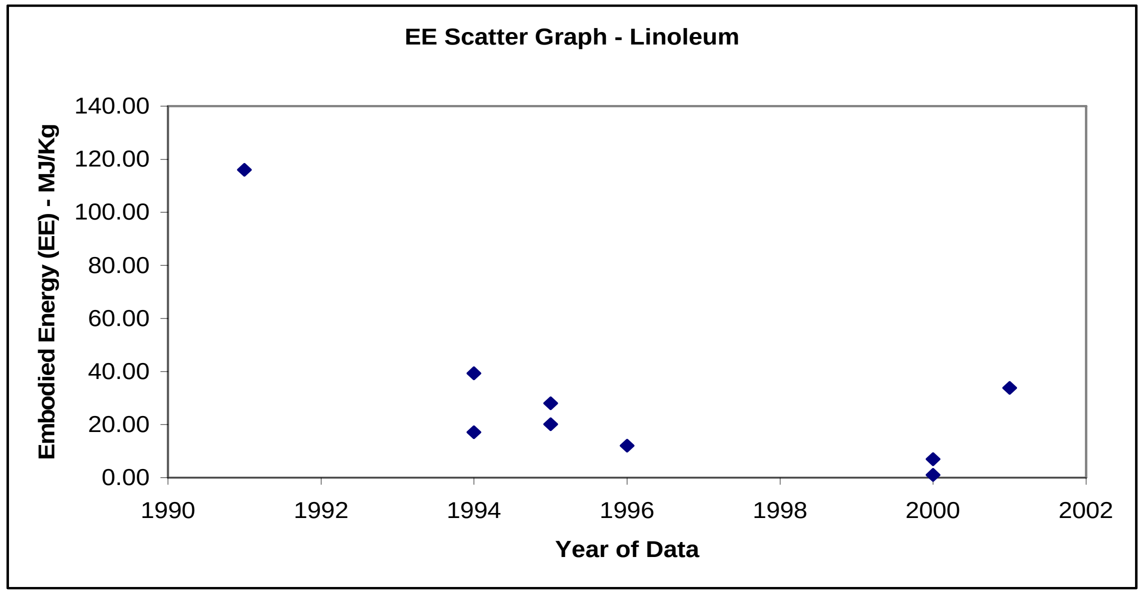
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Linoleum	25	1.21	Cradle to Grave	12	39.4	Small sample size

Comments

The estimate of embodied carbon was uncertain. It is an estimate based on the data available within the database. It is common practice to analyse linoleum from cradle to grave over an assumed lifetime of the product. The above values exclude any feedstock energy from the use of linseed oil in manufacture.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split, embodied carbon was estimated from the data available in the database

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Linoleum		0.19	1200	1470	1.0771E-07

Material Profile: Miscellaneous Materials

NOTE: These **database statistics** have been presented here for a number of miscellaneous materials, **it was not possible to create a standard material profile.**

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average	Standard Deviation	Minimum	Maximum
Miscellaneous	95	160.15	496.64	0.08	3710.00
Argon	1	6.80	6.80	6.80	
Unspecified	1	6.80	6.80	6.80	
Asbestos	1	7.40	7.40	7.40	
Virgin	1	7.40	7.40	7.40	
Calcium Silicate	1	2.00	2.00	2.00	
Unspecified	1	2.00	2.00	2.00	
Carpet Cushion/Pad	1	18.60	18.60	18.60	
Unspecified	1	18.60	18.60	18.60	
Carpet Underlay	1	18.50	18.50	18.50	
Unspecified	1	18.50	18.50	18.50	
Cellulose	6	5.71	6.94	0.94	19.60
Unspecified	4	2.59	1.54	0.94	4.36
Virgin	2	11.95	10.82	4.30	19.60
Chromium	1	83.00	83.00	83.00	
Virgin	1	83.00	83.00	83.00	
Cork	1	4.00	4.00	4.00	
Unspecified	1	4.00	4.00	4.00	
Cotton	6	146.38	108.52	27.10	350.00
Unspecified	5	105.66	47.77	27.10	143.25
Virgin	1	350.00	350.00	350.00	
Damp Proof Course/Membrane	5	134.18	36.49	100.00	183.00
Unspecified	4	142.73	35.90	105.90	183.00
Virgin	1	100.00	100.00	100.00	
Felt	5	36.06	24.63	10.08	75.00
Unspecified	4	39.50	27.02	10.08	75.00
Virgin	1	22.30	22.30	22.30	
Flax	1	33.50	33.50	33.50	
Unspecified	1	33.50	33.50	33.50	
Fly ash	2	0.09	0.02	0.08	0.10
Unspecified	2	0.09	0.02	0.08	0.10
General Carpet	6	135.68	127.38	67.90	390.00
Unspecified	4	89.04	32.40	71.73	137.60
Virgin	2	228.95	227.76	67.90	390.00
General Insulation	6	62.68	38.65	14.60	103.35
Unspecified	2	35.00	0.00	35.00	35.00
Virgin	4	76.51	41.51	14.60	103.35
Grit	1	0.12	0.12	0.12	
Virgin	1	0.12	0.12	0.12	
Grout	1	30.80	30.80	30.80	
Unspecified	1	30.80	30.80	30.80	
GRP	2	97.50	3.54	95.00	100.00
Unspecified	1	100.00	100.00	100.00	
Virgin	1	95.00	95.00	95.00	
Lithium	1	853.00	853.00	853.00	
Virgin	1	853.00	853.00	853.00	
Mandolite	1	63.00	63.00	63.00	
Unspecified	1	63.00	63.00	63.00	
Manganese	1	52.00	52.00	52.00	
Virgin	1	52.00	52.00	52.00	
Mercury	1	87.00	87.00	87.00	
Virgin	1	87.00	87.00	87.00	
Mineral Wool	9	21.35	7.51	14.00	37.00
Market Average	1	24.00	24.00	24.00	
Unspecified	6	20.85	8.13	15.12	37.00
Virgin	2	21.50	10.61	14.00	29.00
Molybedenum	1	378.00	378.00	378.00	
Virgin	1	378.00	378.00	378.00	
Nickel	3	164.00	43.59	114.00	194.00
Virgin	3	164.00	43.59	114.00	194.00
Perlite	3	6.91	5.47	0.66	10.87
Unspecified	1	0.66	0.66		
Virgin	2	10.04	1.18	9.20	10.87
Quartz powder	1	0.85	0.85	0.85	
Virgin	1	0.85	0.85	0.85	
Rock wool	5	18.11	4.10	14.00	25.00
Unspecified	4	18.28	4.71	14.00	25.00
Virgin	1	17.43	17.43	17.43	
Shingle	1	11.34	11.34	11.34	
Unspecified	1	11.34	11.34	11.34	
Silicon	1	2355.00	2355.00	2355.00	
Virgin	1	2355.00	2355.00	2355.00	
Silver	1	128.20	128.20	128.20	
Unspecified	1	128.20	128.20	128.20	
Slag	1	1.30	1.30	1.30	
Unspecified	1	1.30	1.30	1.30	
Starch	1	15.00	15.00	15.00	
Unspecified	1	15.00	15.00	15.00	
Stone wool	1	15.43	15.43	15.43	
Unspecified	1	15.43	15.43	15.43	
Straw	1	0.24	0.24	0.24	
Unspecified	1	0.24	0.24	0.24	
Terrazzo Tiles	1	1.40	1.40	1.40	
Unspecified	1	1.40	1.40	1.40	
Vanadium	1	3710.00	3710.00	3710.00	
Virgin	1	3710.00	3710.00	3710.00	
Vermiculite	2	3.97	4.59	0.72	7.22
Virgin	2	3.97	4.59	0.72	7.22
Vicuclad	1	70.00	70.00	70.00	
Unspecified	1	70.00	70.00	70.00	
Water	1	0.20	0.20	0.20	
Unspecified	1	0.20	0.20	0.20	
Wax	1	52.00	52.00	52.00	
Unspecified	1	52.00	52.00	52.00	
Wood stain/Varnish	1	50.00	50.00	50.00	
Unspecified	1	50.00	50.00	50.00	
Wool	4	33.23	49.24	3.00	106.00
Predominantly Recycled	1	20.90	20.90	20.90	
Unspecified	3	37.33	59.47	3.00	106.00
Yttrium	1	1470.00	1470.00	1470.00	
Virgin	1	1470.00	1470.00	1470.00	
Zirconium	1	1610.00	1610.00	1610.00	
Virgin	1	1610.00	1610.00	1610.00	

Material Profile: Paint

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Paint	**35**	**67.55**	**29.95**	**3.11**	**117.00**
Paint, General	35	67.55	29.95	3.11	117.00
Unspecified	21	75.61	31.51	24.00	117.00
Virgin	14	55.47	23.60	3.11	93.00

Comments on the Database Statistics:

None

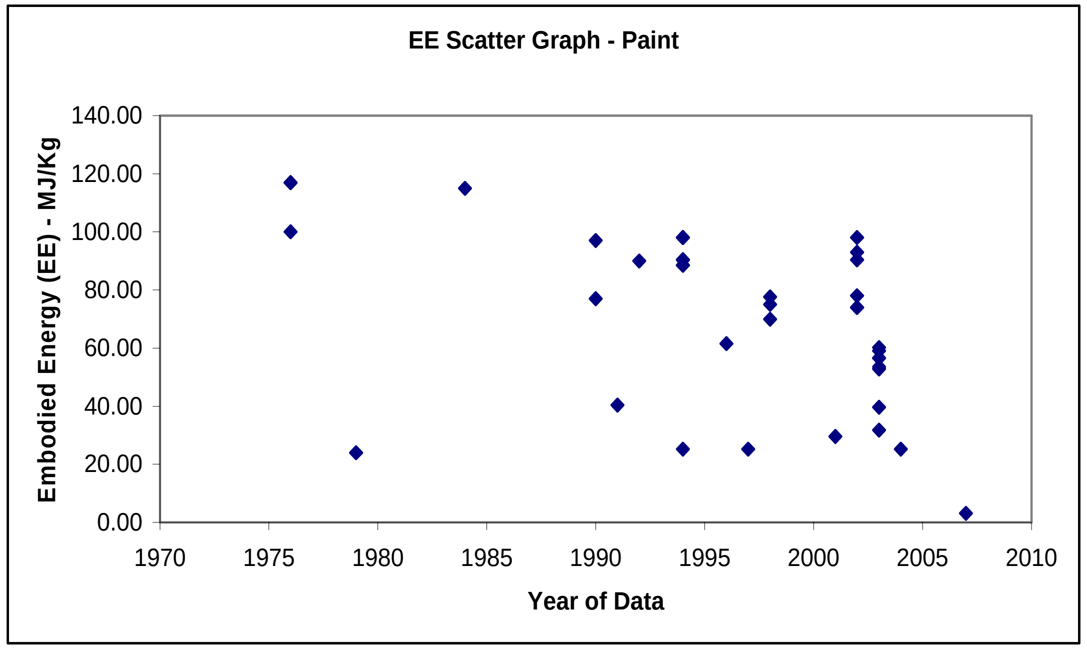
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Paint	68	3.56	Cradle to Gate	High variation perhaps as high as +/- 50%		Large variations in data, especially for embodied carbon.
EXAMPLE: Single Coat	10.2 MJ/Sqm	0.53 kgCO2/Sqm				Assume 6.66 Sqm Coverage per kg
EXAMPLE: Double Coat	20.4 MJ/Sqm	1.06 kgCO2/Sqm				Assume 3.33 Sqm Coverage per kg
EXAMPLE: Triple Coat	30.6 MJ/Sqm	1.60 kgCO2/Sqm				Assume 2.22 Sqm Coverage per kg

Comments

Embodied Carbon values experience a particularly large data range for embodied carbon.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	2.0%	2.5%
Natural gas	25.5%	22.5%
Electricity	72.5%	75.0%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry.

Material Profile: Paper

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Paper	**58**	**27.75**	**14.07**	**5.18**	**61.26**
Paper, Cardboard	11	29.97	14.51	10.70	60.00
Other Specification	4	26.31	16.13	10.70	40.83
Predominantly Recycled	4	25.66	9.16	13.20	35.27
Unspecified	2	43.15	23.83	26.30	60.00
Virgin	1	35.50	35.50	35.50	-
Paper, General Paper	47	27.22	14.08	5.18	61.26
Market Average	2	11.83	5.90	7.66	16.00
Other Specification	3	14.60	3.73	12.20	18.90
Predominantly Recycled	4	16.82	12.93	5.18	31.80
Unspecified	14	27.94	9.90	9.30	42.00
Virgin	24	31.58	15.45	12.70	61.26

Comments on the Database Statistics:

None

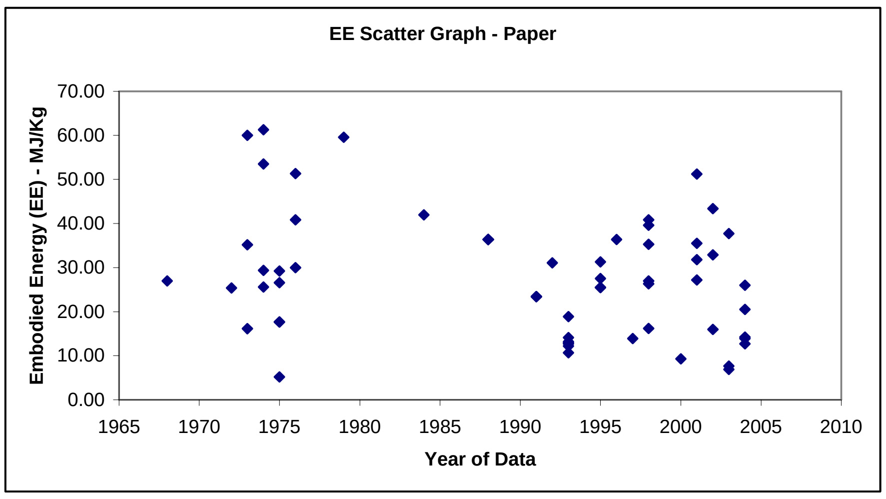
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg Low EE	Best EE Range - MJ/Kg High EE	Specific Comments
Paperboard (General construction purposes)	24.80	1.32	Cradle to Gate	10	39	-
Fine Paper	28.20	1.50		12	42	-
Wallpaper	36.40	1.93		(+/- 30%)		-

Comments

Much of the data in the database was outdated for paper. Notable improvements have been made within this industry in this time period. The best values in the database were selected and then modified to take into account the current situation. The values exclude the CV (Calorific Value) of wood and the effect of carbon sequestration, which is a complex discussion (see the material profile for timber).

Material Scatter Graph



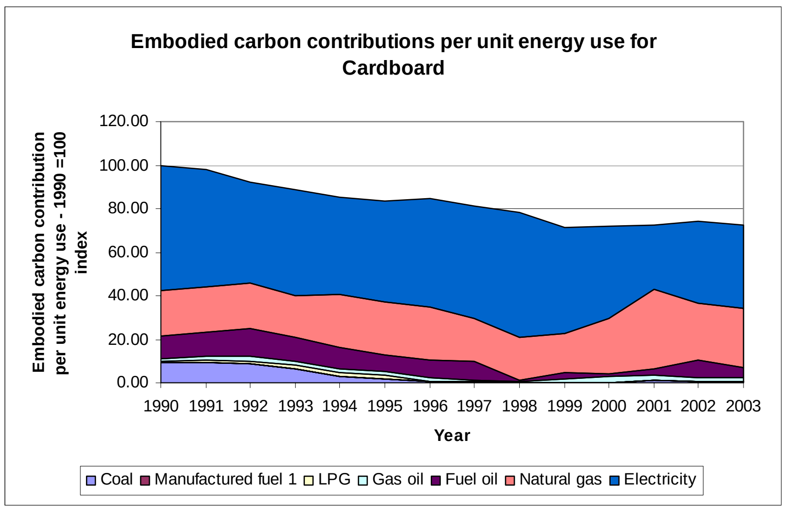
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	4.3%	6.7%
LPG	0.0%	0.0%
Oil	0.3%	0.4%
Natural gas	31.8%	27.7%
Electricity	63.6%	65.2%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in the paper and paperboard industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
- bitumen impregnated paper		0.06	1090	1000	5.50459E-08
- laminated paper		0.072	480	1380	1.08696E-07

Material Profile: Plaster

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Plaster	**40**	**4.03**	**2.55**	**0.03**	**12.20**	None
Plaster, General	7	3.50	2.85	1.40	9.73	
Unspecified	5	2.57	0.90	1.40	3.24	
Virgin	2	5.83	5.52	1.93	9.73	
Plaster, Gypsum	16	3.48	2.06	0.90	8.64	
Market Average	1	3.20	3.20	3.20	-	
Unspecified	14	3.62	2.16	0.90	8.64	
Virgin	1	1.81	1.81	1.81	-	
Plaster, Plasterboard	17	4.76	2.79	0.03	12.20	
Predominantly Recycled	1	2.24	2.24	2.24		
Unspecified	10	4.95	1.89	2.70	8.60	
Virgin	6	4.86	4.14	0.03	12.20	

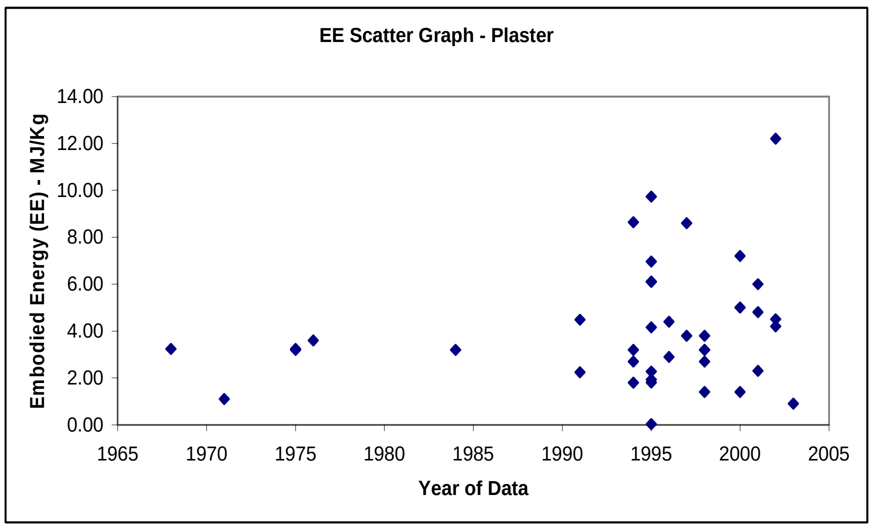
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Plaster	1.8	0.12	Cradle to Gate	1.4	3.2	The selected values are from the lower end of the range, please see comments.
Plasterboard	6.75	0.38		-		

Comments

The values quoted in the literature display a large variation, West et al believe this is because of past aggregation of plaster data with cement. The net effect of separating these industries would be to reduce the embodied energy of plaster. There was very poor background data on carbon, only a few authors specified the embodied carbon.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split, embodied carbon was estimated from a main resource.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Cement plaster		0.72	1760	840	4.87013E-07
		1.5	1900	840	9.3985E-07
Cement plaster, sand aggregate		0.72	1860	840	4.60829E-07
Cement screed		1.4	2100	650	1.02564E-06
gypsum		0.42	1200	840	4.16667E-07
gypsum plaster		0.51	1120	960	4.7433E-07
gypsum plaster, perlite aggregate		0.22	720	1340	2.28027E-07
gypsum plaster, sand aggregate		0.81	1680	840	5.7398E-07
Gypsum Plasterboard		0.16	800	840	2.38095E-07
		0.65	1100	840	7.03463E-07
Gypsum plastering		0.8	1300	840	7.32601E-07
limestone mortar		0.7	1600	840	5.20833E-07
plaster		0.22	800	840	3.27381E-07
		0.35	950	840	4.38596E-07
		0.52	1200	840	5.15873E-07
plaster ceiling tiles		0.38	1120	840	4.03912E-07
plaster, lightweight aggregate		0.23	720	840	3.80291E-07
Plaster, sand aggregate		0.82	1680	840	5.81066E-07
plasterboard		0.16	950	840	2.00501E-07
render, synthetic resin, exterior insulation		0.7	1100	900	7.07071E-07
rendering	Moisture content 1%	1.13	1430	1000	7.9021E-07
	Moisture content 8%	0.79	1330	1000	5.93985E-07
		0.2	720	840	3.30688E-07

Material Profile: Plastics

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Plastics	**219**	**93.91**	**42.84**	**1.24**	**380.00**	Care needs to be taken when examining these statistics, the inclusion or exclusion of feedstock energy is not apparent here, but only when analysing data within the main ICE-Database. The majority of the records include the feedstock energy, hence the statistics should be more representative of the inclusion of the feedstocks.
Plastics, ABS	8	77.83	45.17	1.24	114.20	
Market Average	1	95.30	95.30	95.30	-	
Predominantly Recycled	2	7.19	8.41	1.24	13.13	
Unspecified	4	99.70	15.19	79.90	112.20	
Virgin	1	114.20	114.20	114.20	-	
plastics, Acrylic	3	90.67	37.82	56.00	131.00	
Unspecified	2	70.50	20.51	56.00	85.00	
Virgin	1	131.00	131.00	131.00	-	
Plastics, General	24	105.30	37.67	45.70	162.00	
Unspecified	11	123.57	41.59	73.60	162.00	
Virgin	13	89.84	26.70	45.70	151.10	
Plastics, High Density Polyethylene (HDPE)	11	79.67	25.39	18.60	103.00	
Market Average	2	80.55	5.44	76.70	84.40	
Predominantly Recycled	1	18.60	18.60	18.60	-	
Unspecified	6	95.15	8.96	80.98	103.00	
Virgin	2	62.90	16.83	51.00	74.80	
Plastics, Low Density Polyethylene (LDPE)	7	77.72	16.26	51.00	103.00	
Market Average	2	83.70	7.92	78.10	89.30	
Unspecified	3	82.55	18.28	67.80	103.00	
Virgin	2	64.50	19.09	51.00	78.00	
Plastics, Nylon	13	160.07	66.60	79.70	365.00	
Market Average	1	138.60	138.60	138.60	-	
Unspecified	11	143.39	27.76	79.70	190.00	
Virgin	1	365.00	365.00	365.00	-	
Plastics, Polyamide Resin (PA)	1	137.60	137.60	137.60	-	
Unspecified	1	137.60	137.60	137.60	-	
Plastics, Polycarbonate	5	109.30	30.59	80.30	158.51	
Market Average	1	112.90	112.90	112.90	-	
Unspecified	4	108.40	35.25	80.30	158.51	
Plastics, Polyester	7	103.83	122.11	53.70	380.00	
Unspecified	6	57.80	9.90	53.70	78.00	
Virgin	1	380.00	380.00	380.00	-	
Plastics, Polyethylene	14	89.72	32.77	59.04	188.59	
Market Average	1	85.83	85.83	85.83	-	
Unspecified	11	89.96	35.88	59.04	188.59	
Virgin	2	91.00	91.00	91.00	-	
Plastics, Polyethylterepthalate (PET)	11	90.45	32.88	21.90	153.30	
Predominantly Recycled	1	21.90	21.90	21.90	-	
Unspecified	6	89.18	18.03	59.40	107.00	
Virgin	4	109.50	31.77	77.30	153.30	
Plastics, Polypropylene	21	93.97	31.14	40.20	171.00	
Market Average	3	95.89	21.06	73.37	115.10	
Unspecified	15	90.89	31.56	40.20	171.00	
Virgin	3	107.44	43.94	62.20	149.95	
Plastics, Polystyrene	36	100.09	22.86	58.40	151.00	
Market Average	4	92.90	10.90	86.40	109.20	
Predominantly Recycled	1	90.25	90.25	90.25	-	
Unspecified	18	99.38	19.64	74.43	151.00	
Virgin	13	104.03	30.09	58.40	149.35	
Plastics, Polyurethane	11	80.10	15.95	65.20	110.00	
Unspecified	10	77.66	14.47	65.20	110.00	
Virgin	1	104.60	104.60	104.60	-	
Plastics, PVC	44	70.61	21.00	15.10	120.00	
Market Average	6	68.95	13.59	57.54	95.10	
Predominantly Recycled	1	15.10	15.10	15.10	-	
Unspecified	27	72.73	19.61	30.83	120.00	
Virgin	10	71.53	23.37	38.20	106.62	
Plastics, Resin	1	200.00	200.00	200.00	-	
Unspecified	1	200.00	200.00	200.00	-	
Plastics, UPVC	2	94.70	35.78	69.40	120.00	
Market Average	1	69.40	69.40	69.40	-	
Unspecified	1	120.00	120.00	120.00	-	

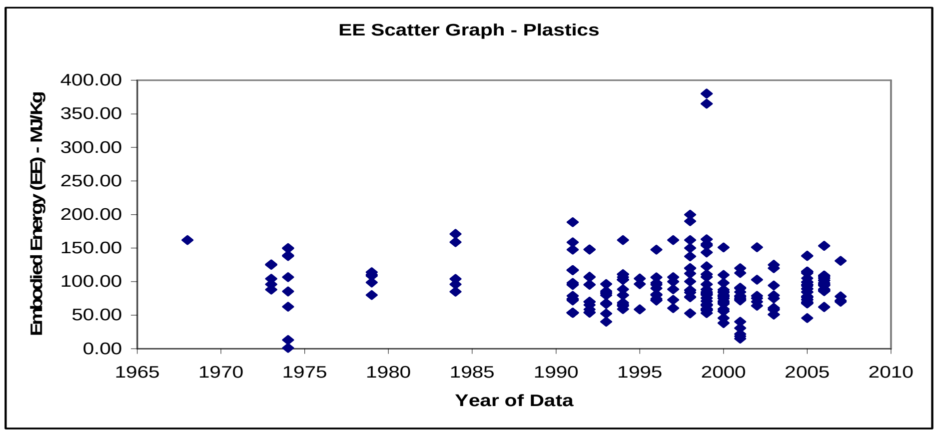
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Plastic	80.5	35.6	2.53	Cradle to Gate	(+/- 30%)		type of plastic used in the European construction industry. Average density 960 kg/m^3
ABS	95.3	48.6	3.1				
General Polyethylene	83.1	54.4	1.94				Based on average use of types of PE in European construction
High Density Polyethylene (HDPE)	76.7	54.3	1.6				
HDPE Pipe	84.4	55.1	2				
Low Density Polyethylene (LDPE)	78.1	51.6	1.7				
LDPE Film	89.3	55.2	1.9				
Nylon 6	120.5	38.6	5.5				
Nylon 6,6	138.6	50.7	6.5				
Polycarbonate	112.9	36.7	6				
Polypropylene, Orientated Film	99.2	55.7	2.7				
Polypropylene, Injection Moulding	115.1	54	3.9				
Expanded Polystyrene	88.6	46.2	2.5				
General Purpose Polystyrene	86.4	46.3	2.7				
High Impact Polystyrene	87.4	46.4	2.8				
Thermoformed Expanded Polystyrene	109.2	49.7	3.4				
Polyurethane	72.1	34.67	3				Poor data availability of feedstock energy
PVC General	77.2	28.1	2.41				Based on the market average use of types of PVC in the European construction industry
PVC Pipe	67.5	24.4	2.5				
Calendered Sheet PVC	68.6	24.4	2.6				
PVC Injection Moulding	95.1	35.1	2.2				
UPVC Film	69.4	25.3	2.5				

Material Profile: Plastics

Comments	Most of the selected values are from the Association of Plastic Manufacturers in Europe (APME), see www.plasticseurope.org, who have completed many detailed LCA studies for plastics. Their data is available freely on the internet. With the selected mix of plastics the average density for general plastic was 960 kg/m^3.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Electricity	44.8%	42.4%
Oil fuels	22.3%	27.2%
Other Fuels	32.9%	30.4%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fuel split data was estimated from the data available from the APME and the assumed use of plastic types in the construction industry. The APME did not provide details of the embodied carbon split or information about the emission factors they apply. The above carbon values are an estimation. They exclude the feedstock energy (59.6% Oil, 40.4% oil fuels).

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Polyvinylchloride (PVC)		0.16	1380	1000	1.15942E-07
tiles		0.19	1200	1470	1.0771E-07
Foam:					
phenol		0.04	30	1400	9.52381E-07
phenol, rigid		0.035	110	1470	2.1645E-07
polyisocyanate		0.03	45	1470	4.53515E-07
polyurethane		0.028	30	1470	6.34921E-07
polyurethane, freon-filled		0.03	45	1470	4.53515E-07
polyvinylchloride		0.035	37	1470	6.43501E-07
urea formaldehyde		0.04	10	1400	2.85714E-06
urea formaldehyde resin		0.054	14	1470	2.62391E-06
plastic tiles		0.5	1050	840	5.66893E-07
polyurethane, expanded		0.023	24	1590	6.02725E-07
polyurethane, unfaced	At 10°C	0.023	32	1590	4.52044E-07

Material Profile: Rubber

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Rubber	**16**	**96.88**	**38.86**	**40.30**	**150.40**
Rubber, General	8	109.33	44.90	40.30	150.40
Unspecified	5	140.59	12.58	119.56	150.40
Virgin	3	57.24	15.06	40.30	69.11
Rubber, Natural	4	68.98	1.68	67.50	70.80
Unspecified	4	68.98	1.68	67.50	70.80
Rubber, Synthetic	4	99.88	37.15	64.40	147.60
Unspecified	4	99.88	37.15	64.40	147.60

Comments on the Database Statistics:

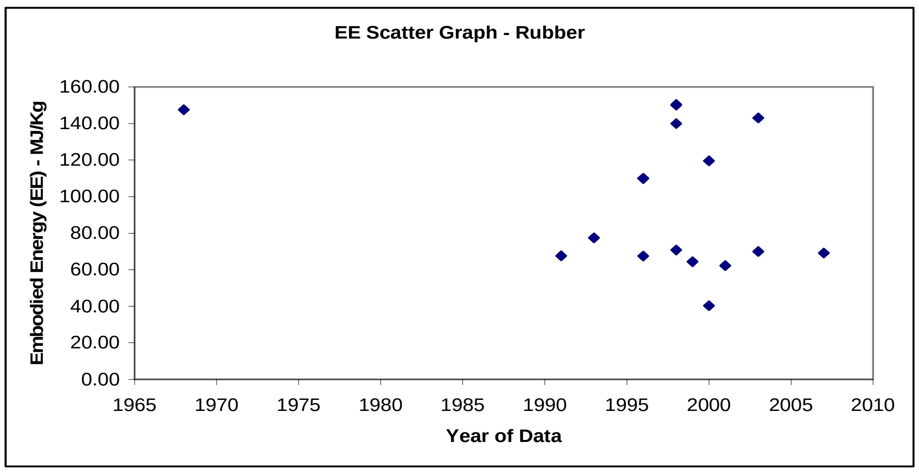
Care must be taken with these statistics, some include and some exclude feedstock energy. The best indicators are those selected by the authors, who have analysed the data knowing which data points include feedstocks and which exclude them.

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Rubber	101.7	41.1	3.18	Cradle to Gate	Not enough data for accurate range. Estimated range +/- 30%		Assumes that natural rubber accounts for 35% of market (between 30-40%; info source: Materials Information Service & http://www.azom.com/)
Synthetic Rubber	120	42	4.02				
Natural Rubber	67.6	39.43	1.63				The feedstock energy was from the production of carbon black, which is used in natural rubber production.

Comments It was difficult to estimate the carbon emissions.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	12.3%	17.4%
LPG	0.0%	0.0%
Oil	11.3%	12.8%
Natural gas	11.1%	8.8%
Electricity	65.3%	60.9%
Other	0.0%	0.0%
Total	**100.0%**	**99.9%**

Fuel Split & Embodied Carbon Comments:

The selected values of embodied carbon are from the typical UK fuel mix in the rubber industry. The above fuel mix does not include the feedstock energy.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
Rubber		0.17	1500	1500	7.55556E-08
expanded board, rigid		0.032	70	70	6.53061E-06
hard		0.15	1200	1200	1.04167E-07
tiles		0.3	1600	1600	1.17188E-07

Material Profile: Sand

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Sand	**17**	**0.22**	**0.23**	**0.02**	**0.63**
Sand, General	17	0.22	0.23	0.02	0.63
Unspecified	12	0.24	0.24	0.02	0.63
Virgin	5	0.16	0.22	0.02	0.55

Comments on the Database Statistics:

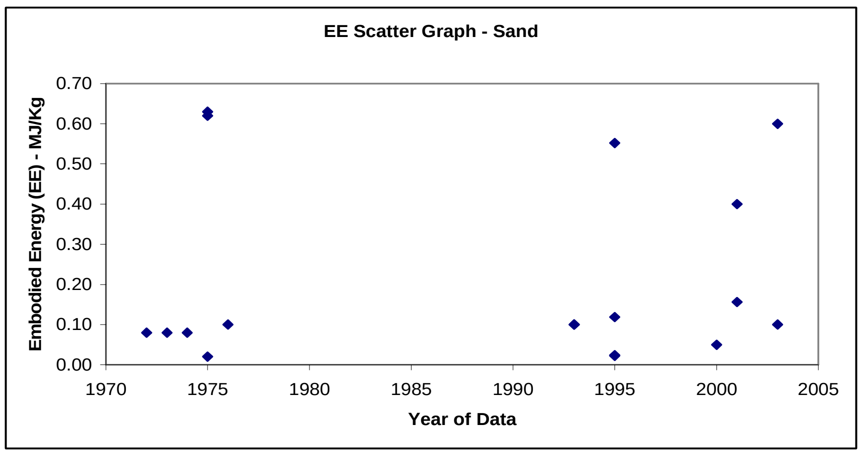
These statistics are obscured by a few high values (See scatter chart)

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Sand	0.1	0.005	Cradle to Gate	0.05	0.15	None

Comments	It can be observed from the scatter graph that the median is in the region of 0.1 MJ/kg. Transport will likely be significant for sand.

Material Scatter Graph



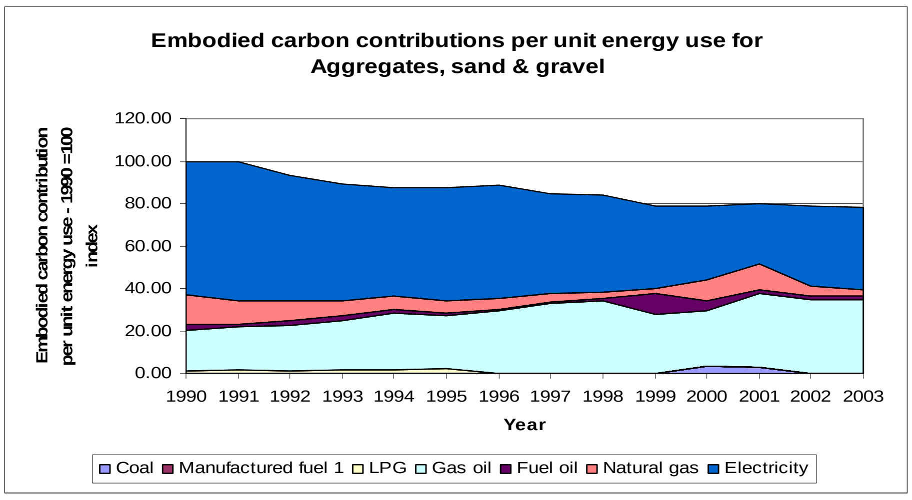
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	19.8%	22.7%
Natural gas	14.9%	12.6%
Electricity	65.3%	64.7%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
sand		1.74	2240	840	9.24745E-07

Material Profile: Sealants & Adhesives

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Sealants and adhesives	**15**	**86.62**	**46.81**	**8.00**	**200.00**	
Sealants and adhesives, Epoxide Resin	2	139.96	0.91	139.32	140.60	
Market Average	1	139.32	139.32	139.32	-	
Unspecified	1	140.60	140.60	140.60	-	
Sealants and adhesives, General Adhesives	2	61.67	23.57	45.00	78.34	
Unspecified	2	61.67	23.57	45.00	78.34	
Sealants and adhesives, General sealants	1	8.00	8.00	8.00	-	There were more materials (sealants and adhesives) in the ICE database than have been used for this inventory, as can be observed from the database statistics. limited data from quality resources made selection of coefficients difficult.
Unspecified	1	8.00	8.00	8.00	-	
Sealants and adhesives, Mastic Sealant	2	131.14	97.38	62.28	200.00	
Unspecified	2	131.14	97.38	62.28	200.00	
Sealants and adhesives, melamine resin	1	112.81	112.81	112.81	-	
Unspecified	1	112.81	112.81	112.81	-	
Sealants and adhesives, Phenol Formaldehyde	2	88.16	1.64	87.00	89.32	
Unspecified	2	88.16	1.64	87.00	89.32	
Sealants and adhesives, Urea Formaldehyde	5	67.34	15.85	40.00	78.20	
Unspecified	5	67.34	15.85	40.00	78.20	

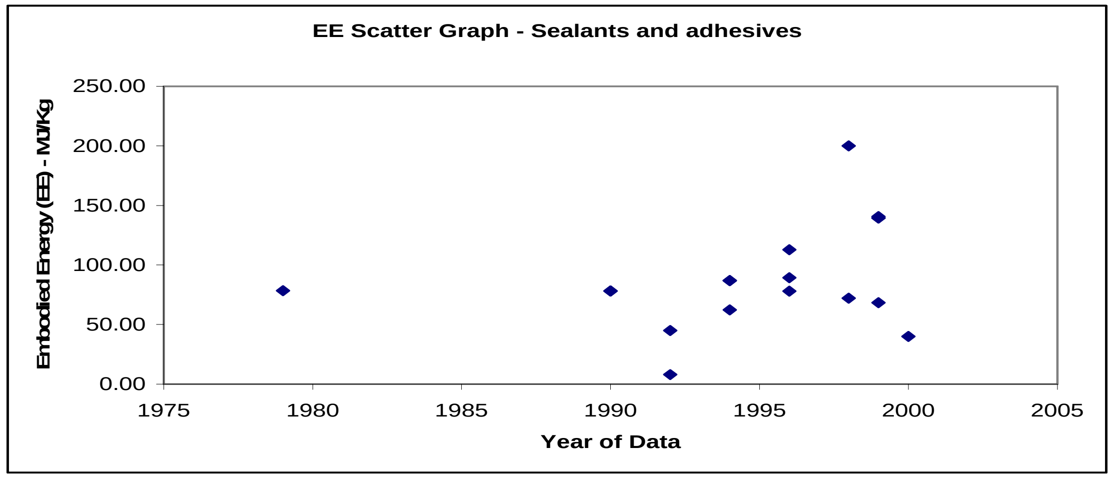
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
					Low EE	High EE	
Epoxide Resin	139.32	42.6	5.91	Cradle to Gate	(+/- 20%)		
Mastic Sealant	62.28 to 200	?	?	Two different values from two sources, they have different boundaries: Lower value Cradle to Gate, upper value Cradle to Site!	-	-	Only two data sources, with large range, data includes an unknown value of feedstock energy!
Melamine Resin	113	?	?	Cradle to Gate	-	-	Reference 77
Phenol Formaldehyde	87 to 89.32	?	?	Cradle to Grave	-	-	data includes an unknown value of feedstock energy!
Urea Formaldehyde	40 to 78.2	?	1.3 to 2.26	Cradle to Site	-	-	data includes an unknown value of feedstock energy!

Comments

The data on sealants & adhesives was very limited. There was very little feedstock and embodied energy data. The values for mastic sealant, phenol formaldehyde and urea formaldehyde include feedstock energy, which is an unknown quantity in these materials.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split, any specified embodied carbon was taken from the literature.

Material Profile: Soil

Embodied Energy (EE) Database Statistics - MJ/Kg

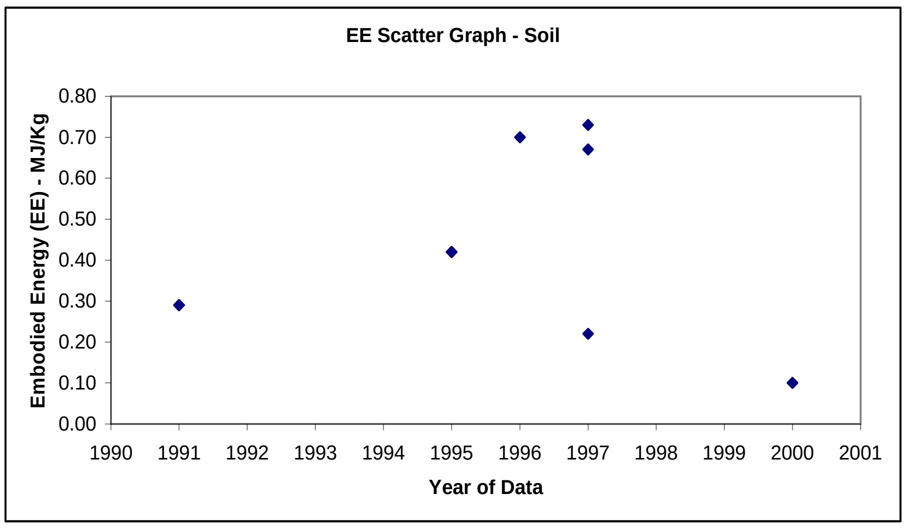
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Soil	**7**	**0.45**	**0.26**	**0.10**	**0.73**	None
Soil, General	7	0.45	0.26	0.10	0.73	
Unspecified	7	0.45	0.26	0.10	0.73	

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General (Rammed) Soil	0.45	0.023	Cradle to Site	0.15	0.73	-

Comments: See embodied carbon comments.

Material Scatter Graph



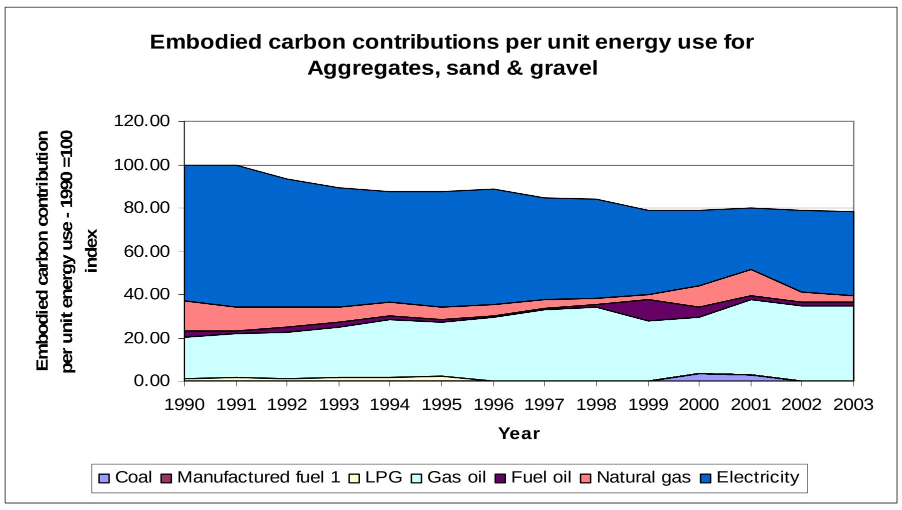
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	19.8%	22.7%
Natural gas	14.9%	12.6%
Electricity	65.3%	64.7%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

There was almost no embodied carbon data for soil It was assumed that soil had similar fuel use to the most closely related material, which was sand. The embodied carbon was estimated by using the UK typical fuel split in this industry. Assuming the average UK industrial fuel use (from all sectors) also produced similar results of embodied carbon. For this reason it is believed that this provides a sufficient estimate in the absence of quality data on embodied carbon.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
earth, common		1.28	1460	880	9.96264E-07
earth, gravel-based		0.52	2050	180	1.40921E-06

Material Profile: Steel

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Steel	**180**	**31.25**	**16.50**	**6.00**	**95.70**	None
Steel, General	154	29.36	13.45	6.00	77.00	
50% Recycled	2	32.75	20.86	18.00	47.50	
Market Average	11	25.68	5.92	18.20	36.00	
Other Specification	2	19.40	0.71	18.90	19.90	
Predominantly Recycled	33	13.60	4.86	6.00	23.40	
Unspecified	49	31.96	10.61	12.50	77.00	
Virgin	57	37.48	12.07	12.00	63.42	
Steel, Stainless	21	45.68	28.84	8.20	95.70	
Market Average	3	48.36	6.22	40.20	51.48	
Predominantly Recycled	2	11.00	0.00	11.00	11.00	
Unspecified	8	43.10	32.21	8.20	95.70	
Virgin	8	57.80	28.76	12.00	81.77	
Steel, Structural	5	30.91	3.74	25.50	35.90	
Unspecified	2	28.67	4.48	25.50	31.83	
Virgin	3	32.40	3.10	30.00	35.90	

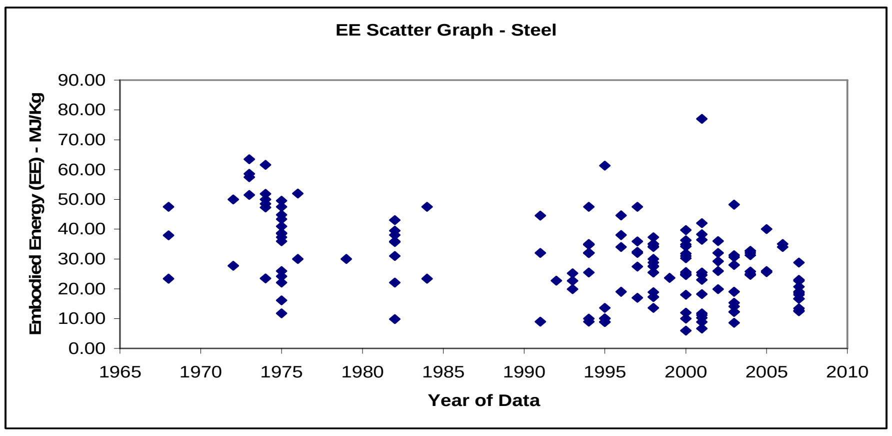
Selected Embodied Energy & Carbon Values and Associated Data

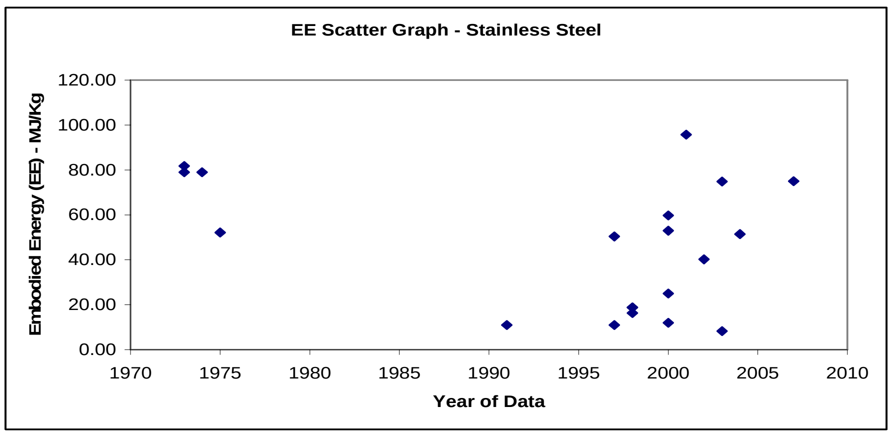
Material	Embodied Energy - MJ/Kg			Embodied Carbon - Kg CO2/Kg			Boundaries	Best EE Range - MJ/Kg		Specific Comments
	UK Typical	Primary	Secondary	UK Typical	Primary	Secondary		Low EE	High EE	
General Steel	24.4	35.3	9.50	1.77	2.75	0.43	Cradle to Gate	(+/- 30%)		Estimated from UK's consumption of types of steel, and worldwide recycled content 42.7%
Bar & rod	24.6	36.4	8.8	1.71	2.68	0.42				
Engineering steel	-	-	13.1	-	-	0.68				
Pipe	-	34.4	*NTMR*	-	2.7	*NTMR*				NTMR = Not Typical Manufacturing Route
plate	-	48.4	*NTMR*	-	3.19	*NTMR*				NTMR = Not Typical Manufacturing Route
Section	25.4	36.8	10.0	1.78	2.78	0.44				
Sheet	-	31.5	*NTMR*	-	2.51	*NTMR*				NTMR = Not Typical Manufacturing Route
Sheet - Galvanised	-	39.0	-	-	2.82	-				
Wire	-	36.0	-	-	2.83	-				
Stainless	56.7	-	-	6.15	-	-		11	81.8	4.3 MJ/kg Feedstock Energy (Included). World average data from Institute of Stainless Steel Forum (ISSF) was selected due to the large extent of the study. Values specified are for the most popular grade (304).

Comments

Assumed 42.7% worldwide recycled material, as used to estimate the typical market values. The best data resource was from the International Iron & Steel Institute (IISI), who completed to most detailed steel LCI to date. Some of the IISI data has been processed to fit into the categories (Primary, secondary material). The results of this study are in line with that expected from other sources. **Please see note on recycling methodology at the front of the document.**

Material Scatter Graph





Fuel Split & Embodied Carbon Data

No breakdown of fuel use or carbon emissions was available. There has not been an estimate of this breakdown by the author because the steel industry is complicated by the production of by-products (which may be attributed energy or carbon credits), excess electricity (they produce some of their own electricity) and non-fuel related emissions from the calcination of lime during the production process.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
stainless steel, 5% Ni		29	7850	480	7.69639E-06
stainless steel, 20% Ni		16	8000	480	4.16667E-06
steel		45	7800	480	1.20192E-05

Material Profile: Stone

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Stone	**54**	**1.26**	**2.35**	**0.02**	**13.90**
Stone, General	18	1.23	1.74	0.02	6.80
Predominantly Recycled	1	0.40	0.40	0.40	-
Unspecified	10	1.47	2.12	0.10	6.80
Virgin	7	1.00	1.24	0.02	3.60
Stone, Granite	5	4.10	6.01	0.10	13.90
Unspecified	5	4.10	6.01	0.10	13.90
Stone, Limestone	18	0.41	0.58	0.03	2.45
Unspecified	17	0.42	0.60	0.03	2.45
Virgin	1	0.37	0.37	0.37	-
Stone, Marble	3	1.88	1.52	0.30	3.33
Unspecified	3	1.88	1.52	0.30	3.33
Stone, Slate	1	0.03	0.03	0.03	-
Virgin	1	0.03	0.03	0.03	-
Stone, Slate	9	1.40	1.97	0.08	5.06
Unspecified	7	1.07	1.58	0.10	4.57
Virgin	2	2.57	3.52	0.08	5.06

Comments on the Database Statistics:

None

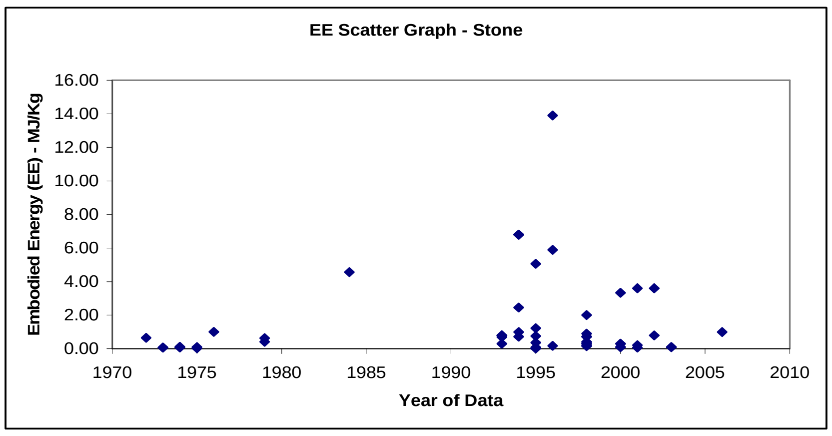
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg Low EE	Best EE Range - MJ/Kg High EE	Specific Comments
General Stone	1 (?)	0.056 (?)	Cradle to Gate	0.1	3.6	Wide data range.
Stone Gravel/Chippings	0.3	0.017		0.3	0.9	only 3 data points The European sources quote 0.3 MJ/Kg which is at the low end of the range.
Granite	0.1 to 13.9 (!?)	0.006 to 0.781 (!?)	Cradle to Gate	Not enough data for accurate range. Estimated range +/- 30%		Reference 22
Limestone	0.3	0.017	Cradle to Gate	0.14	0.34	
Marble	2	0.112		Not enough data for accurate range. Estimated range +/- 30%		
Marble tile	3.33	0.187	Cradle to grave			Reference 36
Shale	0.03	0.002	Cradle to Gate	-	-	
Slate	0.1 to 1.0	0.006 to 0.056	Cradle to Gate	-	-	Large data range

Comments

Several values were selected based on single sources of data, but because of the importance of stone in construction it was decided that these values should be used if they were from a quality data source. Data on stone is generally poor.

Material Scatter Graph



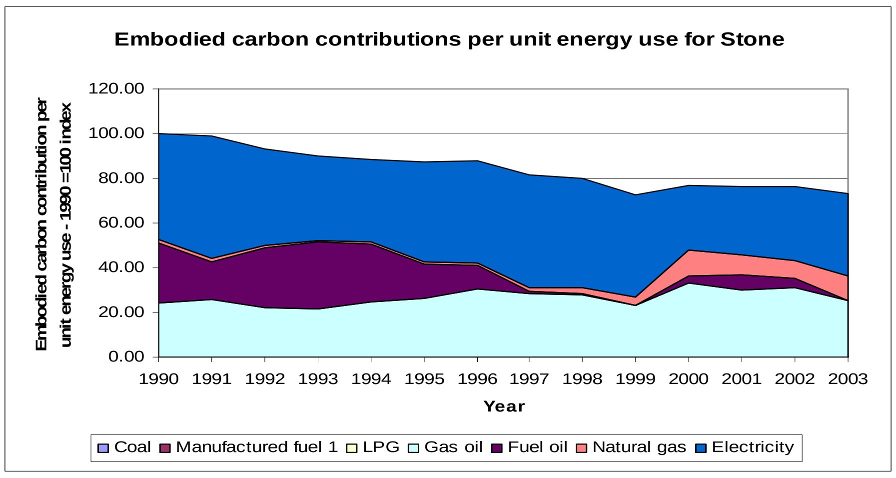
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	34.3%	38.2%
Natural gas	9.8%	8.1%
Electricity	55.9%	53.7%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in this industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
stone chippings for roofs		0.96	1800	1000	5.33333E-07
basalt		3.49	2880	840	1.44263E-06
gneiss		3.49	2880	840	1.44263E-06
granite		3.49	2880	840	1.44263E-06

Material Profile: Stone

granite, red		2.9	2650	900	1.21593E-06
hard stone (unspecified)		3.49	2880	840	1.44263E-06
		2.9	2750	840	1.25541E-06
limestone		1.5	2180	720	9.55657E-07
		2.9	2750	840	1.25541E-06
	At 50'C	1.8	2420	840	8.85478E-07
		2.9	2750	840	1.25541E-06
	Dry	2.91	2750	840	1.25974E-06
	Moist	3.49	2750	840	1.51082E-06
marble, white		2	2500	880	9.09091E-07
petit granit (blue stone)	Dry	2.91	2700	840	1.28307E-06
	Moist	3.49	2700	840	1.5388E-06
porphyry		3.49	2880	840	1.44263E-06
sandstone		1.83	2200	710	1.17157E-06
		3	2150	840	1.66113E-06
		1.3	2150	840	7.19823E-07
		5	2150	840	2.76855E-06
sandstone tiles	Dry	1.2	2000	840	7.14286E-07
slate		1.44	1600	1470	6.12245E-07
	At 50°C	1.72	2750	840	7.44589E-07
slate shale		2.1	2700	840	9.25926E-07
white calcareous stone	Firm, moist	2.09	2350	840	1.05876E-06
	Firm, dry	1.74	2350	840	8.81459E-07
	hard, moist	2.68	2550	840	1.25117E-06
	Hard, dry	2.21	2550	840	1.03175E-06
tufa, soft	Dry	0.35	1300	840	3.20513E-07
	Moist	0.5	1300	1260	3.0525E-07

Material Profile: Timber

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Timber	**162**	**9.36**	**8.19**	**0.30**	**61.26**	None
Timber, General	63	7.75	4.81	0.72	21.30	
Unspecified	38	6.78	3.58	0.72	14.85	
Virgin	25	9.29	6.07	1.33	21.30	
Timber, Hardboard	12	21.54	15.84	3.43	61.26	
Predominantly Recycled	1	3.43	3.43	3.43	-	
Unspecified	8	17.85	8.78	4.00	31.70	
Virgin	3	37.42	22.68	16.12	61.26	
Timber, Hardwood	12	4.59	4.47	0.33	16.00	
Predominantly Recycled	1	0.33	0.33	0.33	-	
Unspecified	10	5.15	4.68	0.50	16.00	
Virgin	1	3.30	3.30	3.30	-	
Timber, MDF	4	11.02	1.40	8.96	11.90	
Unspecified	3	10.72	1.55	8.96	11.90	
Virgin	1	11.90	11.90	11.90	-	
Timber, Particle Board	23	12.48	10.14	2.00	36.29	
50% Recycled	1	5.10	5.10	5.10	-	
Other Specification	1	10.22	10.22	10.22	-	
Unspecified	16	11.41	9.41	2.00	36.00	
Virgin	5	17.82	13.35	4.60	36.29	
Timber, Plywood	12	13.58	6.34	7.58	27.60	
Unspecified	7	14.33	4.92	8.30	21.40	
Virgin	5	12.53	8.48	7.58	27.60	
Timber, Softwood	33	5.55	3.26	0.30	13.00	
Unspecified	24	5.42	3.43	0.30	13.00	
Virgin	9	5.88	2.92	2.80	9.70	
Timber, Woodwool	3	11.98	7.50	5.13	20.00	
Unspecified	3	11.98	7.50	5.13	20.00	

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General	8.5	0.46	Cradle to Gate	High range, perhaps +/- 40%		Estimated from UK consumption of timber products in 2004
Glue Laminated timber	12	0.65 (?)		8	14	Unknown embodied carbon
Hardboard	16	0.86	Cradle to Gate	15	35	
Laminated Veneer Lumber	9.5	0.51 (?)		-	-	Ref 126
MDF	11	0.59		Not enough data for accurate range. Estimated range +/- 30%		AUS & NZ data, only two data points
Particle Board	9.5	0.51		4	15	Very large data range, difficult to select best value
Plywood	15	0.81	Cradle to Gate	10	20	
Sawn Hardwood	7.8	0.47		0.72	16	Highly dependent upon the distance travelled, which explains the incredible range. The selected values represent typical UK timber, they were selected giving high preference to values from UK sources
Sawn Softwood	7.4	0.45		0.72	13	
Veneer Particleboard (Furniture)	23	1.24		(+/- 40%)		

Comments

Data on timber was particularly difficult to select, of all the major building materials timber presented the most difficulties. These values do not include the effect of carbon sequestration. The inclusion or exclusion of sequestered carbon is a complex argument. The following extract highlights some of the difficulties:

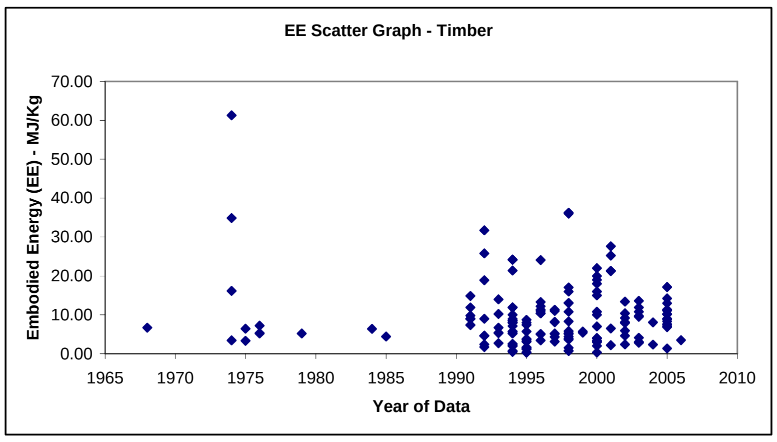
The following extract was taken from A. Amato *"A comparative environmental appraisal of alternative framing systems for offices"* 1996, Reference 1: *"There are counter arguments against taking sequestered CO2 into consideration. In measuring embodied CO2, what is being sought is the CO2 burden to society which consequent upon society's use of a particular material. The deduction of a CO2 value sequestered by the material during its manufacture from the total embodied CO2 burden is not appropriate just because a material is deemed renewable and is surely only appropriate when a world wide steady state has been achieved between consumption and production, i.e. it has achieved sustainability. Renewability does not automatically confer the attribute of sustainability to a material. If we consider the world resource of timber and its consumption as a complete system, then clearly much greater quantities of timber are being consumed than are being replenished at present, most being consumed as fuel in third world countries. Thus, in terms of anthropogenic CO2 resultant from the world's use of its timber resource, more is being released into the atmosphere than is fixed by the renewal of timber in new plantations and by natural seeding. it therefore appears that the sequestered CO2 argument is only applicable where a steady state has been achieved.*

...Finally, it seems a somewhat dubious practice to credit timber benefit of sequestered CO2 without taking into account the methane emissions resultant from the disposal of timber. Methane, like CO2 is a greenhouse gas, but it is estimated as being 24 times more potent than carbon dioxide as stated previously. It is emitted in the UK, mainly from landfill waste, animals, coal mining, gas pipe leakage and offshore oil and gas operations. Methane is produces as timber bio-degrades in landfill sites."

The focus of this study is on energy and carbon dioxide, but as the previous paragraph highlights the topic of carbon sequestration in an environmental context goes beyond this because of the importance of methane, which is considered outside the scope of this study. Furthermore it would be inappropriate to include carbon sequestration without considering the end of life of timber, which may or may not result in the release of methane. For the reasons highlighted above and the scope of this study the author chose to exclude the effects of carbon sequestration, this leaves it open for the user to decide if the effects of carbon sequestration should be included or excluded.

Material Profile: Timber

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	72.8%	76.0%
Natural gas	3.0%	2.3%
Electricity	24.2%	21.7%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The above fuel mix is for general sawn timber taken from the UK industrial typical fuel use. The below values are for wood boards. These two have been separated due to the large difference in fuel mix.

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	0.0%	0.0%
LPG	0.0%	0.0%
Oil	19.3%	22.9%
Natural gas	28.5%	24.5%
Electricity	52.2%	52.6%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
fir, pine		0.12	510	1380	1.70503E-07
hardwood (unspecified)		0.05	90	2810	1.97707E-07
	Dry	0.17	700	1880	1.29179E-07
		0.23	800	1880	1.52926E-07
maple, oak and similar hardwoods		0.16	720	1260	1.76367E-07
oak, radial		0.19	700	2390	1.13568E-07
oak, beech, ash, walnut	Moist	0.23	650	3050	1.16015E-07
meranti	Dry	0.17	650	2120	1.23367E-07
pine, pitch pine	Dry	0.17	650	2120	1.23367E-07
	Moist	0.23	650	3050	1.16015E-07
red fir, Oregon fir	Dry	0.14	520	2280	1.18084E-07
	Moist	0.17	520	3440	9.50358E-08
resinous woods (spruce, sylvester pine)	Dry	0.12	530	1880	1.20434E-07
softwood		0.12	510	1380	1.70503E-07
		0.13	630	2760	7.47642E-08
		0.14	550	1880	1.35397E-07
timber	At 50'C	0.072	480	1680	8.92857E-08
	At 50°C	0.14	720	1680	1.15741E-07
timber flooring		0.14	650	1200	1.79487E-07
willow, North Canadian gaboon		0.12	420	2400	1.19048E-07
willow, birch, soft beech		0.14	520	2280	1.18084E-07
Wood derivatives:	Moist	0.17	520	3440	9.50358E-08
cellulosic insulation, loose fill		0.042	43	1380	7.07786E-07
chipboard	At 50°C	0.067	430	1260	1.23662E-07
chipboard, bonded with PF	Dry	0.12	650	2340	7.88955E-08
	Moist	0.25	650	5020	7.66166E-08
chipboard, bonded with UF	Dry	0.12	630	2260	8.42815E-08
	Moist	0.25	630	5020	7.90489E-08
chipboard, bonded with	Dry	0.12	630	2260	8.42815E-08
melamine	Moist	0.25	630	5020	7.90489E-08
chipboard, perforated	At 50°C	0.066	350	1260	1.4966E-07
flooring blocks		0.14	650	1200	1.79487E-07
hardboard		0.08	600	2000	6.66667E-08
		0.12	880	1340	1.01764E-07
		0.29	1000	1680	1.72619E-07
multiplex, beech	Dry	0.15	650	2300	1.00334E-07
multiplex, North Canadian gaboon	Dry	0.12	450	2300	1.15942E-07
multiplex, red fir	Dry	0.13	550	2300	1.02767E-07
	Moist	0.21	550	2300	1.66008E-07
particle board		0.098	750	1300	1.00513E-07
		0.17	1000	1300	1.30769E-07
		0.12	800	1300	1.15385E-07
plywood		0.12	540	1210	1.83655E-07
		0.15	700	1420	1.50905E-07

Material Profile: Tin

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Tin	**12**	**84.44**	**87.83**	**19.17**	**284.30**	None
Tin, General	12	84.44	87.83	19.17	284.30	
Other Specification	1	36.11	36.11	36.11		
Predominantly Recycle	1	20.85	20.85	20.85		
Unspecified	2	33.50	5.66	29.50	37.50	
Virgin	8	111.16	98.23	19.17	284.30	

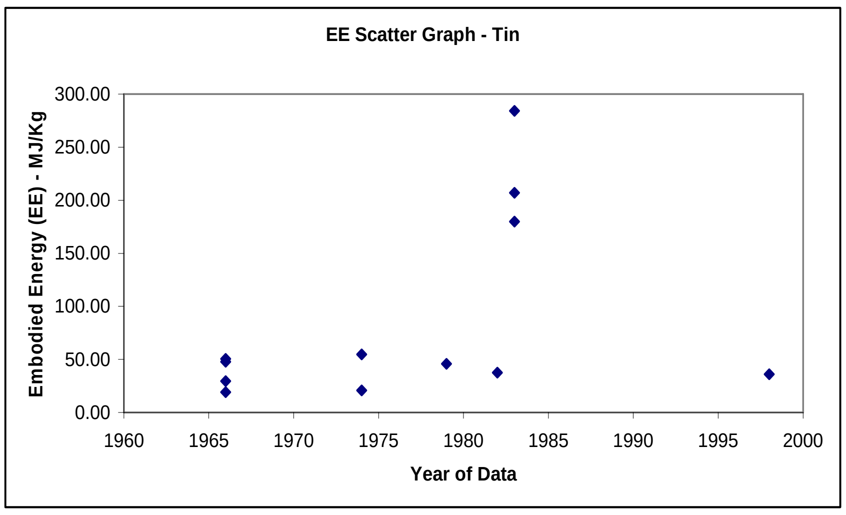
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
Tin Coated (Steel)	19.2 to 54.7	1.03 to 2.93	Cradle to Gate	-	-	-
Tin	250	13.7	Cradle to Gate	19.5	55.5	lack of modern data, large range of data

Comments

There was a lack of modern data on tin, as reflected in the scatter graph. There was also a very large range of data, which was considered to be a result of tin coated steel products. These products contain small amounts of tin and are predominantly steel.

Material Scatter Graph



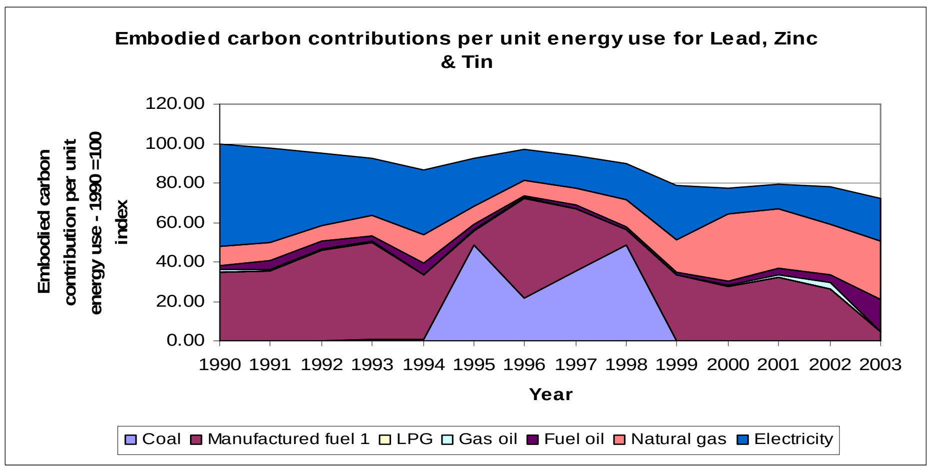
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	7.6%	11.7%
LPG	0.0%	0.0%
Oil	4.5%	5.3%
Natural gas	44.3%	38.5%
Electricity	43.6%	44.5%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK tin industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
tin		65	7300	240	3.71005E-05

Material Profile: Titanium

Embodied Energy (EE) Database Statistics - MJ/Kg

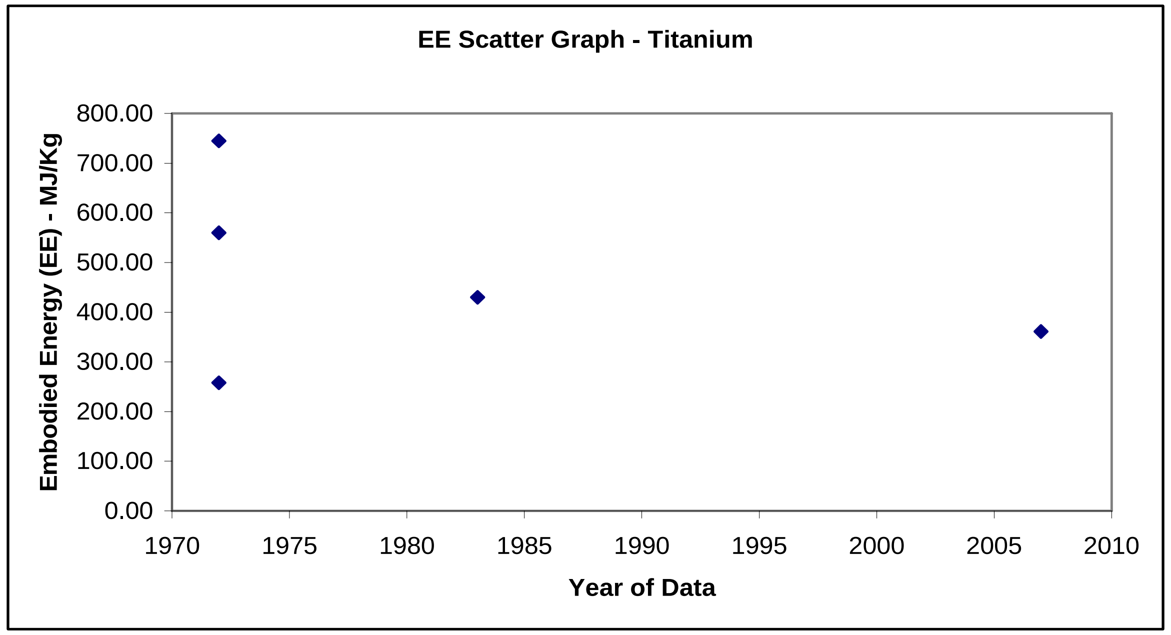
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Titanium	**5**	**470.67**	**188.43**	**257.84**	**744.70**	
Titanium, General	5	470.67	188.43	257.84	744.70	Very limited data
redominantly Recycled	1	257.84	257.84	257.84	-	
Unspecified	1	361.00	361.00	361.00	-	
Virgin	3	578.17	158.15	430.00	744.70	

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Primary Titanium	361 to 745	?	Cradle to Gate	-	-	-
General Recycled Titanium	258	?		Not enough data		-

Comments	There was very limited data. Fortunately titanium is not an important building material, with very limited use in construction and in buildings. However, unlike aluminium it does not appear that the benefits of recycled material could help reduce the burden of primary material production. Both recycled and primary titanium have very high embodied energy.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Unknown fuel split and embodied carbon data

Material Profile: Vinyl Flooring

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Vinyl	**10**	**53.69**	**34.82**	**11.80**	**120.00**
Vinyl, General	10	53.69	34.82	11.80	120.00
Unspecified	10	53.69	34.82	11.80	120.00

Comments on the Database Statistics:

Care needs to be taken when looking at these statistics due to feedstock energy. It is only apparent when examining the (separate) database records whether feedstock energy is included or excluded, sometimes it is not known and assumptions need to be made.

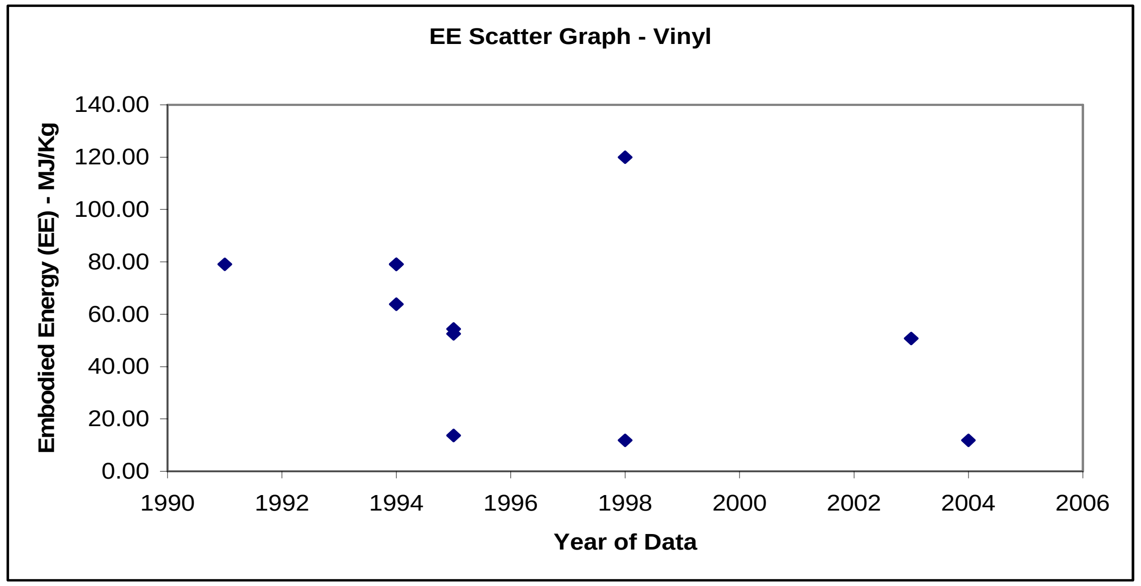
Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Vinyl Flooring	65.64	23.58	2.29	Cradle to Gate	11.8	96	Same value as PVC calendered sheet, this value is in agreement with the other values in the database for vinyl flooring.
Vinyl Composite Tiles (VCT)	13.7	?	?	Cradle to Grave	Not enough data to specify a range.		Reference 77

Comments

It should be noted that in the scatter graph below most of the specified values include feedstock energy. It is not possible from the scatter graph alone to determine which include and which exclude feedstock energy. This data is stored within the ICE-Database.

Material Scatter Graph



Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Electricity	41.8%	39.3%
Oil fuels	15.1%	19.8%
Other Fuels	43.1%	40.9%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The energy split was specified in the literature, the carbon split is an estimate, although considered a good indicator. The main fuel classified under 'other' fuels was natural gas.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
vinyl floor covering		0.19	1200	1470	1.0771E-07

Material Profile: Zinc

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE
Zinc	**39**	**59.80**	**25.16**	**8.46**	**105.76**
Zinc, General	39	59.80	25.16	8.46	105.76
Market Average	1	29.10	29.10	29.10	-
Predominantly Recycled	4	9.26	0.91	8.46	10.57
Unspecified	8	47.83	16.31	18.00	68.40
Virgin	26	72.44	15.13	46.00	105.76

Comments on the Database Statistics:

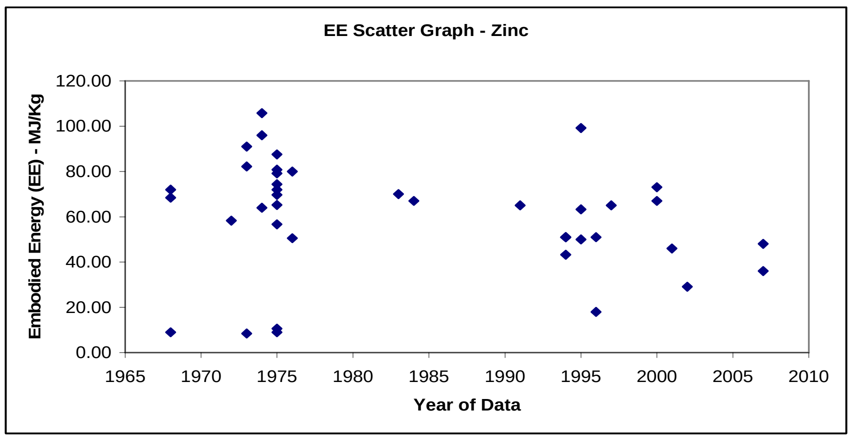
None

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
General Zinc	61.9	3.31	Cradle to Gate	(+/- 30%)		A recycling rate of 16% has been applied (source: the environment agency)
Primary Zinc	72	3.86	Cradle to Gate	57	87	
Secondary Zinc	9	0.48	Cradle to Gate	7.5	10.5	

Comments: None

Material Scatter Graph



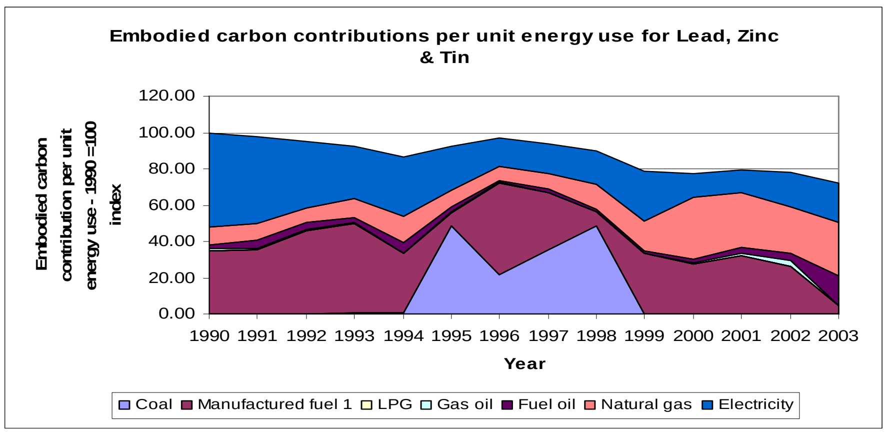
Fuel Split & Embodied Carbon Data

Energy source	% of Embodied Energy from energy source	% of embodied carbon from source
Coal	7.6%	11.7%
LPG	0.0%	0.0%
Oil	4.5%	5.3%
Natural gas	44.3%	38.5%
Electricity	43.6%	44.5%
Other	0.0%	0.0%
Total	**100.0%**	**100.0%**

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK zinc industry.

Historical embodied carbon per unit fuel use



Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
zinc		113	7000	390	4.13919E-05

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